THE TRANSITION TO NON-LEAD AMMUNITION:

an essential and feasible prerequisite for sustainable hunting in modern society

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1 Foreword

Shortly after I was employed by the Danish hunters' organisation in November 1985, the government issued its first regulation of lead ammunition on 24th 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 different. Instead of lobbying against the governmental initiative, it became evident that my challenge 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 relationship with both 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. This was especially timely given the contemporary progress that had been made to remove human and environmental exposure to toxic lead from all other sources wherever possible. During my presidency of the CIC Migratory Birds Commission and membership of the African Eurasian Waterbird Agreement (AEWA) Technical Committee (2001-2009), the debate about lead ammunition was ever-present, 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.

In hindsight, it is perhaps unsurprising that, given this role, the hunting 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 hunting stakeholders. Because of this (and for other reasons) it became increasingly obvious that I needed to change my working affiliation and by establishing the Danish Academy of Hunting in 2007, I created a platform from which to advise independently on all aspects of sustainable hunting and its effective implementation, including the issues surrounding the use of lead ammunition and possible transition to non-lead alternatives.

In 2017, I was invited to affiliate my business with Aarhus University, a move which enabled me to concentrate my activities concerning lead ammunition more strategically in the form of a research programme. Initially, this centered on projects demonstrating the severe toxicological consequences of using lead ammunition, but later concentrated increasingly on guiding successful change to the use of non-lead and non-toxic alternatives to lead. From this grew the title of my doctoral dissertation submitted to Aarhus University in 2021: "*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 my work with this subject is described in more detail in later sections of this book but springs overall 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 to the fore in my mind. This is not just because of the added 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 work represents an expression of a personal deep passion and respect for wild animals – for these animals as individuals and collectively in robust and healthy populations.

The gathered experiences 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 help safeguarding its future acceptance in wider society.

The dissertation was defended in October 2022. However, it was only distributed to a limited circle of experts and has not been published as such. This led to the idea of this book, which is based on the original dissertation thesis updated with recent research, including some of my own work since 2021. It has been revised against the backdrop of the many valid and highly relevant discussions that arose during the defense process.

Niels Kanstrup, wildlife biologist, DSc
May 2024

2 Acknowledgements

This book and the dissertation that lies behind it are the result of personal endeavours. Most of it was written in 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 to give critical technical comments to section drafts as they developed and gave the whole work 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 former and present representatives from the hierarchy of Aarhus University, Department of Bioscience (today: Ecoscience), including Ole Hertel, Mikkel Tamstorf, Flemming Skov, Aksel Bo Madsen, and Ole Therkildsen for providing the formal and practical institutional support to the project throughout. Furthermore, a great thank you to the assessment committee consisting of professors Jesper Madsen, William Sutherland, and Philippe Grandjean for their hard work and great support in scrutinizing and evaluating my dissertation.

From far across the sea, Vernon Thomas has been indispensable in his support of much of the scientific work, particularly 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. 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. I owe gratitude to my friend Tom Roster who 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 department colleagues and external contacts for providing laboratory work, field assistance, technical support, layout and proofreading and other valuable contributions to the dissertation and its defense including Claus Lunde Pedersen, Lars Haugaard, Kavi Askholm Mellerup, Peter Mikkelsen, Preben Clausen, Jens Søndergaard, Hanne Fensbæk, Karin Balle Madsen, Tinna Christensen, Anne Mette Poulsen, Lisa Vergin, Claus Adam Jarlø, Poul Hartmann, Bjarne Clausen, Frank Vigh-Larsen, Dick Dyreby, Lars T. Andersen, Nicholai V. Knudsen, Eva K. Kanstrup, Johannes V. Kanstrup, Susanne and Lars Kjelgaard, Michael Johansen, Anne Fox, and Charlotte Reenberg. Many individual hunters assisted with collection of data, and gun stores gave valuable information on ammunition.

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3 Summary in English

This book is the result of 35 years of work as a consultant, scientist and active hunter. 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 but has an increasing obligation to keep up 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).

This book and the dissertation that lies behind it are 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 book is to put the adverse consequences of ammunition lead for 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 work 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 and lobbying against the industries involved. Ammunition, including that used for hunting, has traditionally been made

of lead, and its use has spread the raw form of the 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-19th 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 affected individuals and thus has significant adverse animal welfare consequences.

The continued use of lead to produce 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, non-toxic, safe and effective marketed alternative types of hunting ammunition, where lead has been replaced with, for example, iron, bismuth and copper. 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. Several 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 in Denmark, hunting with lead rifle ammunition has been banned from 1st April 2024.

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 subject 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 analysis, 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 this book 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 ammunition, with emphasis on the risks posed by lead 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, because fundamental to the concept of hunting as 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.

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 have been 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, 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 that both hunters as the core group but also individual hunters and the population as a whole are 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.

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 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. Transition from lead to non-lead ammunition will disconnect hunting from a toxic substance and thereby enhance its sustainability. It will show hunting in the context of wildlife management to be adaptable to changes in modern society.

4 Introduction

4.1 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 work, 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 2006a).

Not only does responsibility for the management of wildlife habitats gene-rally 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.

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.

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.

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) suggested hunting sustainability to be

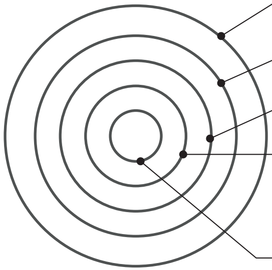


Figure 4.1. The gradient from all animals in the population (outer circle) to the animals that are harvested (innermost circle). In between lie the animals that are affected by the disturbance caused by the harvesting activity (circle 2 from outside), animals that are shot at indirectly or directly (circle 3 from outside), and birds that are hit but not necessarily retrieved (circle 4 from outside). After Kanstrup (2006).

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 4.1).

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). 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).

4.2 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 book and the dissertation behind represent 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 is toxic lead shot (ECHA 2018). 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. 2019a). Dispersed lead shot persists and creates an enduring global toxic legacy, the cost of which is externalized to society (Kanstrup and Thomas 2020; Pain et al. 2019b). 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) of which the majority are less than 100 μm in diameter (Leontowich et al. 2022). 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).

The objective of this work 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 5) 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 is the chapter "Transition" (Chapter 6), 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 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 present 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.

This present work 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.

5 Background

5.1 Definitions and scoping

5.1.1 Hunting

The word hunting is present in the Middle-English language spoken from late 10th until the late 15th 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. Therefore, the following definition and description are given. It applies to the entire text. When used here, "hunting" means the activity of pursuing 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 the work 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 and Thomas 2020). Worldwide, hunting has many different facets and rests on diverse national and regional purposes and traditions. Thomas et al. (2021) 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

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

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.

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 14th century and evolved over the next few centuries into effective tools for use in both war and wild animal pursuit.

Throughout the 19th and 20th 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 basic technology over the past 100 years.

5.1.2 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 book, the term hunting pressure defines the sum of hunting impacts on wildlife individuals and populations and their habitats and ecosystems, as illustrated in Figure 5.1, where the single slices (impacts) represent parts of the total hunting pressure.

$I_{harvest}$ 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.

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

Figure 5.1. The elements of direct impact of hunting that form the total hunting pressure.

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 (Grzegorczyk et a.l 2024; 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).

$I_{wounding}$ 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.

$I_{disturbance}$ 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).

$I_{landscape}$ 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[1]. 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.

$I_{ammunition}$ includes the impact on ecosystems, wildlife and humans caused by the dispersal of ammunition parts (Kanstrup et al. 2019a). 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). 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 work lays within the $I_{ammunition}$ element of $P_{hunting}$.

5.1.3 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[2] 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). Sustainability often conceptualised in the structure of three pillars: environmental, economic and social (also described informally as plan-

1 http://whc.unesco.org/en/list/1469
2 https://www.ramsar.org/

et, profits and people). To analyse the sustainability of harvest (hunting), Kanstrup (2006) condensed this structure to two pillars: ecological, and political (Figure 5.2), 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 other societal elements and determined by what is "allowable" within a political region, typically a country, and within a given time period.

Throughout this book, 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 book will address hunting sustainability in a simple structure of a descriptive "ecological" and a normative "political" pillar (Kanstrup 2006a).

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),

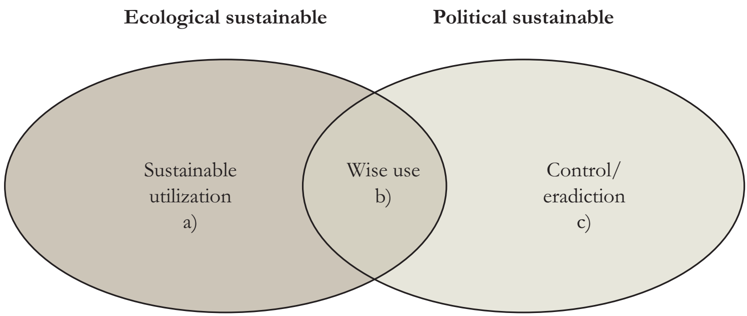


Figure 5.2 Terms of sustainability. Fields of activities: a) ecologically, but not politically, sustainable harvest; b) ecologically and politically sustainable activities ("wise use"); c) politically acceptable activities that cause reduction or (local) extinction of populations according to clearly set goals. After Kanstrup (2006a).

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, $I_{disturbance}$ 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 $I_{ammunition}$ 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 (section 6.3).

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.

5.2 Arms/firearms and their ammunitions

Hunting weapons of relevance to this book 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

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

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). Alternatives to lead ammunition are described in section 5.5.

5.3 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

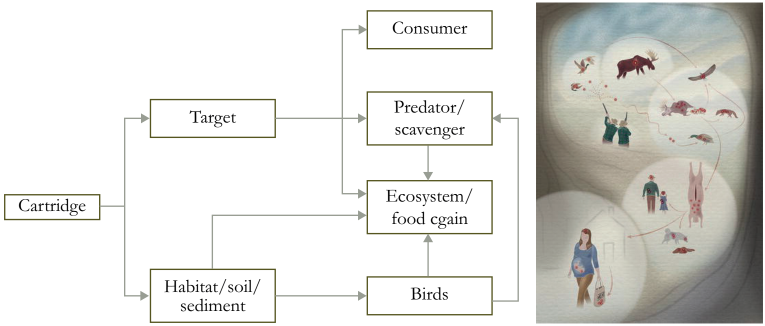


Figure 5.3. The flow from dispersal of ammunition lead to ecosystems, wildlife and consumers. Sources: Kanstrup (2009) and Arnemo et al. (2016). See section 5.4.6 for more details.

flowchart (Kanstrup 2009) (Figure 5.3, 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 5.3, right).

5.4 The lead problem (impact wildlife, ecosystems, humans)

5.4.1 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^3

Melting point: 327.5° C

Four stable isotopes: ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}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.

Lead is used as radiation shielding and has thus been indispensable for many of the investigations that form the basis of this book, where fragments from ammunition have been analyzed using X-ray equipment.

5.4.2 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 one of the first metals 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 Classical 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 (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.

5.4.3 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 2nd 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

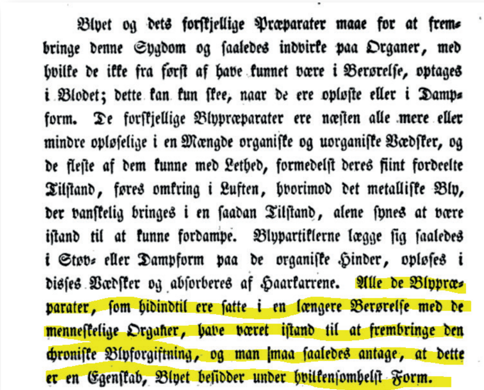

Blyet og dets forskjellige Præparater maae for at frembringe denne Sygdom og saaledes indvirke paa Organer, med hvilke de ikke fra først af have kunnet være i Berørelse, optages i Blodet; dette kan kun skee, naar de ere opløste eller i Dampform. De forskjellige Blypræparater ere næsten alle mere eller mindre opløselige i en Mængde organiske og uorganiske Vædsker, 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 Vædsker 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 chroniske Blyforgiftning, og man maa saaledes antage, at dette er en Egenskab, Blyet besidder under hvilkensomhelst Form.

Figure 5.4. A Danish reference to some of the first modern clinical descriptions of lead toxicity (Ahrensen and Kayser 1848).

(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 5.4.

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 valency as Ca^{+}+; thus, lead is a potent reversible and selective blocker of voltage-dependent calcium channels at low concentrations (Figure 5.5.) (Büsselberg et al. 1993).

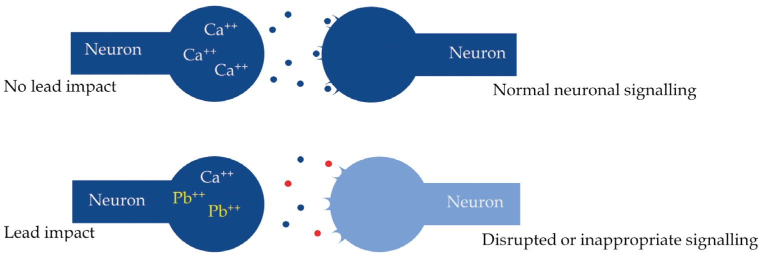


Figure 5.5. Even at low concentrations lead is a potent reversible and selective blocker of neuronal voltage-dependent calcium channels.

Lead also contributes to oxidative stress in the body (Flora et al. 2012; Saxena and Flora 2004). Declines in blood lead levels in adults, even when small (0.1–1.0 µg/dL), are associated with reductions in systolic blood pressure (Lieberman-Cribbin et al. 2024). 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)[3] and there is a suggested involvement of lead in the pathophysiology of ALS (Amyotrophic Lateral Sclerosis) (Kamalian et al. 2023).

