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Research Article

Increasing the Awareness of Health Risks from Lead-Contaminated Game Meat Among International and National Human Health Organizations

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ABSTRACT

Lead bullets and gunshot frequently fragment on impact in game animals and the resulting lead particles are bioavailable. Dietary exposure to this lead source can present health risks to vulnerable groups including young children and frequent consumers such as hunters, subsistence indigenous communities, and recipients of game meat from food banks. Many of the frequent game meat consumers in the European Union (EU) are likely to be drawn from the 13.8 million people, including 1.1 million young children, belonging to hunters' households. It is estimated that 10 million people are potentially at risk in the USA. National food and health advisories and regulatory considerations appear confined to Europe. Despite the European Commission requesting restrictions on lead ammunition, the World Health Organization (WHO), the Food and Agricultural Organization of the UN (FAO), the UN Children's Fund (UNICEF), and individual countries have not adequately recognized this lead source nor developed mitigation measures. In contrast, several agreements administered by the UN Environment Programme (UNEP), have well-developed risk reduction strategies for lead ammunition exposure of wildlife. These agencies could play a leadership role, stimulating appropriate international accords and national regulatory changes requiring the use of non-lead ammunition. Establishing a maximum allowable level of lead in game meat under FAO/WHO Codex Alimentarius and EU Regulation 1881/2006, and harmonizing inter-agency human and environmental health approaches would be an important start.

Keywords: United Nations, FAO, UNEP, UNICEF, WHO, CDC, disconnect, toxicity, IQ reduction, solutions

INTRODUCTION

Lead is a non-essential toxic element that can be absorbed mainly through the lungs or intestine and its deleterious health impacts have been recognized for millennia (Hernberg, 2000). No level of exposure to lead is known to be without harmful effects and no known safe blood lead concentration exists (CDC, 2021a; WHO, 2021). Many nations have implemented restrictions on various uses of lead including gasolines, paints, solders, and glass (Pohl et al., 2017). Consequently, most exposure in nations with advanced economies is now dietary and legal thresholds are set for lead in some foods and drinking water such as EC Regulation 1881/2006 (E. C., 2006) and Directive (EU) 2020/2184. Several United Nations agencies such as the World Health Organization, the United Nations Environment Programme, the United Nations Children's Fund, and The Food and Agriculture Organization of the United Nations, multi-national agencies such as the European Food Safety Authority, and national agencies such as the US Centres for Disease Control and Prevention, have produced detailed recommendations and/or programs for lead reduction from the above-mentioned sources to protect human health (CDC, 2012; EFSA, 2012; UNEP, 2010; UNICEF and Pure Earth, 2021; WHO, 2011) .

Historically, lead has been the preferred metal used in ammunition manufacture. The acute and chronic toxic effects of ingested lead shot and bullet fragments on wild birds are extremely well-researched and publicized and span more than a century (Pain et al., 2019a). When the use of lead hunting ammunition has been regulated, the principal rationale has been to reduce deleterious impacts on wetland bird species and