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; Talayero et al. 2023). 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). Stud-

[3] https://www.iarc.fr/. Webpage of the International Agency for Research on Cancer

ies have suggested that for every 10 µg/1dl 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 µg/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: µg/dl) is the most commonly used biomarker for lead exposure in humans (Sakai 2000). Several studies have 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 µg/dl represents background levels which cause no risk of health impacts, but that 5–10 µg/dl cause possible impacts like hypertension, kidney dysfunction and spontaneous abortion. At levels of 11–20 µg/dl, the risk expands to *inter alia* possible subclinical neurocognitive deficits, reduced birth weight and postnatal developmental delay. At 21–29 µg/dl, hypertension and kidney dysfunction are evident, and subclinical neurocognitive deficits and spontaneous abortion are possible. At 30–39 µg/dl, clinical neurocognitive deficits become possible and the risk of spontaneous abortion is evident. At levels from 40 to79 µg/dl, major bodily dysfunctions become evident and development of lead-related symptoms like anemia and pain is common. At lead levels exceeding 80 µg/dl, all health impacts, including also gout and severe brain damage (encephalopathy), are very likely. Levels above 100 µg/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 µg/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 Thordsen, 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 μg/dl for mammals and 71 μg/dl for birds based on the 5th percentile of the "no observed effect concentrations". A very recent review found that 28 out of 45 studies that investigated health effects concluded adverse health effects in a total of 57 species (Hydeskov et al. 2024).

5.4.4 Lead in ammunition

Lead has been used in ammunition since Classical 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).

5.4.5 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). 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 (Sonne, et al. 2023) and there is growing evidence that this source also poses a risk to human consumers of game meat (Kanstrup and Thomas 2020). Evidence for the poisoning of wild species as a result of lead gleaned from ammunition sources is overwhelming (Kanstrup et al. 2019a).

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 5.6), including his prediction of lead poisoning to assume greater importance "*as time goes on*", are striking and his documentation 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*".

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 per-

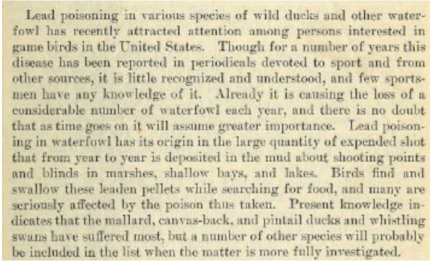
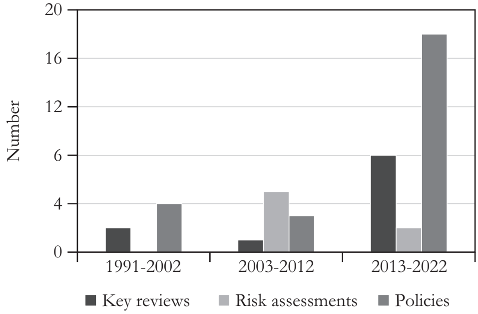

Lead poisoning in various species of wild ducks and other waterfowl has recently attracted attention among persons interested in game birds in the United States. Though for a number of years this disease has been reported in periodicals devoted to sport and from other sources, it is little recognized 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.

Figure 5.6. Section of Wetmore's article in 1919 (Wetmore 1919).

spective 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). 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. (2019a) (Figure 5.7) including both new research papers and summaries of key conclusions from earlier reviews updated with results from the substantial literature published during 2015-2019.

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 se-



Timeline illustrating the increasing number of key reviews of evidence, publications of European food safety agency advice, and national and international policies. Redrawn and updated from Cromie et al. 2019.

rious 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. 2019a). 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).

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 Southeast 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, 2023) and South America (e.g. Argentina; Ferreyra et al. (2015)).

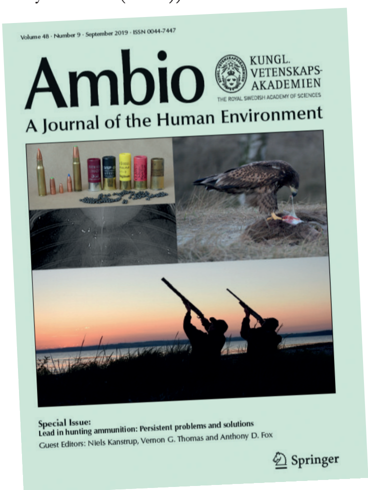


Figure 5.7. Front cover of the Ambio Special Issue (Kanstrup et al. 2019a) – the most recent compilation of evidence of adverse impacts of lead in ammunition used as a key reference, for instance for the 2020 and 2023 European Scientists' Open Letters on the Risks of Lead Ammunition (European Scientists 2020, 2023).

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; European Scientists 2023; 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).

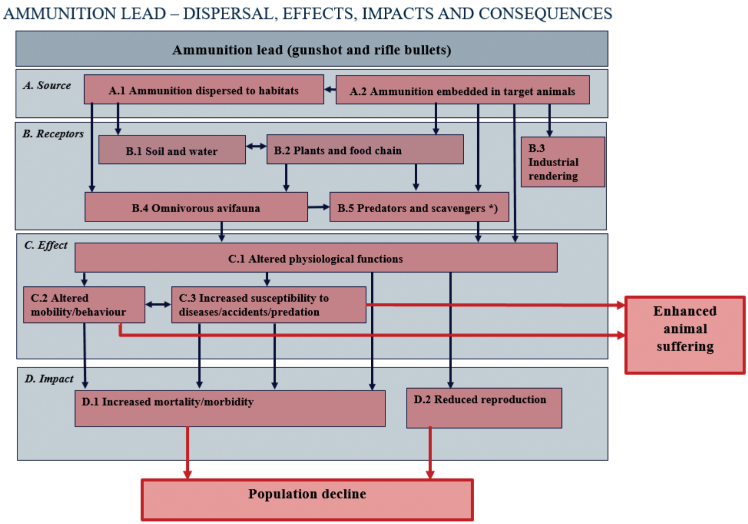


Figure 5.8. Summary of dispersal, effects, impacts and consequences (the two red-framed boxes) of leaded gunshot and rifle bullets used for hunting. The following text documents the single steps in the flowchart and gives references to some unique historical research and to the most recent documentation. *) in B.5 indicates the inclusion of humans

5.4.6 Dispersal, effects, impacts and consequences

Figure 5.8 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 5.8.

A. Source

A.1 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). 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* ≤ 1 % (Cromie et al. 2010); thus, ≥ 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^2 per year. However, the dispersal is highly uneven and concentrated to hunted areas with particular high dispersal in hunting hotspots (Figure 5.9) (Kanstrup et al. 2020; Mateo 2009). The most recent update on shot densities in European wetlands is given by Pain et al. (2019a),

Figure 5.9. 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^2 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).

confirming densities of >300 shot/m^2 in hunted areas and documenting also densities >1,000 shot m^2 in wetlands in the vicinity of shooting ranges.

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[4].). 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; Leontowich et al. 2022) (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. (2019a)).

A.2 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

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animal tissue and leave traces of both invisible and visible particles (Andreotti et al. 2016; Pain et al. 2010). Kanstrup (2012) 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; Kollander et al. 2017; Wilson et al. 2020, McTee et al. 2023) and thereby cause lead metal deposition in the tissues of the hunted animal (Haase et al. 2023). 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 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 Ruffled 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

B.1 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) 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). 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 bioavailable 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^2 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 5.8). 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.

B.2 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 (Mendes et al. 2023)). 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).

B.3 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

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.

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 (2019a) 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 here. 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

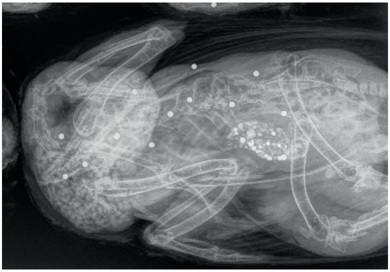


Figure 5.10. Pheasant carcass showing the gizzard with ingested shot (17 bismuth and 1 steel) and the embedded shot that killed the bird (all steel). From Kanstrup and Balsby (2019a).

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 5.10), of the widespread ingestion of gunshot (Pain et al. 2019a). 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).

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 be 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).

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 (2019b) defined *occurrence (o)* as the average number of ingested shot per bird in the total sample

$$o = \left(\sum_{n=i0}^{n=imax} N\,i \right) / N$$

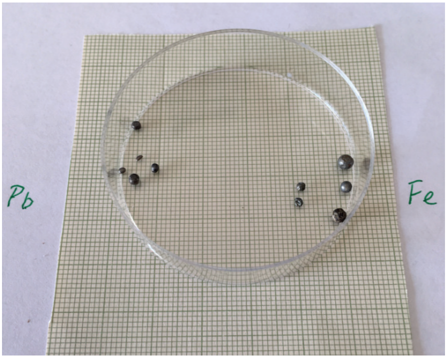


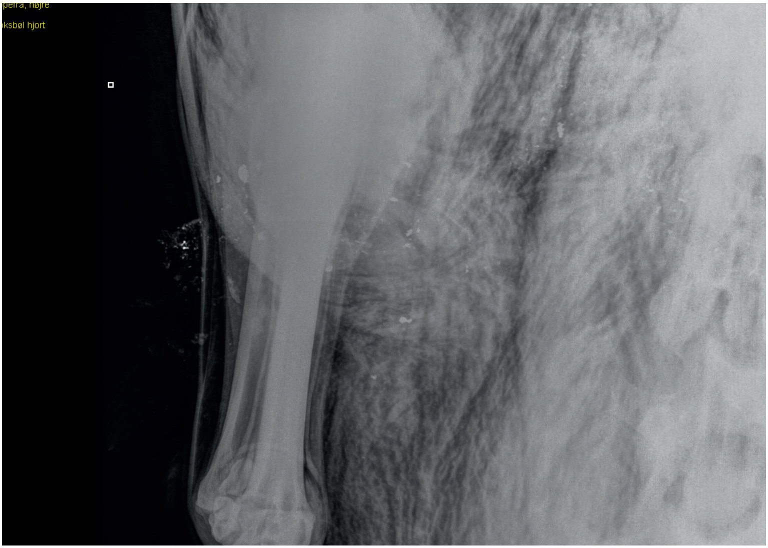
Figure 5.11. Lead and steel shot removed from a mallard gizzard during the laboratory work in the project by Kanstrup and Balsby (2019b). Degradation is obvious for both shot types, but relative degradation rates are poorly studied.

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). Figure 5.11 shows 5 lead and 5 steel shot removed from a single mallard gizzard. A degree of degradation/deformation can be seen in both types.

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) (Pauli and Buskirk 2007; Bassi et al. 2021; Monclús et al. 2020; Hampton et al. 2023). At least 5–6 million gut piles from deer and boars may be discarded annually throughout Europe (Thomas et al. 2020).

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.



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.

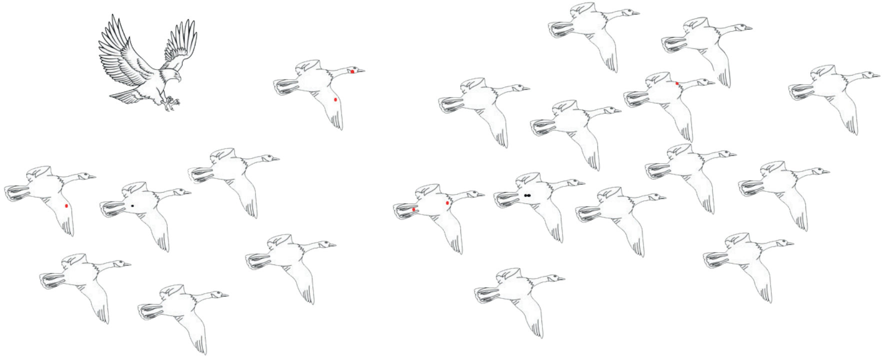


Figure 5.12. A figurative illustration of the exposure of birds of prey to ingested and embedded shot in their prey based on empirical data from published evidence: a flock (n=20) of an arbitrary avian prey species with ingested shot (black dots; occurrence=0.15 (10% with pellets, average number 1.5)) 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%).

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, lead 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 5.12.

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).

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,*Tasmanian Wedge-Tailed Eagle *Aquila audax fleayi,* and White-Backed Vulture *Gyps Africanus* (Church et al. 2006; Ishii et al. 2020; Kenntner et al. 2001; Madry et al. 2015; Pay et al. 2020, Menzel el al. 2021; van den Heever et al. 2023), just as evidence is emerging also for contamination of mammalian predators and scavengers (reviewed by Pain et al. (2019a) and studied later, e.g. in Brown bear *Ursus arctos* (Brown et al. 2023)).

Miller et al. (2023) identified key threats by examining the reasons for animals to be brought to rehabilitation centres and found seasonal patterns in lead exposure which highlighted the threats posed by hunting with lead ammunition. Additionally, domestic dogs and other carnivorous pets may be become contaminated by lead from food made from meat and offal from game animals killed with lead ammunition (Paulsen et al. 2024).

From a strictly biological standpoint, humans *Homo sapiens* can be regarded as predators and/or scavengers when consuming game meat (Figure 5.8*)) 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; Hampton et al. 2018). Green et al. (2024) found that the mean concentration of lead in meat from pheasants killed using lead shot was 2.10 mg/kg w.w., which exceeds the European Union's maximum permitted level for lead concentration in meat from domesticated animals by more than 20 times. 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). 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 5.4.3 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 is 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. (2019a) give a thorough review and update on this aspect.

D. Impact

D.1 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.

D.2 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 5.8 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. (2019a) 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), 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. 2019a). 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). 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 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). 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 to 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.

5.5 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). 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[5].

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). 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). 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). 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

[5] https://www.barnesbullets.com/history/

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 saboted 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 been carried out that give a good indication that the precision of non-lead types is equal to that of traditional types[6].

5.5.1 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 suggest-

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

ed 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).

5.5.2 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), Figure 5.13.

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

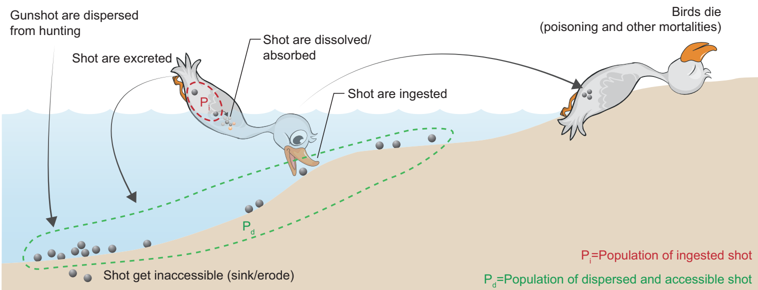


Figure 5.13. The connection and flow between the two "populations" of gunshot: Pd = dispersed and accessible shot; Pi = ingested shot retained in the bird's gizzards (from Kanstrup and Balsby 2019).

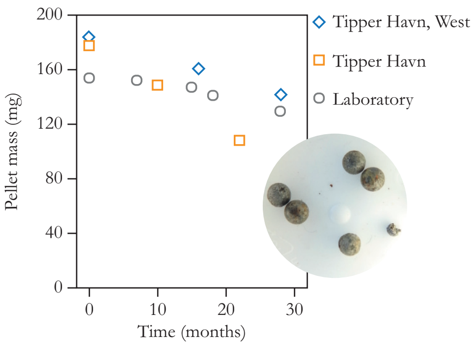


Figure 5.14. Mass loss of steel shot seeded at two locations next to the small harbour at Tipperne, Tipper Havn. The inserted photo shows that pellets were degraded unevenly. They appeared shiny immediately after recovery but changed quickly "rusty". Results from a laboratory test are included too. The figure is based on Kanstrup et al. (2020) and unpublished follow-up data.

decades after deposition (Kanstrup et al. 2020; Béchet et al. 2024). Degradation rates of non-lead ammunition in natural systems have been poorly investigated. However, Kanstrup et al. (2020) 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 2020 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 5.14 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) 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, min = 17 g, 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, min = 28 g, max = 167 g), 21% per year; Laboratory average loss: 25 g in 28 months (n = 2, min = 24 g, 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.

5.5.3 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; Kanstrup and Andersen 2003; Kanstrup et al. 2021). 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 (x) (V_x)). The shot energy (E) is expressed by the formula:

$$E_x = ½ M V_x^2$$

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 5.1.

Table 5.1. Ballistic parameters of lead compared with steel shot based on a 30 g load fired with V0=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).

Diam. (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 5.1) – 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; Thomas et al. 2015). 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 5.15). 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

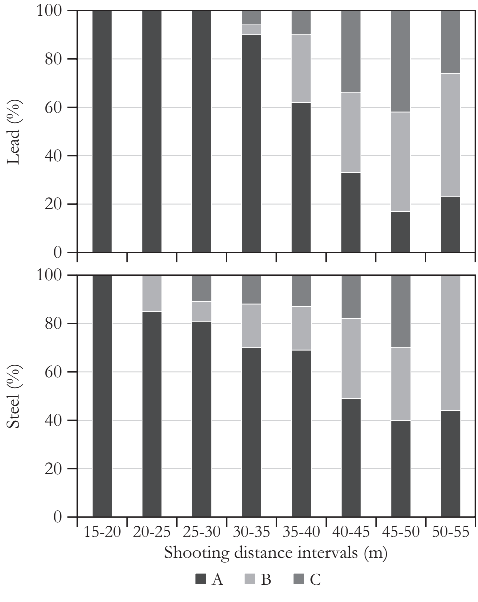


Figure 5.15. Redrawn graphics from a study of the lethality of lead versus steel shot carried out by the Danish hunters' organizations in 1987 (Kanstrup 1987). The dataset consisted of 671 common eider harvested with steel and lead shot. Capital letters indicate target reaction: A: Clean kill; B: Lethally 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.

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). Ellis and Miller (2022) evaluated 37 years of waterfowl harvest data in Illinois, United States, both before and after the transition to non-lead shot for waterfowl hunting. They found that the average crippling rate prior to the lead shot ban was 23% for both ducks and geese which reduced to an average of 15% for ducks and 11% for geese following the ban.

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). 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.

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; Martin et al. 2017; McCann et al. 2016; Stokke et al. 2019; Trinogga et al. 2013; Hampton et al. 2022). 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.

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.

2020), .22 and .17 air guns, for which there remains a need for further testing and technical development. Marklund and Pettersson (2024) found that the accuracy of lead-free types of 22LR ammunition was not as good as that of the lead-based ammunition.

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 Jesper Lyck Sevel)[7].

[7] Jesper Lyck Sevel, international top sport shooter. See www.lyckshooting.dk/.

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.

5.5.4 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). Kanstrup and Thomas (2019) 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.

Figure 5.16. 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.

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; Thomas 2015; Thomas et al. 2016). Similar studies with similar results have been carried out for the Danish market (Kanstrup 2015; Kanstrup et al. 2021). Knudsen (2020) identified at least 15 different brands of non-lead rifle cartridges available in the most common calibers (Figure 5.16).

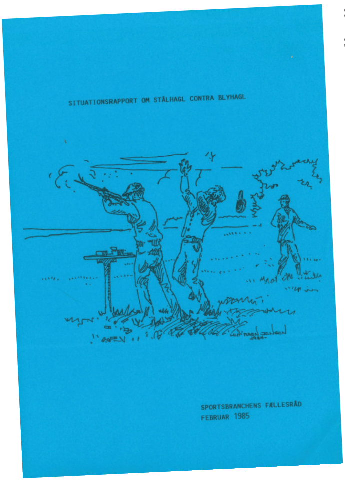
5.5.5 Damage to guns and hunter safety

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). 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.

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). Thus, lead-like shot types, like tungsten matrix shot or bismuth-tin shot, can be used



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). However, illustrations like this left many shooters with a misconception of the risk of using non-lead gunshot.

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 5.16) 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).

5.5.6 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). 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).

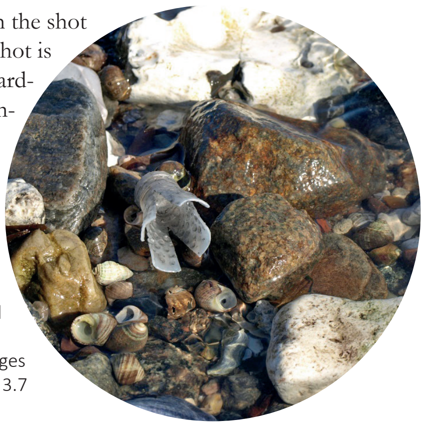
DEVA (2011) compared ricocheting in lead and non-lead rifle bullets and found no difference in ricochet angles but a higher ricochet energy in some non-lead types. However, no difference was detected between lead-core bullets with strong jackets (bonded) and non-lead bullets. As for slugs, DEVA (2013a) 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 by 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).

5.6 Dispersal of other ammunition components

5.6.1 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



Macro plastic items are a cosmetic and aesthetic problem that causes harm to marine animals. They decompose to micro plastic that accumulate in food chains. Kanstrup and Balsby (2018) found that the prevalence of plastic shotgun litter (here a wad) ranges from zero to 41 items per 100 m with an average of 3.7 items per 100 m on Danish coastlines.

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 (e.g. 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 hevishot (1) shot (Figure 5.17). 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 5.17, bottom, right) were not found in other types, though the fiber wad in one bismuth shot cartridge (top, 2nd from right) was a similar construction with no cup or other features to prevent contact between gun barrel and load.

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 5.17, bottom, 1st to 4th from left), the zinc shot cartridge (top, 4th from left) and one bismuth cartridge (top, right), while it is smaller or absent in the steel shot cartridges (middle row), the hevishot (top, left) and the tin shot (top, 2nd 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 cre-

Figure 5.17. Wad construction in a selection of shotgun cartridges. All caliber 12. Bottom: lead; Middle: steel; Top (from left): hevishot, tin, tungsten, zinc and two bismuth. See text for details.

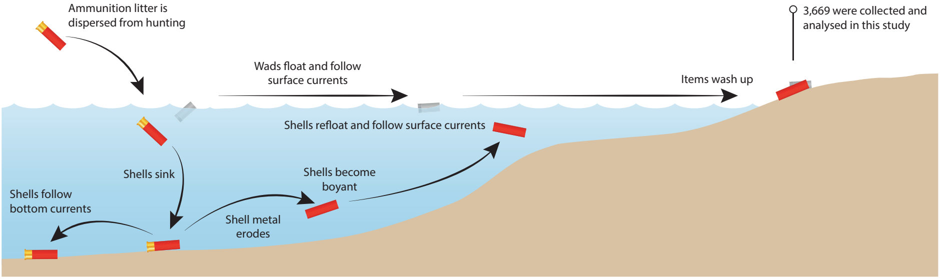


Figure 5.18. The flow of ammunition litter when dispersed during hunting in coastal areas. Shells may be retrieved by the hunter and disposed of with household garbage. From Kanstrup and Balsby (2018).

ated 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).

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 app. 1,860 kg per annum (Kanstrup and Balsby 2018). 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[8] (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[9]. 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).

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[8] Microsoft Word - LAG_meeting_minutes_12_250614.docx (leadammunitiongroup.org.uk)

[9] John Swift personal communication 2017.

The most thorough study of dispersal of plastic from ammunition is that undertaken by Kanstrup and Balsby (2018) (Figure 5.18), 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 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) 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 5.19).

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

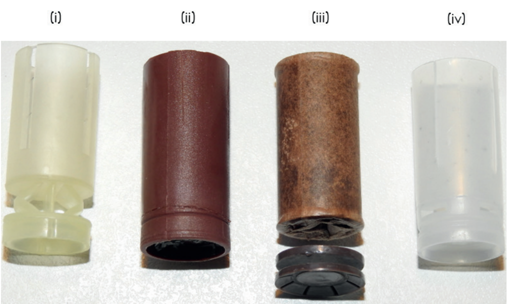


Figure 5.19. Wads made from biodegradable materials are available at the European marked: (i) PVAL, (ii) PHA and (iii) fibre with a liner. Also shown is (iv) a traditional wad made from LDPE. All originate from shotgun cartridges caliber 12/70 (the most commonly used ammunition gauge).

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.

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[10] 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, Andersen 2024).

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). 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.

[10] http://www.plasticpollutioncoalition.org/

5.6.2 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 (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), and any campaign to motivate hunters to retrieve, recycle or reuse empty shells as proposed by Kanstrup and Balsby (2018) would contribute positively to the long-term sustainability of hunting, *inter alia* in terms of resource utilisation. 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 bottles, thereby enhancing the motivation for retrieval and recycling (Kanstrup and Balsby 2018).

5.7 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; 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) 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 leaded centre-fired rifle ammunition with the coming into force by 1st April 2014 (Thomas et al. 2021; Sonne et al. 2022).

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[11] with date of applicability in February 2023.

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 February 2021, ECHA announced a restriction[12] 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[13]. This process is ongoing (at the time of writing early 2024), the provisional timetable was outlined in Thomas et al. (2021).

Several countries outside of Europe have introduced regulation of lead ammunition. In Australia, South Australia, Northern Territory, Queensland, Tasmania,

[11] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0057&from=EN

[12] Towards sustainable outdoor shooting and fishing – ECHA proposes restrictions on lead use - All news - ECHA (europa.eu)

[13] Lead in outdoor shooting and fishing ANNEX XV report (europa.eu)

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 and since then developed regulation of rifle ammunition (Avery and Watson 2008; Byrne 2023). 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). 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)

In addition to legal regulations, some countries have introduced voluntary programmes where hunters are recommended to use non-lead ammunition. Mateo and Kanstrup (2019) 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) 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; Schulz et al. 2020; Widemo 2021; Béchet et al. 2024). Even total legal bans on the import, trade and possession of lead ammunition have their shortcomings if the law is not properly enforced. Kanstrup (2012) 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) 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). 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). McIntosh et al. (2023) demonstrated how banning the use of lead shot in key waterbird roosting sites with high compliance and enforcement can minimize but not eliminate lead shot ingestion, because foraging occurs outside wetlands for many waterfowl species.

Studies from 2018 and 2019 indicate that compliance with the Danish regulations on lead gunshot is high, but for some hunting forms it may not yet be complete. However, no follow-up evaluation of compliance has taken place since then.

6 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-facetted socio-economic and political discussions surrounding change, as seen in many other nature conservation and society issues.

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

6.1 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). The technical aspects of changing from lead to non-lead have been well investigated (see section 5.5). The issue is well studied and evidence points to the conclusion that existing alternatives to lead ammunition largely fulfil the demands for safe and humane hunting at the same level as traditional leaded 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 mainly are used for 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; Thomas et al. 2016).

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.

6.1.1 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).

6.1.2 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).

6.1.3 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; Kanstrup and Balsby 2019). The lessons learnt from this process have been documented in several studies (e.g. (Beintema 2004; Kanstrup 2006b; Kanstrup 2015; Kanstrup and Andersen 2009; Pain 1992) and were summarised in a review in 2018 (Kanstrup 2018) 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 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. 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). During the last few years, the agenda has been set for a phase-out of leaded 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). 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*".[14] 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 leaded rifle ammunition for hunting purposes in 2023. This was enacted in a 2022 regulation banning the use and carrying of central-fired lead rifle ammunition in hunting as from 1st April 2024 (Sonne et al. 2022).

6.1.4 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*

[14] https://www.jaegerforbundet.dk/om-dj/dj-medier/nyhedsarkiv/2019/bly-i-riffelammunition-pa-vej-ud/

Denmark banned the use of lead shot for hunting in wetlands in 1986 and extended the ban to all other habitats in 1996. As of April 2024, regulations have also been introduced regarding leaded rifle ammunition. Denmark is considered a frontrunner in the effort to eliminate lead from hunting practices.

(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[15].

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 very high degree of ethical and moral integrity among the participants[16] in order to justify its perpetuation.