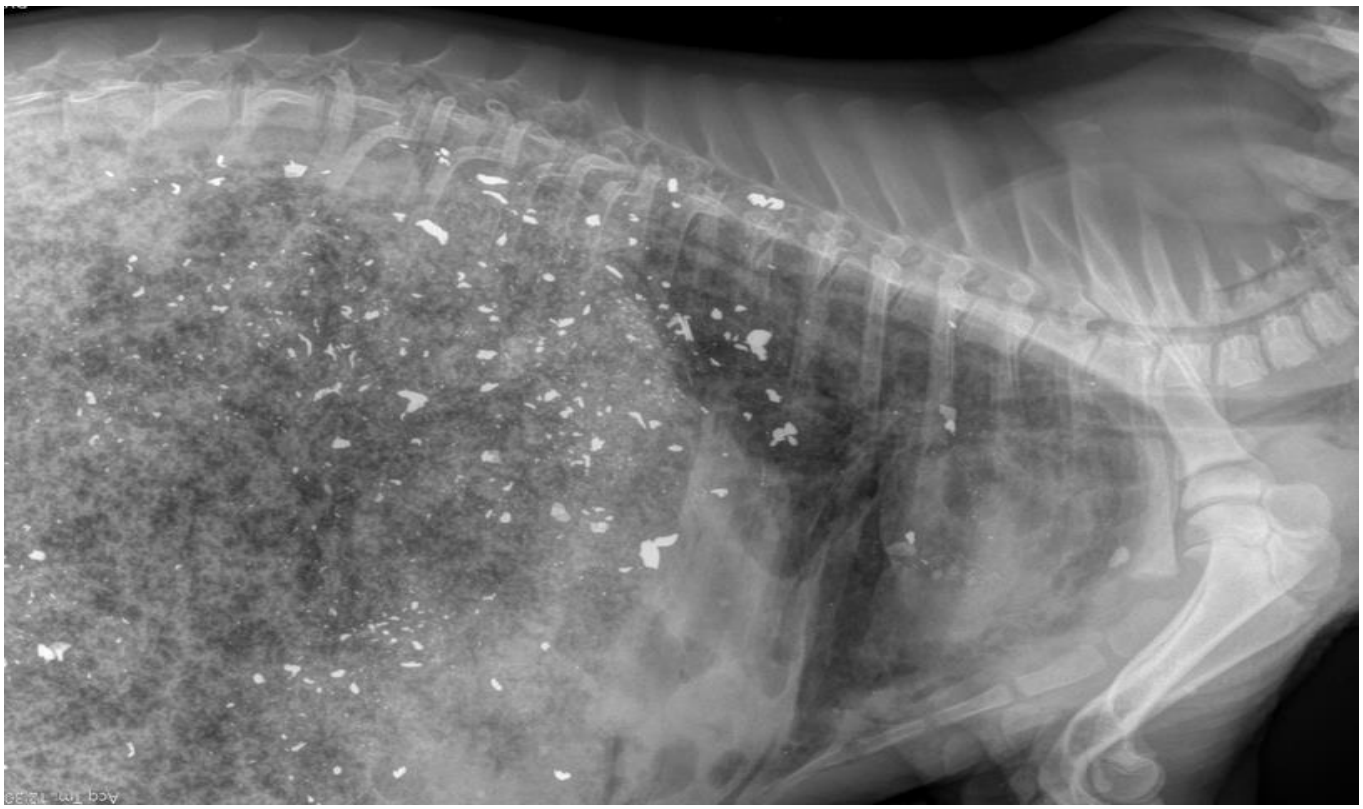

Figure 1. X-ray image of the thorax of a feral pig shot with a 130 grain .308 caliber lead-based hollow point bullet in New South Wales, Australia. Lead bullet fragments appear white (Photo credit Hampton et al., 2018)

endangered or threatened avian raptors (e.g. AEWA, 2018; AB-711, 2013). Thus, the European Union passed into law (EU) Regulation 2021/57 in 2021, that bans the use and possession of lead shotgun ammunition while hunting in and around wetlands throughout the EU, primarily to enhance the health of wetland species and their environment (European Union, 2021).

Levels of exposure to ingested lead from ammunition are generally far lower in humans than in such birds. Nonetheless, the ingestion of fragments of lead from spent ammunition in wild game meat poses a health risk to vulnerable groups of people, including children and pregnant women and to frequent consumers (Green and Pain, 2019; Nkosi et al., 2021; Pain et al., 2010). However, this source of lead exposure has received little attention from international and national health agencies relative to others and has not driven, nor substantially contributed to, regulatory restriction in any country. Although lead from hunting ammunition has been mentioned in relation to environmental pollution in different UN agency reports (e.g. UNEP, 2010), none has engaged in a detailed analysis of lead in game meats and issued action plans for the elimination of this contributor to human lead exposure.

In this paper, we discuss the human health effects associated with ingestion of lead from ammunition and highlight the communities most at risk. We document the lack of consideration given to this exposure route among the leading UN/intergovernmental and national human health agencies, in contrast to comparable wildlife/environmental agencies. We indicate how this could be addressed through including associated risk reduction measures in their lead reduction programs and facilitating broader societal change. Emphasis on the European Union and the UK relates to these countries' supporting a wild game meat retail market valued at over 1.1 thousand million Euros annually (Thomas et al., 2020). Also, both the EU and UK governments and private sectors have initiated, or are considering, progressive regulatory and policy developments on the use of lead ammunition and lead in game foods. The situation in the USA is dealt with because of the US Centres for Disease Control and Prevention emphasis on lead reduction in the human environment, because of the national importance of hunting, and the large donations of wild game meat to food banks. Paradoxically, lead in game meat is not regulated in the USA. The implications of the findings expressed in this paper concerning the creation of awareness and the formation of policy and regulation apply to all nations in which wild game meat is consumed by humans.

EXPOSURE TO AND ABSORPTION OF LEAD FROM WILD GAME MEAT

Fragments of lead from hunting rifle bullets may disperse widely into adjacent tissues (Trinogga et al., 2019) (**Figure 1**). Lead concentrations from these fragments can be elevated up to 30 cm from the bullet tract (Dobrowolska and Melosik, 2008). Large numbers of nanoparticles, of median diameter c. 60 nm, have also been found within 10 cm of the bullet tract (Kollander et al., 2017). Lead shot from shotgun hunting may remain in the carcass and can also fragment, as when hitting bone. This makes it difficult and impractical to remove contaminated meat in small game animals, like gamebirds

(Green and Pain, 2019). For large game animals, even after the removal of visible lead fragments, in the absence of effective screening and removal of large amounts of meat around wounds, consumers face elevated lead exposure from such food (Gerofke et al., 2018; Lenti et al., 2021).