6.1.5 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 leaded 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 5.5.3.). 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 leaded ammunition was in the past, greatly assisted in successful transition (Gremse and Rieger 2015; Harmuth 2011; Spicher 2008). The regulation of leaded 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-

[15] The Department of Conservation and Environment (DCE), Victoria.

[16] http://www.gma.vic.gov.au/education/fact-sheets/non-toxic-shot/why-has-the-change-been-made

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).

6.1.6 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 leaded rifle ammunition culminating with the total ban on all lead ammunition for hunting in California in 2019 shows that this option is possible. However, so far information on the success or lack of success of this step is not publically available.

6.2 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; 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 the smallest 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). The market availability is less complete. Kanstrup and Thomas (2019) 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) 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) and Figure 6.1. The single elements are thoroughly described in the original paper.

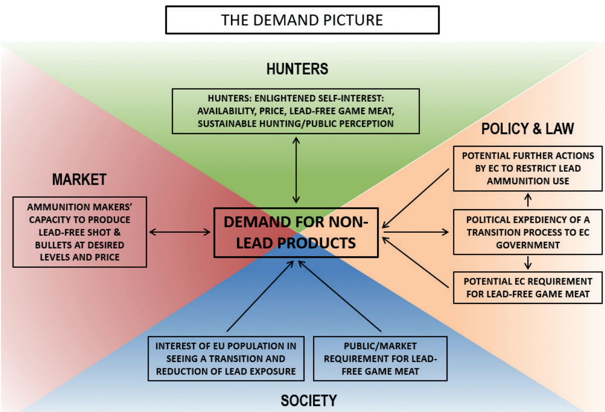


Figure 6.1. The four major components that interact to determine the demand for non-lead ammunition products. From Kanstrup and Thomas (2020).

The price of non-lead ammunition tends to be slightly higher than that of equivalent traditional lead types (see section 5.5.4). 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). In the case of some lead alternative metals, such as bismuth- and tungsten-based gunshot, the raw materials are significantly more expensive and as a result will not 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) 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). 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[17]) revealed that retail prices of clay shooting ammunition in 2021 were 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) 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 (Kan-

[17] https://guntex.dk/

strup 2018; Kanstrup et al. 2021) 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), and the effect on sales volumes and use has been poorly documented. To the knowledge of the author of this book, 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 un-leaded 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; Kanstrup and Thomas 2019). 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 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.

6.3 Lead ammunition is not sustainable

Kanstrup et al. (2018) 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); Kanstrup (2015); Kanstrup and Thomas (2020).

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 poses a risk to the benign public perception of hunting (Kanstrup and Thomas 2020) but can also be related to the economic aspects of sustainability of the use of lead ammunition as described in Pain et al. (2019b), 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[18] Article 191 and European Union Directive 2004/35/[19], Article 1) (Kanstrup et al. 2018). However, this principle has, in reality, not often been applied and societal costs are therefore likely to be externalised (Kanstrup and Thomas 2020).

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 5.1.3. This can be related to lead exposure in both biotic and abiotic systems.

Although lead adversely affects physiological processes in living organisms (section 5.4.3.), 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

[18] 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

[19] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0035

Carcass of slaughtered fallow deer calf trimmed according to Scandinavian veterinary standards for game killed with lead ammunition. Approximately 2 kg venison out of a total of 14 kg was discarded. This demonstrates an avoidable economic loss caused by the use of lead ammunition.

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. (2019b) 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 (2019b) 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). 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 5.1.3), 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).

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.

6.4 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[20] (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*

[20] https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf

environmental degradation", the Convention of Migratory Species' Raptors Memorandum of Understanding[21] (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 [22] 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[23] 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[24] 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[25] 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, 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 pro-active 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.

[21] https://www.cms.int/raptors/en/page/agreement-text

[22] https://www.cbd.int/convention/articles/?a=cbd-00

[23] https://www.unep-aewa.org/sites/default/files/basic_page_documents/agreement_text_english_final.pdf

[24] 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

[25] https://www.unep-aewa.org/sites/default/files/publication/cg_11_0.pdf

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 standpoint 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.

6.5 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.

6.5.1 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[26]. 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*"[27]. 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 re-

[26] https://www.afems.org/lead/

[27] https://www.afems.org/download/lead/independent-studies/Consumer-and-Animal-Protection.pdf

ference was given to the massive legacy of scientific literature demonstrating both the severe adverse impact that lead ammunition can pose to wildlife, ecosystems and humans, nor was reference made to the broad variety of existing suitable alternatives (e.g. Delahay and Spray (2015); Kanstrup et al. (2019a); 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). 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 6.2.

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; Mateo and Kanstrup 2019) call for research and development to

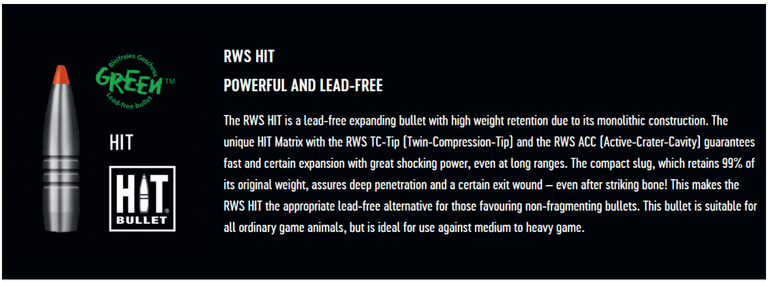


Figure 6.2. An example of a manufacturer's recommendation of a "powerful and lead-free" rifle cartridge, in this case the German product RWS[1].

[1] https://rws-ammunition.com/en/infotainment/rws-bullets/rws-hit

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 disrespected. 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"*[28]. 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

[28] https://gallery.mailchimp.com/068f43d6728c3bcee6f5c89ee/files/52636584-640d-4c8e-94d4-a246ad4f09c0/Press_Release_AFEMS_ECHA_restriction.pdf

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). 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.

6.5.2 Hunters – representatives and citizens

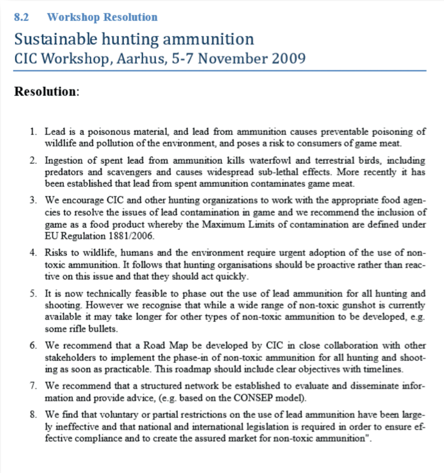
Many national hunters' organisations and their international associates positively support the phase-out of lead shot – at the very least for hunting over wetlands (e.g. FACE 2020). However, they do not proactively campaign for such change and do not actively contribute to measures to improve enforcement where legislation is in place (Kanstrup et al. 2018; Thomas et al. 2021). 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 non-lead alternatives (Kanstrup and Thomas 2020). 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; Kanstrup and Thomas 2020; 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.

Figure 6.3. An example of a British countryside and hunting stakeholder campaigning to fight the threat to lead (CA 2013).

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). 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 6.3). 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).

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). 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 6.4) stating *inter alia* that risks from lead ammuni-



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

tion 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.

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[29]. 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.

[29] https://www.youtube.com/channel/UCaarm993sAqdiCC681egapw/playlists

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 6.4) 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, 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[30]. Interestingly, however, high ranking employees and board members of the Danish Hunters' Association 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

[30] https://www.face.eu/2020/08/phasing-out-lead-gunshot-over-wetlands-why-the-ec-proposal-is-unworkable/

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 30th October 2018 to Ms. Elzbieta Bieñkowska, 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)[31]. 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[32]. In Sweden, 195,000 of 29,000 hunters (67%) are members of the largest hunting organisation, Svenska Jägareförbundet, and in Belgium 13,000 of 20,000 hunters (65%) are members of a national hunting organisation[33]. 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'

[31] http://www.leadammunitiongroup.org.uk/wp-content/uploads/2019/12/Minutes-of-the-23rd-LAG-meeting-with-appendix.pdf

[32] https://basc.org.uk/about-us/

[33] https://www.face.eu/members/

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.

organisations in the respective countries to the individual hunters are long and probably totally insufficient to ensure their effective participation in 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).

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 compliance with these.

6.6 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; 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). 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); 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*"[34]. 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.*

[34] https://www.youtube.com/watch?v=PtPfn-24b64&index=15&list=PLFJWKcWN4Qf5XkZ99qPrI3tmDSJhy72HN

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".[35] A representative from the British food market chain, Waitrose, at a October 2020 conference[36] 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 book 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 exhange 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 ammuntion (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 year. Twelve (34%) respondents were members of a hunting association, 17 (49%) were a member of a nature protection assosiation, 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. Ellis and Miller (2023) concluded that despite concerns that lead ammunition bans are hunting bans in disguise, no country with full or partial lead ammunition bans has reported declines in hunting participation.

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[35] https://www.unep-aewa.org/en/news/it-time-let-go-lead

[36] https://www.eventbrite.co.uk/e/game-2020-conference-tickets-90124582051#

Game is traded and exported with buried remains of ammunition. This deep-frozen "pot ready" Wood Pigeon *Columba palumbus* was purchased by the 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.

6.7 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 5.4.6). 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), 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). 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), 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.

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[37], and no minimum levels of lead have been set for game meat within the European jurisdiction (Thomas et al. 2020; Thomas et al. 2021).

[37] http://www.fao.org/fao-who-codexalimentarius/about-codex/en/#c453333

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; Kanstrup et al. 2018; Kanstrup and Thomas 2020). 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). 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 of providing economic and ethical underpinning for hunting and game management will be lost (Kanstrup et al. 2018).

The Action CA22166[38], Safety Game Meat Chain (SafeGameMeat) under the European Cooperation in Science & Technology (COST), was established in 2023. It applies a transnational and multidisciplinary One-Health approach to enable the exchange of experiences and concepts through networking, thereby promoting the strengthening and harmonization of food safety standards in a growing European game meat market. The network consists of all relevant players along the game meat supply chain "from forest to fork". A particular focus is on the identification and assessment of known and emerging chemical and biological risks associated with the consumption of game meat, including lead from ammunition.

6.8 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 achieved 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; Thomas et al. 2021). In the case of lead ammunition,

[38] https://www.cost.eu/actions/CA22166/

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).

6.8.1 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 on 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; Thomas et al. 2021; 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; Kanstrup et al. 2021). 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 noncompliance: 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). Despite this, evidence of subsequent illegal use appeared, but today compliance seems to be almost complete (Kanstrup and Balsby 2019) – albeit that this may vary between hunting types (Kanstrup and Balsby 2018).

Regulation of lead ammunition has been implemented at different levels, resulting in contrasting legal impacts, either directly or indirectly. Organizations such as AEWA, The Bern Convention, and other MEAs have recommended the removal of lead from ammunition. However, these recommendations are not politically binding, and their implementation is therefore not mandatory for the contracting parties.

The most significant step to eliminate lead from hunting was the REACH regulation[39,40], which prohibits lead shot over wetlands. This regulation, effective from 15 February 2023 in all European Union countries, prohibits discharging and carrying lead shot in or within 100 metres of wetlands. However, there are no reports on enforcement of and compliance with this regulation at member state level.

The European Commission initiative to impose a wider restriction on lead ammunition resulting the European Chemicals Agency (ECHA) Annex XV dossier proposing restrictions on lead in outdoor shooting and fishing[41], would set the conditions for the prohibition of manufacture, use, marketing and import of lead ammunition. These restrictions would apply directly and legally to all member states and their citizens, although the individual member states will retain formal responsibility to ensure enforcement and communication. However, in the time of writing (early 2024) the Commission has not published its proposed amendment to the list of restrictions under the REACH Regulation. This delay has raised concern and has been addressed in several public outlets including open letters (European Scientists 2023).

In addition to direct regulation from the European Union and legal regulations at national (federal) or, in some cases at subnational (states, departments) level, 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 implemented, indicates a preparedness of the private and commercial marketplace to intervene to eliminate the use of lead ammunition from the human food chain.

Setting of maximum levels for lead in game within the European Union Regulation 1881/2006, as suggested by Thomas et al. (2020), or by single member states (Kanstrup et al. 2016) 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)

39 https://environment.ec.europa.eu/news/new-rules-banning-hunting-birds-lead-shot-wetlands-take-full-effect-2023-02-16_en

40 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2021.024.01.0019.01.ENG&toc=OJ%3AL%3A2021%3A024%3ATOC

41 https://echa.europa.eu/documents/10162/2c82ef18-ce5d-4b4f-8ff0-002932154acc

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). The consequences for animal welfare of lead ammunition use have been widely ignored because such consequences have 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 6.5 and also addressed in Thomas et al. (2021) and Thomas and Kanstrup (2023), are complex. However, it is obvious that legal instruments must be applied. The

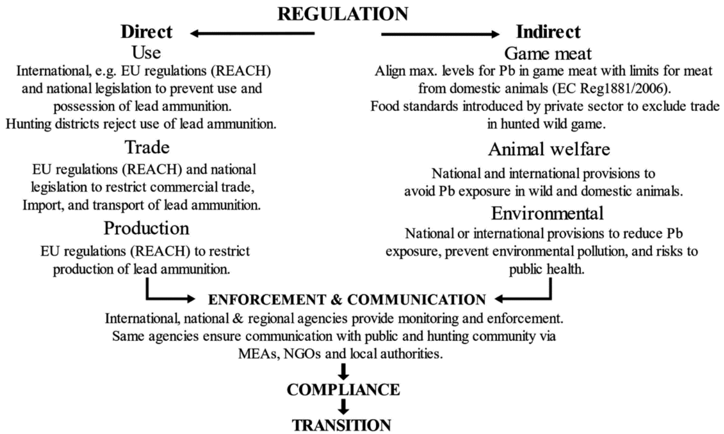

Figure 6.5. Regulation may focus directly on the use, possession, trade and/or production of lead ammunition or indirectly through restrictions on the impacts of lead ammunition, including contamination of foods, unnecessary suffering of the hunted target animal or provisions for people in certain professions. Figure from Thomas and Kanstrup (2023).

recent 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; Thomas et al. 2019; Thomas and Kanstrup 2023). 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, the environment, and society.

6.8.2 Voluntary systems

Segerson (2013) found three primary types of voluntary approaches in environmental protection programmes: 1) unilateral initiatives, where polluters 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), they have largely been unsuccessful in terms of obtaining efficient transition (Cromie et al. 2015; Green et al. 2021; Kanstrup and Thomas 2020; 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) 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) predicted a further shift from use of lead to non-lead ammunition among Danish rifle hunters, they saw little prospect for such a voluntary 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 of 2024 holds large potential to be successful (Kanstrup 2024).

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 5.6.1 and Kanstrup and Balsby (2018). This problem has been addressed by hunting organisations in both the UK (GWCT et al. 2020) and Denmark[42]. The Danish government addressed this 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

[42] https://www.jaegerforbundet.dk/om-dj/dj-medier/nyhedsarkiv/2018/slut-med-haglskale-i-plast/

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 2024) 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 Danish 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). The latest update on types and availability in Denmark can be found in Andersen (2024).

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 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.

6.9 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 ("this is not about lead, it is about hunting", see section 6.6). 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 was summarized by Arnemo et al. (2019) 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) reducing risks from lead ammunition to the health of human consumers of game as demonstrated in Pain et al. (2022); 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; Pain et al. 2019b; Thomas et al. 2021).

These benefits to society should be regarded also as clear benefits to hunters as an integrated feature of society (Sonne et al. 2019). 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 hunt-

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

ers' 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). 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; Thomas et al. 2021), 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.

On 20 May 2020, the European Commission adopted a Communication[43] on a "EU Biodiversity Strategy for 2030 – Bringing nature back into our lives", em-

[43] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380

phasising 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 contaminated 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[44] 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, conservations goals in strictly protected areas. In this context, the present and irreversible legacy of already dispersed leaded 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 book 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. Only time will tell whether the phasing out lead is be a prerequisite for demonstrating hunting can be accepted as an integrated and legitimate part of modern society.

6.10 Target shooting

This book 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

[44] https://www.jaegerforbundet.dk/media/16265/biodiversitetsstrategi_kommission_vejledning.pdf

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 is low and recovery and recycling of ammunition material are a realistic option. Clay target shooting is commonly

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

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; 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; 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) 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.

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 safely 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), 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). 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[45]).

[45] EN-Olympic-Charter.pdf

7 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). 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; 2023; 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; Thomas et al. 2021). 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), 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 book, 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. 2019a). 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). 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), 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. (2019a), 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[46], OMPO[47] 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 and publications. The mere fact that this book includes more than 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 are 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), this represents a very major block to transition.

[46] Office National de la Chasse et de la Nature

[47] Migratory Birds of the Western Palearctic

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 carrier 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[48]. His suggested change of paradigm has created much dispute, not least in academia, and has by some been interpreted as "knowledge is 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 publication. 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

[48] https://www.ucl.ac.uk/friends-of-wisdom/

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 vertical communication where the composition, complexity and language must be adapted to enhance mutual perception and understanding. Sundström (2023) found that despite perceived hurdles associated with the acceptance of non-leaded ammunition among Swedish hunters, these barriers seemed to diminish with increased familiarity and experience, suggesting that focused education and improved availability could promote its adoption.

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. 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, 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). Richards et al. (2024) used the Theory of Planned Behaviour to predict the use of non-lead ammunition in the California Condor recovery zone of southwestern Utah. They found that integrating moral norms and stewardship identity had significant direct and indirect influences on behavioural intentions. They concluded that managers could emphasize a moral obligation to use non-lead ammunition and tap into hunters' desire to steward the landscape and the hunting tradition in their communication and outreach efforts.

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).

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). 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 book. 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 leads 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 title of a 2019 Science-letter: "*Time to ban lead hunting ammunition*" (Sonne et al. 2019).

The prospects of a smooth and effective phase-out of lead rifle ammunition from 2024 in Denmark are very positive. During 2023, there has been a proactive information campaign both in the media and via physical meetings with local hunters. Surveys indicate that a large proportion of hunters has already changed from lead to non-lead ammunition even before the new legislation has come into force (Kanstrup 2024).

In Denmark, the current *c.*170.000 hunters comprise approximately 3% of the total population which is among the highest proportions in Europe. Hunting is inspired by both Scandinavian, German, French, and British traditions and influences. So despite its being relatively small in land area, Denmark has a long tradition of hunting and effective wildlife management. Denmark's lead-free hunting journey can be an inspiring example of how Europe and other continents can build a non-toxic future for hunting globally.

8 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 degradation, including reductions in the size of populations of species of wild animals. Therefore, the continued practice jeopardizes international and national nature conservation goals. Lead poisoning from this source causes death and severe suffering to millions of individuals from wildlife populations and poses a risk of poisoning to human consumers of game. Therefore, it contradicts ethical and existing food safety standards agreed by society. Furthermore, the costs from lead dispersal from hunting ammunition are significant and externalized to the community, and the 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 efforts by relevant statutory authorities and due to a strong commercial lobby. This is even though non-lead, non-toxic, safe and efficient alternatives to lead ammunition are currently available on the market or, where locally absent, will be available once the demand for such products is ensured through the phase-out of lead ammunition through effective regulation. It is obvious to conclude from extensive research and existing experience that hunting can be practiced without lead in ammunition and the adverse impacts arising from its continued use are unnecessary and avoidable.

The successful transition from lead to non-lead hunting ammunition will only occur through direct and indirect regulatory actions backed by effective enforcement. 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. Voluntary systems have proven ineffective. Efforts by some conservationists and scientists to promote the transition from lead to non-lead ammunition in hunting 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. Hunting will be disconnected from a toxic substance and from the present costs externalized to society. Hunting in the context of wildlife management will have shown to be adaptable to changes in modern society and will have enhanced its sustainability.

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 have 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.

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10 Summaries in Danish, French, Spanish and German

10.1 Resumé på dansk

Denne bog er resultatet af 35 års virke som rådgiver, forsker og aktiv jæger. Den bygger på en syntese af mange års arbejde, erfaring og forskningsresultater inden for emnet blyholdig og blyfri jagtammunition.

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).

Bogen og afhandlingen bag 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. Arbejdet påpeger de alvorlige toksikologiske konsekvenser, der følger af spredning af bly fra den traditionelle anvendelse i jagtammunition. Det er formålet 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 dyreværnsmæssige 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 forarbejde 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 Tyskland i en årrække haft områdevis regulering af blyholdig riffelammunition, mens der i Danmark er indført et forbud mod blyholdig, centraltændt riffelammunition fra 1. april 2024.

Forskning og erfaringer fra en række lande, der har gennemført regulering, har givet sikkert 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. Det konkluderes, at bly kan undværes som materiale i jagtammunition.

Et centralt emne er 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 påvirkes negativt og vedvarende selv ved lave doser af eksponering. Mange naturlige systemer har ligeledes 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.

Trods den omfattende dokumentation af ammunitionsblyets giftighed og uforenelighed med bæredygtig naturforvaltning er det fortsat det langt mest udbredte ammunitionsmateriale. Det skyldes 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 jægernes rettigheder, hvilket har medført en udhuling af jægernes 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 naturligt 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.

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 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 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, fremhæves 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.

10.2 Résumé en français

Ce livre est le résultat de 35 années de travail en tant que consultant, scientifique et chasseur actif. Le travail reconnaît la gestion de la faune comme un élément essentiel de la conservation moderne de la nature.

La gestion de la faune a ses racines dans la philosophie de l'exploitation durable des stocks de gibier par la chasse. Alors que la gestion du gibier s'est traditionnellement concentrée principalement sur la façon dont la récolte affecte la taille des stocks chassables, elle a accordé moins d'attention à certains autres impacts négatifs d'autres aspects de la chasse. La gestion de la faune a 100 ans ou plus et a constamment besoin de suivre le rythme des changements survenant dans la société. La prise de conscience croissante de la société de la nécessité de durabilité dans l'utilisation des ressources naturelles a également mis en lumière la nécessité de comprendre les concepts de systèmes pour pouvoir contrer l'impact des perturbations (résistance) et la capacité d'un système à répondre aux perturbations et à se rétablir après que la source de changement a été éliminée (résilience).

Ce livre et la thèse qui le sous-tend sont basés sur le fait que la chasse disperse des fragments de munitions dans l'environnement. Ces fragments doivent être considérés comme faisant partie de l'empreinte de la chasse sur la nature et les écosystèmes et en tant que tels, font partie du concept de pression de chasse. Pour cette raison, il est essentiel d'intégrer les conséquences de la dispersion de ce matériau dans l'environnement dans l'évaluation globale de la durabilité de la chasse en même temps que l'évaluation d'autres impacts. La thèse identifie en particulier les conséquences hautement toxiques de la dispersion de fragments de plomb dans les environnements naturel et humain par l'utilisation traditionnelle du plomb dans les munitions de chasse. Le but de ce travail est de mettre cette contribution à l'environnement en lumière et de documenter certains des problèmes que ce matériau crée, tout en proposant des solutions pour réduire les impacts environnementaux

et en présentant des propositions de gestion qui, en particulier, peuvent garantir le passage efficace du plomb à des munitions sans plomb dans toutes les branches de la chasse. Le travail est principalement basé sur des données recueillies dans des conditions danoises et européennes, mais ces données, résultats et conclusions sont pertinentes partout où la chasse avec des armes à feu est pratiquée, et devraient également être considérées comme un moyen de traiter d'autres défis environnementaux et de gestion de la nature connexes.

Le plomb est un métal largement répandu et hautement adaptable que la société utilise depuis des millénaires et dont la toxicité est reconnue depuis presque aussi longtemps. Pourtant, ce n'est que depuis le dernier demi-siècle que la société a activement cherché à éliminer l'utilisation du plomb, par exemple dans l'essence et la peinture, pour des raisons de santé humaine, et seulement après une recherche prolongée et des campagnes actives contre les industries et le lobbying. Les munitions, y compris celles utilisées pour la chasse, ont traditionnellement été fabriquées en plomb, et son utilisation a répandu le métal dans l'environnement où il sert de source majeure d'empoisonnement pour les animaux sauvages et constitue une contamination majeure de leurs habitats. La chasse reste aujourd'hui la plus grande source unique de plomb dispersé dans la nature. Les résidus de munitions sont déposés dans les tissus des proies cibles, où ils deviennent une source d'empoisonnement pour les consommateurs, que cela se produise dans les écosystèmes naturels, où les animaux blessés ou tués ou leurs parties du corps finissent par servir de nourriture pour les prédateurs et/ou les charognards, ou s'il s'agit d'humains qui consomment la viande de gibier contaminée. On sait depuis le milieu du XIXe siècle que les munitions en plomb de chasse peuvent causer un empoisonnement des oiseaux ingérant des plombs de chasse en plomb, et au cours des 70 dernières années, l'héritage de preuves du risque d'empoisonnement s'est considérablement accru grâce à la recherche principalement menée en Amérique du Nord et en Europe. En plus de l'accumulation de plomb dans les environnements naturels, l'empoisonnement par les munitions en plomb a entraîné une augmentation de la mortalité parmi les espèces à la fois chassables et non chassables, souvent vulnérables, ce qui peut affecter négativement leur statut de conservation. Parallèlement, l'empoisonnement au plomb entraîne une morbidité et une souffrance accrues chez les individus, ce qui a des conséquences significatives sur le bien-être animal.

L'utilisation continue du plomb pour la production de munitions est principalement basée sur la tradition de le faire, renforcée par l'inertie résultant du grand incitatif commercial à continuer d'utiliser le plomb comme base pour le matériau des munitions. De plus, le plomb est bon marché et facile à traiter et est considéré comme ayant de bonnes propriétés balistiques. Cependant, pour presque toutes les utilisations, il existe des types de munitions non toxiques, sûrs et efficaces, fabriqués en série et commercialisés, où le plomb a été remplacé par, par exemple, le fer, le bismuth et le cuivre. En plus du plomb, d'autres matériaux sont également dispersés comme conséquence du tir d'armes à feu pendant la chasse, et ici, l'accent est surtout mis sur les composants en plastique des cartouches de fusil de chasse, pour lesquels des efforts sont actuellement déployés pour remplacer ceux-ci par des matériaux biodégradables, y compris des polymères et des fibres.

L'empoisonnement par les munitions en plomb a fait l'objet d'une grande attention scientifique, notamment de nombreuses conférences, et la quantité de connaissances publiées sous forme d'études individuelles, de revues et de compilations est désormais très étendue, convaincante et unanime. Un certain nombre d'organisations internationales ont pris l'initiative de promouvoir l'élimination progressive des balles en plomb pour la chasse, notamment l'Accord sur les oiseaux d'eau d'Afrique-Eurasie (un traité international relevant du Programme des Nations unies pour l'environnement de la Convention sur les espèces migratrices), qui dès 1995 a appelé les États membres à éliminer progressivement les balles en plomb pour la chasse sur les zones humides d'ici l'an 2000. La plupart des pays européens ont aujourd'hui mis en place des règles pour la chasse aux balles en plomb dans les zones humides, mais le tableau général montre que ces règles ne sont contrôlées et respectées que dans une mesure limitée. De même, la mise en œuvre géographique inégale de différents niveaux de réglementation ne résout pas le problème lorsqu'on la considère dans un contexte global plus large, y compris, par exemple, les voies de migration internationales utilisées par les oiseaux migrateurs. Plus récemment, la Commission européenne a décidé d'éliminer progressivement les balles en plomb pour la chasse dans les zones humides dans tous les États membres à partir de 2023 et prévoit également des restrictions sur les balles en plomb pour la chasse dans d'autres écosystèmes ainsi que sur le plomb dans les munitions de fusil. Un certain nombre de pays en dehors de l'Europe ont interdit les balles en plomb pour la chasse dans les zones humides, comme les États-Unis et le Canada. Au niveau mondial, seule la Californie a interdit généralement toutes les munitions de chasse contenant du plomb, y compris les munitions de fusil. En Europe, seule l'Allemagne a mis en œuvre une réglementation étendue sur les munitions de fusil contenant du plomb, tandis que le Danemark a interdit la chasse avec des munitions de fusil à percussion centrale en plomb à partir du 1er avril 2024.