Once absorbed into the blood stream, lead is transported around the body and has a negative effect on most body systems, acting in a broadly similar way in humans and other vertebrates. Lead in blood is the most widely used and best indicator of recent exposure. Lead from ammunition in game meat has been shown to be bioavailable. This was illustrated by Hunt et al. (2009) who fed minced venison containing radiodense metal fragments from lead-based bullets to pigs (four experimental and four controls). Blood lead levels rose rapidly in these animals and were significantly higher than those of controls. Blood lead levels have been positively correlated with the extent of game consumption in hunting communities (e.g. Bjermo et al., 2013; Green and Pain, 2012). A simple multi-national comparison of blood lead levels in humans who have and have not consumed meat killed with lead-based ammunition is presented in Table 1 of Hampton et al. (2018), which indicates significantly higher levels in most of those who consume game meat compared to controls. There is a large and growing scientific literature evaluating risks to human health from ingesting lead from ammunition in wild game meat (Knutsen et al., 2015; Nkosi et al., 2021; Sevillano-Caño et al., 2021).

HUMAN HEALTH RISKS FROM LEAD IN GAME MEAT

Risk from ingested lead in game meat is mainly a function of how much lead is consumed per meal (determined by meal size and lead concentration), how frequently game meats are eaten, age and sex of consumers, and their susceptibility to the effects of ingested lead, all of which can vary considerably (European Chemicals Agency, 2019). The lead content of consumable meat is determined by a combination of the extent to which bullet and shot fragments are dispersed around the wound channel and within the animal carcass (**Figure 1**), the amount of tissue removed around the entry wound and wound channel(s), and the extent of lead fragment removal prior to cooking. However, even after the removal of large particles of lead, minute lead fragments can remain undetected. The acidity of the cooking medium can also increase the bioavailability of lead (Schulz et al., 2021). These factors result in mean residual lead concentrations in wild-shot game meat that are frequently considerably higher than the legal threshold for marketed meat from domestic animals (EU Maximum Level 0.10 mgPb/kg ww, excluding offal (EC, 2006)) (Green and Pain, 2019).

The Panel on Contaminants in the Food Chain (CONTAM Panel) of the European Food Safety Authority (EFSA) conducted a detailed risk assessment of dietary lead and identified critical effects as being developmental neurotoxicity in young children and cardiovascular effects and nephrotoxicity in adults (EFSA, 2010). Children are particularly vulnerable because they absorb more of the ingested lead than adults (ATSDR, 2020) and lead appears to affect the developing brain more than the mature brain. Dietary lead in pregnant and lactating women readily traverses the placenta and enters breast milk (Gulson et al., 2003); thus, may affect their offspring. Increased blood lead in children under eight years old is associated with decreased IQ (Lanphear et al., 2005). Lead in blood is the most widely used and best indicator of recent exposure. There is no known safe blood lead level and a given increment in blood lead concentration appears to be associated with a greater negative impact on the IQ of children at low than at high blood lead concentrations (EFSA, 2010). The CONTAM Panel used the Benchmark Dose (BMD) approach to derive reference points to enable risk characterization (EFSA, 2010). The BMD is the blood lead concentration which is associated with a pre-specified change in the outcome, a benchmark response. For lead, critical responses include loss in IQ, increase in blood pressure, or increase in the incidence of chronic kidney disease. The lower one-sided 95 % confidence limit of the BMD, denoted BMDL, is then taken as the reference point. The nervous system of children is particularly sensitive and the $BMDL_{01}$ was calculated to be 1.2 µg/dL for a 1% (1 point) reduction in IQ in children, which is considered to be significant at a population level (EFSA, 2010).

The CONTAM Panel found that at current levels of dietary exposure to lead in the general population (i.e. without frequent game consumption) risks to the cardiovascular system or kidneys of adult consumers were low to negligible; nonetheless frequent game consumers were potentially at risk of effects (i.e. the possibility of such risks could not be excluded in this group). Importantly, there was potential concern of neurodevelopment effects for infants, children and pregnant women at current levels of dietary exposure in the general population, i.e. not including frequent game consumption. The consumption of game contaminated with lead was not specifically examined in infants and children but would further increase risks to these vulnerable groups.

The US Agency for Toxic Substances and Disease Registry (ATSDR, 2008) indicated that a blood lead level of 1.2 µg/dL (The $BMDL_{01}$, EFSA, 2010) could be reached quickly by children eating lead-contaminated game meat. Similarly, Green and Pain (2012) used UK food consumption and lead concentration data to evaluate the number of gamebird meals (from game largely shot with lead ammunition) consumed weekly that would be expected, based upon published studies, to result in changes, over and above those resulting from exposure to lead in the base diet, in IQ in children. They found that consumption of less than one meal of gamebird a week may be associated with a one-point reduction in IQ. Children who eat wild game meat more frequently would be at risk of yet greater IQ reductions.

COMMUNITIES AT RISK FROM LEAD CONTAMINATED GAME MEAT

Globally, where lead ammunition is used, a wide range of consumer groups are likely to be exposed to elevated lead levels from eating wild-shot game meat. The main groups are described below.

Recreational and Professional Hunters

Approximately 6.3 million large game animals (mainly deer species and wild boar (*Sus scrofa*) are killed annually in Europe (Thomas et al., 2020). This figure attests to the size of the potential risks to hunting communities. Madden (2021) suggested 43.2 million gamebirds are released annually in the UK for shooting, many of which are consumed directly by the hunting community or marketed and consumed both in the UK and abroad.

Hunted game meat is sold widely in European markets and restaurants, generating a large international trade. Thus, game meat can be purchased and consumed beyond the hunting community. Green and Pain (2015) estimated that in the UK the total annual unprocessed intact weight of upland gamebirds, waterfowl and pigeons intended for human consumption was 24,700 tons. Taking into account the weight of unprocessed gamebird meat relative to the weight of a resulting portion size, this gave an estimate of 4,940 to 9,880 tons of gamebird meat having been eaten by UK consumers annually. Such consumers include not only the hunters, and their families, but also employees or volunteers associated with hunting.

Subsistence Hunters

Subsistence communities reliant on wild-shot game are likely to be frequent consumers. They include, but are not limited to, indigenous people in Australia (Hampton et al., 2018), Canada (Fachehoun et al., 2015; Kwan, 2018), Greenland (Bjerregaard et al., 2004; Johansen et al., 2004), African nations (e.g. Benin (Ahmadi et al., 2018); South Africa (Nkosi et al., 2021)), and South America (e.g. Argentina (Tammone et al., 2021; Uhart et al., 2019) and Peru (Cartró-Sabaté et al., 2019)). Titus et al. (2009) reported on the importance of large and small game animals in Alaskan residents' diet and the large number of animals they take annually. Juric et al. (2018) reported that traditional foods comprised 73% of the diet of First Nations people living on-reserve in Ontario, and that their lead exposure was 1.7 times higher than in the wider Canadian population. In African countries that allow large mammal trophy hunting, the carcass is normally given to local inhabitants (White and Belant, 2015) who may face lead exposure from ingested bullet fragments, especially if wastage of meat is minimized.

Recipients of Food from Food Distribution Charities

People receiving food from food distribution charities ('food banks') providing meat and meals made of wild game shot with lead ammunition are potentially lead-exposed.

We found no explicitly-stated European Food Banks Federation policy on accepting hunter-killed game meat into the international food banks program. Also, the EU guidelines on food donation do not refer to lead in donated game meat (European Union, 2017). In Italy, meat from culled wild boar is donated to food banks in the Piedmont and Tuscany regions. After removal of visible lead fragments, the meat is processed according to prevailing domestic food standards[1]. However, packages are not screened by X-ray for lead. Denmark does not place restrictions on game meat donations. Game meat (including venison and pheasant (*Phasianus colchicus*)) is used in the UK to help those in food poverty by the Country Food Trust, which has provided both meals made with game shot with lead ammunition and meals made with venison that has not been shot with lead. However, it advises recipients of meals containing game that may contain lead not to feed these to vulnerable groups (CFT, 2021).

American food banks receive game meat, especially from white-tailed deer (*Odocoileus virginianus*), and feral pigs (*Sus scrofa*). Venison from multiple carcasses is usually minced to facilitate packaging and distribution, a process that distributes any lead particles throughout the packaged meat. Avery and Watson (2009) calculated that during the 2007-2008 hunting season over one million kg of venison was donated to 74% of the 75 food bank programs providing data.

Cornatzer et al. (2009) detected via X-ray metal fragments in 59% of 100 randomly selected packages of venison donated to a North Dakota food bank, and metal-containing venison was found to have elevated lead concentrations. Wilson et al. (2020) reported that 48% of 27 packages of ground venison from 10 shotgun-harvested white-tailed deer in Illinois contained lead fragments. Only Minnesota food banks accept meat that has been screened by X-ray to confirm the absence of lead from ammunition (MDA, 2021). However, screening programs are unlikely to detect minute lead particles that may be present in game meat (Kollander et al., 2017) and their efficacy in doing this has not been tested empirically.

Consumers Who Choose Game Over Other Meats

Some people not associated with hunting also eat wild game meat. This may be because they prefer this over farmed meat for reasons of personal ethics, because they believe it to be a healthier alternative to many other meats, because they prefer the taste, or because they frequent restaurants or stores specializing in game products. Types of foods demanded by Europeans are changing. The European retail market has recorded a significant increase in people opting for meat-free days (FIBL, 2021). Despite declining demand for farmed meat, there is a growing consumption of wild game meat in European countries as in the UK (Magee, 2020), largely for ethical reasons and its nutritional value (Strazdina et al., 2013). Niewiadomska et al. (2020) concluded that the most important motive to change to game meat related to health care issues, and that consumers for whom the crucial attributes of quality were taste, nutritional value, and low-fat content, might more often include game in their future diet.