Des recherches menées dans plusieurs pays ayant mis en place une réglementation ont fourni des preuves fiables des expériences associées à l'élimination réussie du plomb. Dans le cas des balles en plomb en particulier, l'expérience acquise depuis l'interdiction totale mise en place par le Danemark en 1996 a été l'objet d'une grande attention, tant en ce qui concerne son utilisation pratique, sa gestion (y compris la conformité) que l'importance de maintenir la chasse en tant qu'activité récréative. Des programmes de recherche approfondis en Allemagne, au Danemark et en Norvège montrent que les munitions de fusil sans plomb sont à la fois sûres et efficaces. Les munitions sans plomb sont généralement disponibles pour les chasseurs à des prix qui, pour la plupart des types de chasse, sont comparables aux prix des munitions traditionnelles. La demande croissante stimule le développement d'une gamme de produits appropriée, qui est particulièrement importante dans les pays qui ont déjà réglementé l'utilisation des munitions en plomb. Pour certains types de munitions de petit calibre, l'approvisionnement en munitions alternatives non plombées peut encore être limité, mais ici aussi, on s'attend à ce que la demande accrue stimule le développement de types de munitions conçues pour répondre à tous les besoins généraux. Sur la base de cette partie de l'analyse, on conclut qu'il n'est plus nécessaire que le plomb joue un rôle quelconque en tant que matériau incorporé dans quelque forme que ce soit de munitions de chasse.

Des sections de ce livre travaillent à évaluer dans quelle mesure l'utilisation de munitions en plomb est compatible avec les principes généraux de durabilité, qui sont de plus en plus établis par la société pour la chasse comme forme d'utilisation de la nature. Bien que certains systèmes naturels aient une résistance intégrée à la contamination par le plomb, le tableau général qui émerge montre que la plupart des systèmes sont affectés de manière adverse et persistante même à de faibles doses d'exposition à la toxine. De nombreux systèmes naturels démontrent la capacité à se rétablir correctement après l'arrêt d'un agent de stress donné (c'est-à-dire qu'ils montrent une résilience à cet agent de stress). En revanche, l'héritage historique de décennies de plombs dispersés dans une zone peu profonde étudiée au Danemark, une zone spéciale de protection soumise à une chasse intensive aux oiseaux d'eau, a montré la persistance des plombs accumulés, correspondant à 250 kg/ha dans les sédiments, une charge toxique irréversible qui restera accessible aux oiseaux d'eau dans cet écosystème pendant de nombreuses décennies à venir. Malgré la législation interdisant l'utilisation de tels plombs au Danemark dans les zones humides depuis 1986, ce poison reste actif et accessible, soulignant l'héritage de l'utilisation historique et inutile d'un matériau aussi toxique de manière indiscriminée, ce qui contredit toutes les définitions communément acceptées de la durabilité. Sur la base de cela, on peut clairement conclure que la chasse avec des munitions en plomb ne peut être considérée comme durable.

Malgré la documentation scientifique étendue de la toxicité du plomb et de son incompatibilité avec une gestion durable de la nature, le plomb reste de loin le matériau le plus répandu utilisé pour fabriquer des munitions. La conversion efficace de la connaissance en action a été lente et laborieuse. Une des principales raisons à cela est la faiblesse de certaines des autorités responsables à réglementer efficacement et à communiquer la nécessité de réglementation aux parties prenantes pertinentes et aux citoyens. En conséquence, les chasseurs et d'autres groupes d'intérêt ont généralement été insuffisamment informés et impliqués dans le processus de suppression progressive. Les principaux groupes cibles des campagnes et de l'implication ont principalement été les ONG pertinentes, en particulier les organisations de chasse et les représentants de l'industrie des munitions, où le thème est devenu le sujet des agendas politiques et commerciaux internes. Dans certains pays, les initiatives visant à éliminer les munitions en plomb ont été catégorisées comme une attaque contre la chasse et les droits des chasseurs - perçues comme une manœuvre anti-chasse - ce qui a conduit à une érosion de la confiance des chasseurs dans le processus et ultimement dans leur respect des règles et de la législation.

Ce n'est que ces dernières années que l'accent s'est porté sur l'exposition des personnes à l'empoisonnement au plomb à la suite de la consommation de viande de gibier contenant des munitions de chasse, en mettant l'accent sur les risques pour les groupes particulièrement vulnérables, en particulier les enfants et les femmes en âge de procréer. Cet aspect a accentué la nécessité de progressivement éliminer tout le plomb des munitions, car il est fondamental que la chasse soit une source durable de nourriture, que le gibier récolté représente une ressource alimentaire sûre et saine. Ceci est critique à un moment où de larges secteurs de la société européenne demandent davantage de «produits alimentaires produits naturellement» en réaction aux méthodes de production animale de plus en plus intensives associées à l'agriculture industrialisée. Dans ce contexte, la viande de gibier d'animaux ayant eu une vie libre et une alimentation naturelle non entravée est considérée par beaucoup comme une alternative préférable aux animaux d'élevage en batterie. Dans ce contexte, il est de plus en plus important que les chasseurs, en tant que producteurs primaires, puissent garantir des normes de qualité de sécurité alimentaire. L'élimination du plomb des munitions de chasse ne peut être efficace sans une action réglementaire clé au niveau national ou international. Certains pays ont lancé des expériences en mettant en place des programmes volontaires où les chasseurs sont encouragés à passer des munitions plombées aux munitions non plombées, mais l'expérience montre inévitablement que les systèmes volontaires sont inefficaces. Des études montrent également que l'intervention législative peut être limitée dans son effet si elle n'est pas contrôlée et surveillée efficacement. Par exemple, la législation doit non seulement contrôler l'utilisation des munitions en plomb, mais aussi leur possession et leur commerce si elle doit jamais être vraiment efficace, comme cela a été démontré au Danemark. De plus, des mesures indirectes peuvent également être efficaces, notamment, par exemple, l'établissement de limites maximales pour la teneur en plomb de la viande de gibier correspondant aux limites applicables pour les autres produits carnés d'élevage conventionnels.

Indépendamment du type et du niveau de réglementation, il est crucial qu'il soit accompagné d'une stratégie de communication globale et de l'implication des parties prenantes, reconnaissant à la fois les chasseurs comme groupe central mais aussi les chasseurs individuels et la population dans son ensemble comme des acteurs clés dans la problématique plus large. Les résultats des études de terrain et une simple logique conduisent à la conclusion que la transition du plomb aux munitions de chasse non plombées élimine le risque d'exposition et d'empoisonnement pour les écosystèmes, la faune et les humains. Compte tenu de cette réalité, la conclusion inévitable est que ce processus bénéficiera à tout le monde, en particulier aux chasseurs eux-mêmes.

Les munitions de chasse contenant du plomb sont un problème environnemental relativement simple à résoudre, et leur élimination de l'utilisation n'est pas intrinsèquement complexe par rapport à la résolution d'autres problèmes environnementaux. Les perspectives d'avenir comprennent la nécessité d'efforts de recherche interdisciplinaires intensifiés, intégrant la santé humaine avec le bien-être de l'environnement naturel, des écosystèmes, de la faune et des personnes, d'une manière jusqu'ici non tentée. L'initiative Une seule santé de l'OMS est une plateforme évidente dans laquelle promouvoir un tel développement. Le renforcement des efforts de recherche dans les disciplines scientifiques classiques, les sciences sociales et la technologie est également une condition préalable essentielle pour garantir une transition efficace, à long terme et stable, y compris des mécanismes pour assurer le développement constant de types de munitions alternatives qui sont à la fois sûrs et efficaces. Il est également nécessaire de promouvoir beaucoup plus efficacement la diffusion de l'information et la communication pour convertir la connaissance en sagesse, pour coordonner mieux entre les secteurs individuels, en mettant davantage l'accent sur l'importance du citoyen individuel.

La suppression réussie du plomb dans les munitions éliminera non seulement un problème environnemental et les coûts supplémentaires associés que cela représente pour la société, mais démontrera également que la gestion de la nature et de la faune a la capacité de s'adapter aux nouveaux défis qui découlent d'une société moderne en transition rapide. Elle a le potentiel d'apporter des avantages significatifs en créant la base pour un dialogue constructif amélioré entre les parties prenantes travaillant à promouvoir la biodiversité et à garantir des objectifs de conservation de la nature et de durabilité. La transition du plomb aux munitions non plombées déconnectera la chasse d'une substance toxique et améliorera ainsi sa durabilité. Elle montrera la chasse dans le contexte de la gestion de la faune comme étant adaptable aux changements dans la société moderne.

10.3 Resumen en español

Este libro es el resultado de 35 años de trabajo como consultor, científico y cazador activo. El trabajo es un reconocimiento de la gestión de la vida silvestre como un elemento central en la conservación moderna de la naturaleza.

La gestión de la vida silvestre tiene sus raíces en la filosofía de la explotación sostenible de las poblaciones de las especies cinegéticas a través de la caza. La gestión de la caza tradicionalmente se ha centrado en cómo las capturas afectan al tamaño de las poblaciones cazables y se ha prestado menos atención a algunos otros impactos adversos de la caza. La gestión de la vida silvestre se ha estado llevando a cabo desde hace más de 100 años, pero también tiene la obligación creciente de mantenerse al día con los cambios que ocurren en la sociedad. El aumento de la conciencia social sobre la necesidad de sostenibilidad en el uso de los recursos naturales también ha puesto el foco en la necesidad de comprender los conceptos de sistemas para poder contrarrestar el impacto de las perturbaciones (resistencia) y la capacidad de un sistema para responder a las perturbaciones y recuperarse después de que se elimine la fuente de cambio (resiliencia).

Este libro y la tesis que hay detrás se basan en el hecho de que la caza dispersa fragmentos de munición en el medio ambiente. Estos fragmentos deben ser considerados como parte de la huella de la caza en la naturaleza y los ecosistemas y, como tal, forman parte del concepto de presión de caza. Por esta razón, es esencial integrar las consecuencias de dispersar este material en el medio ambiente en la evaluación general de la sostenibilidad de la caza al mismo tiempo que se evalúan otros impactos. La tesis identifica en particular las consecuencias altamente tóxicas de dispersar fragmentos de plomo en los entornos natural y humano a través del uso tradicional de plomo en la munición de caza. El propósito de este libro es poner de relieve las consecuencias adversas del plomo de las municiones para el medio ambiente y documentar algunos de los problemas que este material crea, así como presentar soluciones para reducir los impactos ambientales y presentar propuestas de gestión que, en particular, puedan garantizar el cambio efectivo de plomo a munición sin plomo en todas las ramas de la caza. El trabajo se basa principalmente en material recopilado en condiciones de uso danesas y europeas, pero estos datos, resultados y conclusiones son relevantes en todas partes donde se practica la caza con armas de fuego y también deberían considerarse como un medio para abordar otros desafíos ambientales y de gestión de la naturaleza relacionados.

El plomo es un metal ampliamente extendido y altamente adaptable que la sociedad ha utilizado durante milenios, y de la misma forma su toxicidad ha sido reconocida desde hace la Antigüedad. Sin embargo, solo en el último medio siglo la sociedad ha buscado activamente eliminar el uso de plomo, por ejemplo, en la gasolina y la pintura, por razones de salud humana, y solo después de una investigación prolongada y una campaña activa contra las industrias involucradas. La munición, incluida la utilizada para la caza, tradicionalmente ha estado hecha de plomo, y su uso ha llevado a la dispersión de este metal en el medio ambiente, donde termina siendo una fuente importante de intoxicación para los animales salvajes y, además, constituye una forma de contaminación importante de sus hábitats. La caza es hoy en día la mayor fuente de contaminación por plomo en la naturaleza. Los residuos de la munición se depositan dentro de los tejidos de la presa disparada, donde se convierten en una fuente de intoxicación para los consumidores de estos animales, ya sea esto en ecosistemas naturales donde los animales heridos o muertos por la caza o partes de su cuerpo terminan como alimento para depredadores y carroñeros, o para los humanos que consumen la carne de caza contaminada. Se sabe desde mediados del siglo XIX que la munición de plomo de caza puede causar intoxicaciones de aves silvestres que ingieren perdigones de plomo y en los últimos 70 años las evidencias del riesgo de envenenamiento han crecido muy rápidamente en base a investigaciones realizadas, principalmente, en América del Norte y Europa. Además de la acumulación de plomo en entornos naturales, la intoxicación por la ingestión de munición de plomo ha resultado en un aumento de la mortalidad de aves, tanto de especies cazables como no cazables, muchas veces vulnerables, lo que puede afectar negativamente su estado de conservación. Al mismo tiempo, la intoxicación por plomo o plumbismo causa un aumento de la morbilidad y el sufrimiento en los individuos afectados y, por lo tanto, tiene consecuencias significativas para el bienestar animal.

El uso continuado de plomo para producir munición se basa principalmente en la larga tradición de usar este material, reforzada por la inercia del gran incentivo comercial para continuar usando plomo como base para el material de munición. Además, el plomo es barato y fácil de procesar y se considera que tiene buenas propiedades balísticas. Sin embargo, para casi todos los usos, hay tipos de munición alternativos, no tóxicos, seguros y eficaces producidos en masa, donde el plomo ha sido reemplazado, como por ejemplo por hierro, bismuto y cobre. Además del plomo, otros materiales también se dispersan como consecuencia de la descarga de armas durante la caza, y aquí el foco está especialmente en los componentes de plástico en cartuchos de escopeta, para los cuales actualmente se están haciendo esfuerzos para reemplazar estos por materiales biodegradables, incluyendo tanto polímeros como fibras.