It is difficult to establish, precisely, the numbers of people at risk from exposure to lead from game in their diet, although broad estimates are possible. By extrapolating from surveys of game consumption in the UK and reviewing studies of game consumption in other countries, Green and Pain (2019) estimated that at least five million people in the EU may be high-level consumers of lead-shot game (i.e. at least once a week), and that tens of thousands of children in the EU (estimated at 83,000 or more) may be consuming such meat sufficiently frequently to result in deleterious effects on their cognitive development. Many of the frequent game meat

[1] Ms A. Aggioni, European Food Banks Federation, Brussels, Belgium. Personal communication. November 4, 2021.

consumers in the European Union (EU) are likely to be drawn from the 13.8 million people, including 1.1 million young children, estimated to belong to hunters' households (ECHA, 2021). Hunt et al. (2009) estimated that the groups at risk in the USA may include ten million hunters, their families, and consumers of food bank game meat. These examples illustrate only a limited subset of the communities at risk of exposure to elevated lead concentrations in game meat, and their geographical distribution. While future trends are hard to predict, the social and economic consequences of the Covid-19 pandemic have seen increases in the number of people reliant on food banks in both Europe and the USA (e.g. IFAN, 2020; USDA, 2021) and recent world events may see demand increase yet further.

EVIDENCE OF LACK OF AWARENESS OF THIS ISSUE AMONG HUMAN HEALTH AGENCIES

Lack of awareness of the importance of lead exposure from game meat, and/or belief in its public unimportance (Thomas et al., 2019) are two probable reasons why leading human health agencies are not dealing with this issue. As evidence of this, Brysse (2019) and Dignam et al. (2019) did not list lead in game meat among the many other sources of lead requiring elimination to protect human health. The American College of Obstetricians and Gynecologists does not list lead from game meat among its 12 most important risk factors for lead exposure in pregnant women (ACOG, 2019), despite their susceptibility to the effects of lead (Wang et al., 2019). Nonetheless, some agencies recognize the risks and recommend that pregnant women avoid eating wild game meat (e.g. NHS, 2020).

The US Centres for Disease Control and Prevention (CDC) and US Department of Health and Human Services do not list potential exposure to lead from ingested game meat in their extensive guidelines for the management of lead exposure in pregnant and lactating women, giving only scant mention to hunted animals (CDC, 2012), and despite the CDC having published research (Iqbal et al., 2009) showing that lead-contaminated game meat was a source of lead exposure to humans.

The United Nations agencies FAO, UNICEF, and WHO have a predominant human focus in their mandates. However, concerns about lead exposure from hunting do not appear among their initiatives on environmental lead reduction related to human health. UNICEF and Pure Earth (2021) reported that hundreds of millions of children, globally, have elevated blood lead levels (>5ug/dL), with the vast majority living in poor countries and being exposed to lead through multiple routes. However, they did not identify dietary lead from ammunition as a risk to children's health, presumably because their attention was focused on other sources of exposure (UNICEF and Pure Earth, 2021).

UNEP administers the Convention on Migratory Species (CMS) and its Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA). There is a legally binding obligation on Parties to AEWA to phase out lead gunshot in wetlands (No.117) and more broadly, Parties to CMS have adopted Resolutions to phase out the use of lead ammunition (gunshot and bullets) across all habitats (No. 118). These obligations exist because it has been long-established that ingestion of lead from ammunition presents substantial health risks to wild birds and contaminates the environment (Kanstrup et al., 2019). Thus, a strong disconnect exists between UN human health and environment agencies, despite there being a single lead exposure issue, whether in wildlife or humans.

The International Council for Game and Wildlife Conservation (CIC) represents sport hunting globally, and, in 2009, commissioned a scientific report on the use of lead ammunition in hunting (Kanstrup, 2009) which recommended a transition to non-lead ammunition as soon as possible. However, this recommendation has not been endorsed nor acted upon. The CIC partners with several UN bodies (FAO, UNEP, UNESCO (United Nations Educational, Scientific and Cultural Organization), CMS, AEWA, and CBD (Convention on Biological Diversity)) (CIC, 2021). These organizations' positions on lead elimination and/or environmental sustainability, while entirely consistent with the view that hunting with lead ammunition is not sustainable (Kanstrup et al., 2018), are inconsistent with the present position of CIC.

Lack of Inclusion of Lead from Ammunition in Global and Regional Food Safety Standards

The Codex Alimentarius is a collection of standards, guidelines and codes of practice adopted by the Codex Alimentarius Commission (CAC), which is the central part of the Joint FAO/WHO Food Standards Programme, established to protect consumer health and promote fair practices in food trade. The Codex Alimentarius General Standard for Contaminants and Toxins (2019) lists the Maximum Levels (MLs) of contaminants in food which are recommended to be applied to commodities moving in international trade. The exposure pathway to lead from ingestion of wild-shot game meat has been absent from the Codex Alimentarius Code of Practice (CoP) on reducing exposure to lead in food (Codex Alimentarius, 2004). However, it is anticipated that the next revision may contain consumer practice advice highlighting dietary risks from game killed with lead ammunition (Codex Alimentarius Commission, 2021). Nonetheless, no ML for lead in human foodstuffs derived from wild-shot game animals has been included in Codex, and none appears to be under consideration as of 2022.