La intoxicación por ingestión de munición de plomo ha sido objeto de gran atención científica, incluyendo numerosas conferencias. La cantidad de conocimientos publicados en forma de estudios individuales, revisiones y compilaciones es ahora muy extensa, convincente y unánime. Un número de organizaciones internacionales han tomado la iniciativa de promover la eliminación progresiva de los perdigones de plomo para la caza, incluyendo el Acuerdo Africano Euroasiático de Aves Acuáticas (un tratado internacional bajo la Convención sobre Especies Migratorias en el marco del Programa de Medio Ambiente de las Naciones Unidas), que desde 1995 había instado a los estados miembros a eliminar el uso de los perdigones de plomo para la caza sobre humedales en el año 2000. La mayoría de los países europeos hoy en día han implementado reglas para la caza con perdigones de plomo en humedales, pero el panorama general muestra que estas reglas solo se controlan y cumplen de manera limitada. Del mismo modo, la implementación geográfica irregular de diferentes niveles de regulación no aborda el problema cuando se ve en un contexto global más amplio, incluidos, por ejemplo, los niveles de rutas migratorias internacionales utilizados por las aves migratorias. Más recientemente, la Comisión Europea decidió eliminar los perdigones de plomo para la caza sobre humedales en todos los estados miembros a partir de 2023 y también está planeando restricciones sobre los perdigones de plomo para la caza en otros ecosistemas, así como sobre el plomo en la munición de rifle. Varios países fuera de Europa han prohibido los perdigones de plomo para la caza en humedales, como los Estados Unidos y Canadá. A nivel mundial, solo California tiene una prohibición general sobre toda la munición de caza que contiene plomo, incluida la munición de rifle. En Europa, solo Alemania ha implementado una regulación extensa de la munición de rifle que contiene plomo, mientras que en Dinamarca la caza con munición de rifle que contiene plomo ha sido prohibida desde el 1 de abril de 2024.

Investigaciones de varios países que han implementado regulaciones han proporcionado evidencias fiables de las experiencias asociadas con la eliminación exitosa del plomo. En el caso de los perdigones de plomo en particular, la experiencia adquirida desde la prohibición total implementada por Dinamarca en 1996 ha sido objeto de mucha atención, tanto en relación con su uso práctico, gestión (incluido el cumplimiento) y la importancia de mantener la caza como actividad recreativa. Programas de investigación extensos en Alemania, Dinamarca y Noruega muestran que la munición de rifle sin plomo es segura y eficaz. La munición sin plomo está generalmente disponible para los cazadores a precios que para la mayoría de los tipos de caza son comparables con los precios de la munición tradicional. La demanda creciente estimula el desarrollo de una gama de productos apropiada, que es notablemente mayor en países que ya han regulado el uso de munición de plomo. Para algunos tipos de munición de calibre pequeño, el suministro de munición alternativa sin plomo puede seguir siendo limitado, pero también se espera que aquí la demanda creciente estimule el desarrollo de tipos de munición diseñados para satisfacer todas las necesidades generales. Sobre la base de esta parte del análisis, se concluye que ya no hay necesidad de que el plomo juegue ningún papel como material incorporado en ningún tipo de munición de caza.

Varias secciones de este libro muestran en qué medida el uso de la munición de plomo es compatible con los principios generales de sostenibilidad, que son cada vez más reconocidos por la sociedad como una necesidad para que la caza sea considerada una forma sostenible de utilización de la naturaleza. Aunque algunos sistemas naturales pueden mostrar cierta una resistencia a la contaminación por plomo generada por la munición de caza, la imagen general emergente es que la mayoría de los sistemas se ven afectados adversa y persistentemente, incluso a dosis bajas de exposición a este metal tóxico. Muchos sistemas naturales muestran el potencial para recuperarse bien después del cese de un estresor dado (es decir, muestran resistencia a ese estresor). En contraste, el legado histórico de décadas de perdigones de plomo dispersos en un área protegida danesa sujeta a caza intensiva de aves acuáticas mostró la persistencia de perdigones de plomo acumulados, que con 250 kg/ha en los sedimentos presente una carga tóxica irreversible que seguirá siendo accesible para las aves acuáticas en ese ecosistema durante muchas décadas futuras. A pesar de la legislación que prohíbe el uso de tales perdigones de plomo dentro de Dinamarca sobre humedales desde 1986, este veneno sigue siendo activo y accesible, subrayando el legado del uso histórico e innecesario de tal material tóxico de manera indiscriminada, lo que entra en conflicto con todas las definiciones comúnmente aceptadas de sostenibilidad. Sobre la base de esto, se concluye claramente que la caza con munición de plomo no puede considerarse sostenible.

A pesar de la extensa documentación científica de la toxicidad del plomo y su incompatibilidad con la gestión sostenible de la naturaleza, el plomo sigue siendo, con mucho, el material más extendido para fabricar munición. La conversión efectiva del conocimiento en acción ha sido muy lenta. Una de las principales razones de esto es la debilidad de algunas de las autoridades estatutarias responsables para regular eficazmente y comunicar la necesidad de regulación a las partes interesadas relevantes y los ciudadanos. Como resultado, los cazadores y otros grupos de interés, generalmente, han sido insuficientemente informados y han participado poco en el proceso de eliminación progresiva. Los grupos principales de objetivos para campañas e implicación han sido principalmente las ONG, especialmente las organizaciones de caza y representantes de la industria de la munición, donde el cambio a municiones no tóxicas se ha convertido en el tema de agendas políticas y comerciales internas. En algunos países, las iniciativas para eliminar progresivamente la munición de plomo han sido categorizadas como un ataque a la caza y los derechos de los cazadores, percibidos como un ardid contra la caza, lo que ha llevado a una erosión de la confianza de los cazadores en el proceso y, en última instancia, en su respeto y cumplimiento de las normas y la legislación.

Solo en los últimos años se ha puesto el foco en la exposición de las personas al plomo como resultado de comer carne de caza que contiene munición de caza, con énfasis en los riesgos que plantea el plomo para grupos particularmente vulnerables, especialmente niños y mujeres en edad fértil. Este aspecto ha acentuado la necesidad de eliminar todo el plomo en la munición, porque fundamental para el concepto de la caza como una fuente sostenible de alimentos es que la carne obtenida representa un recurso alimenticio seguro y saludable. Esto es crítico en un momento en que grandes sectores de la sociedad europea están demandando más "alimentos producidos de forma natural" como reacción a los métodos de producción animal cada vez más intensivos asociados con la agricultura y ganadería industrializada. Visto en este contexto, la carne de caza de animales que han tenido una vida de pastoreo natural se considera por muchos como una alternativa preferible a los animales criados de forma intensiva. En este contexto, es cada vez más importante que los cazadores, como productores primarios, puedan garantizar los estándares de calidad y seguridad alimentaria.

La eliminación del plomo de la munición para la caza no puede ser efectiva sin una acción regulatoria clave a nivel nacional e internacional. Algunos países han lanzado experimentos implementando esquemas voluntarios donde se ha alentado a los cazadores a cambiar de munición con plomo a munición sin plomo, pero la experiencia inevitablemente muestra que los sistemas voluntarios son ineficaces. Los estudios muestran que la intervención legislativa también puede ser limitada en efecto si no se controla y controla eficazmente. Por ejemplo, la legislación no solo debe controlar el uso de la munición de plomo, sino también su posesión y comercio para que sea realmente efectiva, como se demostró en el caso de Dinamarca. Además, las medidas indirectas también pueden ser efectivas, incluido, por ejemplo, el establecimiento de límites máximos para el contenido de plomo en la carne de caza que corresponden a los límites aplicables para otros productos cárnicos convencionales.

Independientemente del tipo y nivel de regulación, es crucial que el proceso regulatorio esté acompañado de una estrategia de comunicación integral y la participación de las partes interesadas, reconociendo que tanto los cazadores, pero también la población en general son actores clave en la resolución del problema. Los resultados de estudios de campo y la simple lógica llevan a la conclusión de que la transición de la munición de caza con plomo a la no contaminante elimina el riesgo de exposición y envenenamiento para los ecosistemas, la vida silvestre y los seres humanos. Dada esta realidad, la conclusión inevitable es que este proceso beneficiará a todos, especialmente a los propios cazadores.

La munición de caza que contiene plomo es un problema ambiental relativamente simple de resolver, y la eliminación de su uso no es inherentemente compleja en comparación con la resolución de otros problemas ambientales. Las perspectivas futuras incluyen la necesidad de intensificar los esfuerzos de investigación interdisciplinarios, incorporando la salud humana con el bienestar del medio ambiente natural, los ecosistemas, la vida silvestre y las personas, de una manera hasta ahora no abordada. La iniciativa de la OMS "Una Salud" es una plataforma obvia dentro de la cual promover dicho desarrollo. Fortalecer los esfuerzos de investigación a través de las disciplinas científicas clásicas, las ciencias sociales y la tecnología también es un requisito esencial para garantizar una transición eficiente, a largo plazo y estable, incluidos mecanismos para asegurar el constante desarrollo de tipos alternativos de munición que sean seguros y eficientes. También hay una necesidad de una promulgación de información y comunicación mucho más efectiva para convertir el conocimiento en sabiduría, para coordinar mejor entre sectores individuales, con un mayor énfasis en la importancia del ciudadano como individuo.

La eliminación exitosa del plomo en la munición no solo eliminará un problema ambiental y los costos adicionales asociados que esto tiene para la sociedad, sino que también demostrará que la gestión de la naturaleza y la vida silvestre tienen la capacidad de adaptarse a nuevos desafíos que surgen como resultado de una sociedad moderna en rápida transición. Este cambio tiene el potencial de traer beneficios significativos como resultado de crear la base para un diálogo constructivo mejorado entre las partes interesadas que trabajan para promover la biodiversidad y garantizar objetivos para la conservación de la naturaleza y la sostenibilidad. La transición del plomo a la munición sin plomo desconectará la caza de una sustancia tóxica y, por lo tanto, mejorará su sostenibilidad. En resumen, mostrará la caza en el contexto de la gestión de la vida silvestre como una actividad adaptable a los cambios que exige la sociedad moderna.

10.4 Zusammenfassung auf Deutsch

Dieses Buch ist das Ergebnis einer 35-jährigen Tätigkeit als Berater, Wissenschaftler und aktiver Jäger. Es basiert auf einer Synthese aus jahrelanger Arbeit, Erfahrung und Forschungsergebnisse zum Thema bleihaltiger und bleifreier Jagdmunition.

Die Arbeit ist ein Ausdruck der Anerkennung des Wildtiermanagements als zentrale Disziplin des modernen Naturschutzes. Wildtiermanagement hat seine Wurzeln in der Philosophie der nachhaltigen Nutzung von Wildtierpopulationen durch die Jagd. Während sich das Wildtiermanagement traditionell hauptsächlich darauf konzentriert hat, wie die jagdliche Nutzung die Größe der Populationen beeinflusst, wurde weniger Aufmerksamkeit auf einige nachteilige Auswirkungen der Jagd gerichtet. Wildtiermanagement existiert bereits seit ca. 100 Jahren und hat den Anspruch, stetig mit den Veränderungen in der Gesellschaft Schritt zu halten. Das zunehmende gesellschaftliche Bewusstsein für die Notwendigkeit der nachhaltigen Nutzung natürlicher Ressourcen hat auch die Bedeutung der Auswirkungen menschlichen Handelns und dessen Folgen in den Fokus des Verständnisses gerückt. So müssen natürliche

Systeme in der Lage sein, den Auswirkungen von Störungen entgegenzuwirken und die Fähigkeit entwickeln, auf Störungen zu reagieren (Resistenz) sowie sich nach der Eliminierung der Ursache zu erholen (Resilienz).

Dieses Buch und die zugrunde liegende Dissertation basieren darauf, dass bei der Jagd Munitionsrückstände in der Umwelt verbreitet werden, die als Teil des Einflusses der Jagd auf die Natur und Ökosysteme und somit auch als Teil des Konzepts des Jagddrucks beurteilt werden müssen. Es ist daher unerlässlich, die Folgen der Ausbreitung dieser Fragmente ebenfalls in die Gesamtbewertung der Nachhaltigkeit der Jagd einzubeziehen. Die präsentierte Arbeit weist insbesondere auf die toxikologischen Folgen hin, die sich aus der Ausbreitung von Bleifragmenten durch die traditionelle Verwendung von bleihaltiger Jagdmunition ergeben. Ziel ist es, diesen Einfluss auf die Umwelt in den Fokus zu rücken, Probleme zu dokumentieren, Lösungen aufzuzeigen und Vorschläge für eine Verwaltung vorzulegen, die einen reibungslosen Übergang von bleihaltiger zu bleifreier Munition in allen Bereichen der Jagd gewährleisten können. Wenngleich sich die Untersuchungen insbesondere auf dänische und europäische Verhältnisse bezieht, sind die Daten, Ergebnisse und Schlussfolgerungen überall relevant, wo mit Schusswaffen gejagt wird. Daher sollten sie als Anregung zur Bewältigung weiterer verwandter Umwelt- und Naturschutzprobleme betrachtet werden.