Similarly, in the European Union EC Regulation 1881/2006, which sets EU MLs for a range of contaminants including lead in marketed domesticated animal meats, does not set an EU ML for lead in game meats (EC 2006). This may be because it was previously assumed that lead bullets or shot would remain relatively intact, and therefore present little risk to consumers who would remove lead particles from food at the table and/or that relatively few people eat wild game frequently. However, both assumptions have been shown to be incorrect (Green and Pain, 2019). Given the elevated lead concentrations frequently found in wild-shot game meat, several authors (Lenti et al., 2021; Taggart et al., 2011; Thomas et al., 2020) have proposed the addition of a wild game meat EUML comparable to that used for domestic meat (0.1 ppm wet weight) as an adjunct to

transitioning to the use of non-lead ammunition. This would help reduce consumer risks from frequent game consumption as identified by EFSA (2010) and others and would harmonize lead safety standards for meats traded across and imported into the EU. Such standards are all the more important as the consumption of wild game meat is increasing in popularity in Europe (Marescotti et al., 2019), partly because it is advertised to be a healthier, free-ranging alternative, to intensely-managed domestic animal species (Taggart et al., 2011). In some countries, including Denmark, game meat is promoted and recommended to school-age children[2].

EUROPEAN ACTION ON EXPOSURE TO LEAD FROM AMMUNITION

In Europe, subsequent to the EFSA CONTAM Panel report (EFSA, 2010), agencies associated with health and/or food safety in six European countries assessed risks from dietary exposure to lead from ammunition in wild game and recommended risk reduction measures (Spain, AESAN, 2012; UK, FSA, 2012; Norway, Knutsen et al., 2015; France, ANSES, 2018; Germany, Gerofke et al., 2018; Sweden, Livsmedelsverket, 2021). Advice is focused on reducing lead exposure, especially for vulnerable groups, and varies from recommending the use of lead-free ammunition or the avoidance by children and pregnant women of consuming game shot with lead ammunition, to butchering food carefully and reducing consumption levels. While these assessments could make a useful contribution to public education about health risks, most have not been widely publicized. We are unaware of risk assessments conducted by national agencies beyond Europe, although assessments have been undertaken by researchers and published in the scientific literature (e.g. Sevillano-Morales et al., 2021).

In 2021, the EU introduced a ban on the use of lead gunshot for wetland hunting across all EU countries, under the EU REACH Regulation, (Registration, Evaluation, Authorisation and Restriction of Chemicals) (ECHA, 2021). This was introduced primarily to protect wetland bird species from lead poisoning and to fulfil legal obligations under AEWA. Further recognizing uncontrolled risks to the EU environment and also human health, the European Commission requested that the European Chemicals Agency (ECHA) prepare a restriction proposal for the 'placing on the market and use of lead in ammunition (shotgun and rifle) and of lead in fishing tackle' (ECHA, 2019). The proposal was published in March, 2021 (ECHA, 2021), and if accepted, the restriction should be adopted later.

The UK left the EU in 2020, and in 2021 the British Government announced a potential ban on lead ammunition to protect wildlife, people, and the environment as part of new plans under its new chemical regulatory mechanism, UK REACH (DEFRA, 2021). Both EU and UK processes are ongoing at the time of writing. If approved, the EU and UK REACH restrictions would be among the first examples of regulations enacted to protect both human and wildlife health from the effects of absorbed lead from ammunition. Thus, only non-lead ammunition would be allowed for all hunting, effectively eliminating lead contamination of game meat procured and consumed within the EU and UK.

The Danish government, supported by the Danish Hunters' Association, announced a forthcoming ban on the use of lead-based hunting rifle bullets, intended to take effect in 2023 (Kanstrup et al., 2021). The ban extends an earlier, 1996, national ban on lead gunshot for hunting in Denmark. This reflects growing awareness of the broader risks that lead from ammunition presents to wildlife species and human health has increased considerably.

Beyond these examples little integration of wildlife and human health concerns appears to exist as a driver for regulatory change at national or international levels, despite this issue being widely recognized as a One Health issue (Arnemo et al., 2016). Nonetheless, a first step has been taken by the United Nations Environment Assembly (UNEA) with a resolution adopted which included (under points 11 and 28) (UNEP, 2018) encouraging governments and relevant stakeholders to develop, adopt, and implement effective measures to minimize risks posed by heavy metals (and other listed chemicals), in particular to pregnant women, infants and children, and to raise awareness of the negative impacts of lead in ammunition.

In addition to regulatory action, several voluntary actions have been taken by various stakeholders, particularly in the UK. These have resulted largely from increased awareness of the human health risks associated with dietary lead from ammunition. For example, in 2019 the UK supermarket Waitrose & Partners, apparently the largest national retailer of wild game, used the following label on wild game:

> "Based on public health advice vulnerable groups, in particular children, pregnant women & women trying for a baby, should not consume this product due to the possible presence of lead shot residue".

This was part of a planned transition towards selling only game killed with non-lead ammunition by the 2021-22 shooting season (Waitrose and Partners, 2021). Such interventions have the potential to influence both consumers and the those providing game to the market. In 2020, following Waitrose's decision and coinciding with the broader regulatory process underway in the EU, nine major UK organizations associated with shooting called publicly for a voluntary end to lead use in shotgun ammunition for game shooting by February 2025 '*in consideration of wildlife, the environment and to ensure a market for the healthiest game products*' (BASC, 2020). However, monitoring found that almost all wild-shot pheasants offered for sale for human consumption in Britain and sampled during the two shooting seasons after this announcement had still been killed with lead shotgun ammunition (Green et al., 2022). Thus, the voluntary nature of this initiative is not *per se* effective in terms of phasing out lead ammunition. Nonetheless, these voluntary moves and statements, along with similarly progressive positions adopted

[2] https://www.jaegerforbundet.dk/media/3015/vildt_kogebog_til_tryk_270115.pdf

recently by other game retailers and providers (LAG, 2022), were undoubtedly important in creating a political environment which facilitated the UK government's 2021 decision to consider restriction of all lead ammunition under UK REACH (DEFRA, 2021).

OPTIONS FOR REDUCING HEALTH RISKS FROM DIETARY LEAD OF AMMUNITION ORIGIN

A key step to further protecting human health and harmonizing international food safety standards would be the adoption of an ML for lead in wild game meat in the next revision of the Codex General Standard for Contaminants and Toxins in Food and Feed. This should be similar to that used for the meat of cattle, pigs, sheep and poultry (currently 0.1 mg/kg ww, Codex Alimentarius, 2019). A similar ML should also be adopted under EC Regulation 1881/2006. This would complement and reinforce ongoing efforts within the EU to achieve a complete transition to non-lead hunting ammunition for all categories of hunting. For example, in Denmark, food standards monitoring of lead levels in game meat identified issues of non-compliance with lead restrictions, resulting in an information campaign and subsequent improved compliance (Kanstrup, 2012).

In 2021, the CDC announced that it was lowering the reference level for elevated blood lead in children from 5 µgPb/dL to 3.5 µgPb/dL (CDC, 2021b). If this revised level were to be recognized and adopted by other jurisdictions, it would enable action to be taken at an earlier stage to reduce children's future exposure to lead, especially from game meat. As a pertinent example warranting attention, Bressler et al. (2019) reported that half of Alaskan children with blood levels >5 µgPb/dL were from homes that consumed lead-shot game meat.

Much scope remains within UNEP's programs and initiatives for further cross-agency integration in developing solutions to the human and wildlife health risks presented by lead ammunition. For example, the CMS Intergovernmental Task Force on Phasing Out the Use of Lead Ammunition and Lead Fishing Weights, was mandated in 2020 by CMS Resolution 11.15 (RevCOP13) (CMS, 2020) with terms of reference developed more recently (CMS, 2021). While these guidelines aim to protect migratory birds, the risks to human health associated with ingestion of lead from ammunition are mentioned explicitly in the background text. The Intergovernmental Task Force presents an opportunity to stimulate cross-UN agency collaboration, and develop and deliver recommendations that are efficient, effective, and harmonized. We suggest that the FAO, WHO and UNICEF are invited to participate in the Task Force. This would represent progress, raising awareness, and facilitating a cross-agency understanding of the issue and solutions, which would then cascade broadly, especially to the United Nations Environment Assembly (UNEA).

In 2020, UNICEF and Pure Earth outlined a six-pronged coordinated approach, based partly on Meyer et al. (2008), needed to address lead pollution and exposure from all sources among children globally (UNICEF, 2021). While lead from ammunition was not mentioned specifically, in **Table 1** we list under the six components actions that could be taken to reduce and eliminate exposure to lead in wild game meat. The last two components apply especially to the present paper which has presented much evidence to warrant that lead in wild game meat be regulated globally and consistently with other human foods.

The FAO, UNESCO, and especially UNEP, could use their partnerships with the CIC to encourage and facilitate a change in CIC policy on lead hunting ammunition. A CIC endorsement of non-lead ammunition use at the global level would promote regulative attempts to effect the transition to non-lead ammunition by the EU and at national levels beyond the EU.

DISCUSSION AND CONCLUSION

Lead fragments from ammunition in game meat present a recognized health risk, especially to vulnerable groups or frequent consumers of wild game. This is now, arguably, the most poorly acknowledged and addressed example of food lead contamination.