Blei ist ein weit verbreitetes Metall, das in der Gesellschaft bereits seit Tausenden von Jahren genutzt wird. Seine Toxizität ist fast genauso lange bekannt, doch erst in den letzten fünf Jahrzehnten hat die Gesellschaft aus Gesundheitsgründen aktiv versucht, die Verwendung von Blei abzuschaffen. Dies geschah, wo es technisch und politisch möglich war, z.B. durch das Ende der Bleizugabe zu Benzin und Farbe. Oft erfolgte dies jedoch erst nach umfangreichen Untersuchungen und Kampagnen gegen Industrieinteressen und Lobbyarbeit. Traditionell wurde Munition, einschließlich jener für die Jagd, aus Blei hergestellt, wodurch bei der Abgabe von Schüssen bleihaltige Rückstände in die Umwelt gelangen, die somit eine Quelle für die Vergiftung von Wildtieren und ihren Lebensräumen darstellen. Bis heute ist die Jagd die bedeutendste Einzelquelle für die Verbreitung von Blei in der Natur. Ebenso hinterlässt die Jagd bleihaltige Rückstände im erlegten Wild, welche eine potenzielle Gefahr für Konsumenten darstellen. Diese Gefahr besteht sowohl in natürlichen Ökosystemen, in denen betroffene Beutetiere oder ihre Überreste Nahrung für Raubtiere und Aasfresser sind, als auch bei Menschen, die Wildfleisch essen. Seit Mitte des 19. Jahrhunderts ist bekannt, dass Bleimunition auch Vögel vergiften kann. In den letzten 70 Jahren hat sich das Ausmaß dokumentierter Vergiftungsrisiken stark erhöht, was insbesondere aus Forschungsergebnissen aus Nordamerika und Europa hervorgeht. Neben der Akkumulation von Blei in der Umwelt führt die Vergiftung durch Bleimunition zu einer erhöhten Sterblichkeit bei jagdbaren und nicht-jagdbaren, oft gefährdeten Arten, was sich negativ auf deren Erhaltungsstatus auswirken kann. Gleichzeitig schwächt und leidet jedes Tier unter der Bleivergiftung, was erhebliche negative Auswirkungen auf den Tierschutz hat.

Die fortgesetzte Verwendung von Blei zur Herstellung von Munition beruht hauptsächlich auf Tradition, begleitet von starken kommerziellen Interessen, die Blei als Munitionsmaterial beibehalten wollen. Hinzukommt, dass Blei kostengünstig, einfach zu verarbeiten ist und gute ballistische Eigenschaften besitzt. Es für fast jede Anwendung gibt jedoch bereits alternative Munitionstypen, die sicher, ungiftig und effektiv sind und Blei durch Materialien wie Eisen, Bismut und Kupfer ersetzen. Neben Blei werden aber auch andere Materialien bei der Abgabe von Schüssen verbreitet, insbesondere Kunststoffkomponenten von Schrotkapseln. Während Polyethylen traditionell das vorherrschende Material war, gibt es Bestrebungen, es durch biologisch abbaubare Alternativen wie Polymere und Fasern zu ersetzen.

Die toxischen Auswirkungen von Bleimunition haben großes wissenschaftliches Interesse erregt, was sich in zahlreichen Konferenzen widerspiegelt, und zu umfangreichen Veröffentlichungen geführt hat. Mehrere internationale Organisationen haben Initiativen ergriffen, um die Verwendung von Bleischrot für die Jagd zu reduzieren, darunter das Abkommen zur Erhaltung der afrikanisch-eurasischen wandernden Wasservögel (AEWA), das bereits 1995 die Mitgliedstaaten dazu aufgefordert hat, die Verwendung von Bleischrot für die Jagd in Feuchtgebieten bis zum Jahr 2000 einzustellen. Die meisten europäischen Länder haben inzwischen Regelungen für die Jagd mit Bleischrot in Feuchtgebieten eingeführt, jedoch werden diese Regeln nur begrenzt kontrolliert und eingehalten. Zudem adressieren diese geografisch isolierten Regelungen das Problem nicht in einem größeren globalen Kontext, beispielsweise auf der Ebene von länderübergreifenden Zugvogelrouten. Zuletzt hat die Europäische Kommission beschlossen, die Verwendung von Bleischrot für die Jagd in Feuchtgebieten in allen Mitgliedstaaten ab 2023 abzuschaffen. Darüber hinaus plant die Kommission auch Beschränkungen für die Verwendung von Bleischrot in anderen Ökosystemen sowie für Blei in Gewehrpatronen. Andere Länder außerhalb Europas haben die Verwendung von Bleischrot für die Jagd in Feuchtgebieten ebenfalls verboten, darunter die USA und Kanada. Auf globaler Ebene gibt es nur in Kalifornien ein generelles Verbot von bleihaltiger Jagdmunition und damit auch von Gewehrpatronen. In Europa gibt es in Deutschland bereits seit einigen Jahren gebietsweise eine Regelung für bleihaltige Gewehrpatronen, während in Dänemark ab dem 1. April 2024 ein Verbot von bleihaltigen Zentralzündungsgewehrpatronen in Kraft trat.

Studien und Erfahrungen aus verschiedenen Ländern, die bereits Regelungen umgesetzt haben, liefern klare Beweise für gute Möglichkeiten, Blei aus der Jagd abzuschaffen. So konnten beispielsweise seit dem generellen Verbot zur Nutzung von Bleischrot, das 1996 in Dänemark eingeführt wurde, wichtige Erfahrung gesammelt werden, die sowohl in Bezug auf die praktische Umsetzung und Verwaltung (insbesondere hinsichtlich der Einhaltung der Vorschriften) als auch auf die Bedeutung für die Erhaltung der Jagd als Freizeitaktivität auf großes Interesse gestoßen sind. Umfangreiche Forschungsprogramme, insbesondere in Deutschland, Dänemark und Norwegen, zeigen, dass bleifreie Gewehrpatronen sowohl sicher als auch effektiv sind. In der Regel sind die meisten Typen von bleifreier Munition für Jäger zu vergleichbaren Preisen wie traditionellen Munitionsarten erhältlich. Eine erhöhte Nachfrage fördert das Produktangebot, das vor allem in Ländern mit regulierter Bleimunition groß ist. Obwohl das Angebot an bleifreien Munitionen für bestimmte Kleinkaliber noch begrenzt ist, besteht hier ebenfalls die Erwartung, dass wachsende Nachfragen die Entwicklung von Alternativen steigern werden, die den jeweiligen Anforderungen gerecht werden. Daraus schließt sich, dass Blei als Material in Jagdmunition durchaus entbehrlich ist.

Ein zentrales Thema ist die Bleimunition im Zusammenhang mit den allgemeinen Nachhaltigkeitsanforderungen an die Jagd als Nutzung der Natur. Obwohl einige natürliche Systeme eine gewisse Resistenz gegen Blei aufweisen, zeigt das Gesamtbild, dass selbst geringe Expositionen negative und langfristige Auswirkungen haben können. Wenngleich sich viele Ökosysteme von bestimmten Belastungen erholen können (Resilienz), stellt die Verbreitung von Blei in stark bejagten Gebieten, wie beispielsweise in dänischen Vogelschutzgebieten, in denen eine Akkumulation von Bleischrot von bis zu 250 kg/ha nachgewiesen wurde, jedoch eine irreversible Belastung dar. Diese wird die Ökosysteme noch über viele Jahre hinweg beeinflussen, unabhängig davon, dass die Nutzung von Bleischrot in Feuchtgebieten bereits 1986 in Dänemark verboten wurde. Eine umfassendere Bewertung legt nahe, dass die unnötige Verwendung von giftiger Bleimunition in der Jagd in erheblichem Maße den politischen Anforderungen an eine nachhaltige Jagd widerspricht. Daraus ergibt sich die Schlussfolgerung, dass die Jagd mit Bleimunition nicht mit den Prinzipien der Nachhaltigkeit vereinbar ist.

Trotz der umfangreichen Dokumentation der Giftigkeit von Bleimunition und ihrer Unvereinbarkeit mit einer nachhaltigen Naturschutzpraxis bleibt sie weiterhin das am weitesten verbreitetes Material für Munition. Dies ist hauptsächlich auf einen Mangel an Regulierung und Kommunikation seitens der Behörden zurückzuführen. Als Folge davon wurden Jäger und andere Bürger im Allgemeinen unzureichend in den Prozess der schrittweisen Umstellung eingebunden. Die Hauptzielgruppen für Kampagnen und Beteiligung waren hauptsächlich Nichtregierungsorganisationen (NGOs), darunter insbesondere Jagdverbände und Vertreter der Munitionsindustrie, bei denen das Thema in vielen Fällen Gegenstand interner politischer und wirtschaftlicher Agenden war. Initiativen zur schrittweisen

Abschaffung von Bleimunition wurden in einigen Fällen als Angriff auf die Jagd und die Rechte der Jäger eingestuft, was zu einer verringerten Achtung gegenüber den Vorschriften und ihrer Einhaltung seitens der Jägerschaft führte.

Erst in den letzten Jahren ist Bleimunition als Expositionsquelle für Menschen, die Wildfleisch essen, verstärkt ins Blickfeld gerückt. Besondere Aufmerksamkeit richtet sich dabei auf die Risiken für gefährdete Gruppen, wie beispielsweide Kinder und Frauen im gebärfähigen Alter. Dieser Aspekt hat die Dringlichkeit einer schrittweisen Umstellung verstärkt, da ein wesentliches Element der Bewertung der Nachhaltigkeit der Jagd darin besteht, dass Wildfleisch als sichere Nahrungsquelle verwendet werden kann. Gleichzeitig gibt es in der europäischen Bevölkerung einen allgemeinen Trend konventionell erzeugte Lebensmittel durch mehr natürlich erzeugte Lebensmittel, wie zum Beispiel Wildfleisch, zu ersetzen. In diesem Zusammenhang ist es essenziell, dass Jäger als primäre Produzenten von Wildfleisch die Lebensmittelsicherheit garantieren können.

Die schrittweise Abschaffung von Bleimunition in der Jagd erfordert zentrale Regulierungsmaßnahmen auf nationaler oder internationaler Ebene, um wirksam zu sein. In einigen Ländern wurde versucht, freiwillige Vereinbarungen einzuführen, um Jäger zur Umstellung auf bleifreie Munition zu ermutigen. Erfahrungen haben jedoch gezeigt, dass freiwillige Systeme ineffektiv sind und selbst gesetzliche Maßnahmen wenig Wirkung haben, wenn sie nicht zentral kontrolliert werden können. In Dänemark beispielsweise betrifft die Regulierung nicht nur die Verwendung, sondern auch den Besitz und Handel von Bleimunition. Neben direkten Maßnahmen gibt es auch indirekte Ansätze, wie die Festlegung von Höchstgrenzen für den Bleigehalt in Wildfleisch, die den geltenden Grenzwerten von anderen Fleischprodukten entsprechen.

Unabhängig von Art und Umfang ist es entscheidend, dass Maßnahmen durch eine umfassende Kommunikation und Einbindung der Nutzer, einschließlich der Gesamtbevölkerung und der Jäger als zentrale Gruppe, begleitet werden. Wissenschaft und gesunder Menschenverstand legen nahe, dass ein Umstieg von bleihaltiger zu bleifreier Jagdmunition sicherstellt, dass im Laufe der Zeit das Risiko der Exposition von Ökosystemen, Wildtieren und Menschen verringern wird. Es ist eine allgemeine Schlussfolgerung, dass dies allen zugutekommen wird, nicht zuletzt den Jägern, indem eine langfristig positive Wahrnehmung der Jagd durch die Bevölkerung gewährleistet wird.

Die Verwendung von bleihaltiger Jagdmunition ist ein vergleichsweise einfaches Umweltproblem, und im Vergleich zur Bewältigung anderer Umweltprobleme stellt ihre schrittweise Abschaffung kein besonders komplexes Thema dar. Perspektiven für die Zukunft betonen die Notwendigkeit von verstärkten interdisziplinären Studien, um gesundheitliche Aspekte für die Umwelt, Ökosysteme, Wildtiere und Menschen kollaborativ zu betrachten. Die WHO-Initiative One Health bietet eine geeignete Plattform für eine solche Entwicklung. Intensive Forschungsarbeiten über klassische Naturwissenschaften, Sozialwissenschaften und Technologie hinweg, erscheinen ebenfalls als wesentliche Voraussetzung für einen effektiven, langfristigen und stabilen Übergang. Dies umfasst auch die kontinuierliche Entwicklung sicherer und effektiver alternativer Munitionstypen. Ebenso ist eine verbesserte Informations- und Kommunikationsarbeit erforderlich, um Wissen in Handlungskompetenz umzuwandeln, besserte Koordinationen zwischen Sektoren sicherzustellen und die Bedeutung jedes einzelnen Bürgers zu betonen.

Die erfolgreiche Abschaffung von bleihaltiger Munition wird nicht nur ein Umweltproblem und die damit verbundenen Kosten für die Gesellschaft beseitigen, sondern auch zeigen, dass die Jagd im Kontext des Wildtiermanagement die Fähigkeit besitzt, sich an die Herausforderungen einer schnelllebigen und modernen Gesellschaft anzupassen. Dies wird bedeutende Vorteile mit sich bringen und gleichzeitig die Grundlage für einen verbesserten und konstruktiven Dialog zwischen Stakeholdern schaffen, die sich für die Förderung der Artenvielfalt sowie die Erreichung von Zielen im Bereich des Naturschutzes und der Nachhaltigkeit einsetzen.

THE TRANSITION TO NON-LEAD AMMUNITION

– an essential and feasible prerequisite for sustainable hunting in modern society

This book is the result of over 35 years of professional advisory, research, and practical experience in wildlife management. It is based on a doctoral dissertation of the same title submitted to Aarhus University in 2021 and defended the year after.

Hunting disperses ammunition fragments into the environment, which constitutes a part of hunting's footprint on nature and ecosystems and, as such, contributes to hunting pressure on the environment. Society must incorporate the consequences of this into the overall evaluation of hunting sustainability.

The work highlights the 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 offers 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. This 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 arising from a rapidly changing modern society.

The transition from lead to non-lead ammunition will benefit everyone by eliminating the ongoing contribution to ecosystems and the resulting exposure to wildlife and humans. Hunting will be disconnected from a toxic substance and from the present costs externalized to society.

The book reflects a deep personal passion and respect for wild animals, both as individuals and collectively in robust and healthy populations. The experiences gathered here serve as an important reminder that hunting practices need regular review to ensure alignment with current thinking. This, along with broader sustainability efforts, will help secure hunting's future acceptance in society.