In addition to the individual health effects of chronic lead exposure, there are likely social costs of reduced IQ (Bierkens et al., 2012). While hunters comprise a minority of the global population (except for in subsistence communities), the human health and environmental costs of continued lead ammunition use are borne by all in society (Kanstrup and Thomas, 2020; Pain et al., 2019b). There is global scientific consensus over the risks that exposure through ingestion of lead from ammunition presents both to wildlife and human health (Arnemo et al., 2016). However, with the exception of Europe, most global regions and nations, along with UNEP and its multilateral agreements, have considered only, or primarily, the wildlife health impacts of ingesting lead from ammunition. Human health impacts have been largely overlooked.

In contrast to other sources of lead that risk human and especially children's health, the replacement of lead in hunting ammunition with non-toxic materials is technically straightforward. A wide range of alternative non-lead rifle and shotgun ammunition has already been developed, approved, and used across much of Europe and North America. Relevant policy and regulatory change is now required to ensure its supply by providing certainty of demand for manufacturers (Kanstrup and Thomas, 2020). However, more needs to be done by international and national human and environmental health agencies to approach this issue in an integrated One Health manner (Nkosi et al., 2021) that achieves a complete transition to non-lead ammunition that benefits people, wildlife, and the environment.

UN agencies can be important influencers of national policy. We urge the FAO, UNEP, UNICEF, WHO and the CDC to take a leading role in acknowledging the breadth of these risks, and to incorporate measures to address them in their updated lead reduction programs and their advisories to governments and the public. The risks to human health from dietary lead of ammunition origin have been overlooked for too long.

Table 1. Suggested actions needed to eliminate human exposure to dietary lead from ammunition sources, based on the six-pronged coordinated approach of UNICEF and Pure Earth (2021)

Suggested actions on the six-pronged coordinated approach
1-Monitoring and Reporting Systems: This includes introducing blood lead level monitoring in household surveys and conducting source apportionment assessments at local levels to determine how children are being exposed.
We suggest the inclusion in such surveys of levels of consumption of wild game shot with lead ammunition. This could also be a more explicit part of household food surveys conducted in many countries, and of the questionnaires used in longitudinal studies of blood lead levels and their effects.
2-Prevention and Control Measures: Prevention of exposure is paramount and includes preventing women and children's exposure to products that contain lead.
We suggest that prevention of exposure to dietary lead from wild game meat would most effectively be achieved through the transition to non-toxic (non-lead) ammunition (which requires regulation–see point 5 below). Before such a transition is complete, measures could be taken to reduce women's and children's exposure to elevated levels of lead in wild game meat. Options for achieving this would be through public awareness influencing behavior change (see point 4 below) and the adoption of maximum lead levels in game meat (see point 6 below).
3-Management, Treatment and Remediation: This includes providing training for healthcare workers about how to identify, manage, and treat lead exposure in children and pregnant women.
We suggest that improved awareness is needed among healthcare workers of elevated lead levels in wild game meat shot with lead ammunition and those groups most at risk.
4-Public Awareness and Behavior Change: This includes creating continual public education campaigns about the dangers and sources of lead exposure.
We suggest the need for awareness campaigns to include, or deal specifically with, information highlighting potentially elevated levels of exposure when consuming wild game shot with lead ammunition. Such campaigns should target the ammunition and shooting sectors, public health agencies, schools, parents, community leaders and healthcare workers. They should also include public and other agencies that shoot wild game and make this available to human food chains, food distribution charities, game processers and traders (nationally and internationally) and game retailers. It is particularly important to reach audiences that may not be aware of these risks, especially the most vulnerable groups (children and pregnant women) and frequent consumers. This could involve the use of food labelling (see point 5 below), existing media and communications resources and mediums.
The US CDC could recognize the risks presented by lead in game meat and use relevant opportunities to influence national policy and disseminate information.
5-Legislation and Policy: Existing resolutions under MEAs, policies and regulations restricting the use of lead ammunition relate primarily to wildlife health.
We suggest that UN agencies collaborate to extended and harmonize these also to protect human health and the environment. Representation of UN health agencies in CMS Intergovernmental Task Force on Phasing Out the Use of Lead Ammunition and Lead Fishing Weights would be a key step.
UN agencies could encourage through their numerous partnerships and interactions, the need for international hunting organizations (e.g. CIC and FACE) to endorse the transition to non-lead ammunition.
Integration among wildlife and health agencies in individual nations is needed, as is adequate impact monitoring and enforcement. Ultimately the risks from lead ammunition to human health, wildlife health and the environment will only be resolved with an effective transition to the use on non-toxic/non-lead ammunition.
Until non-lead ammunition is used, actions such as mandatory food labelling highlighting potential health risks associated with consuming wild-shot game meat that may contain elevated levels would help inform consumers of game in the retail market, albeit this represents only a limited group of consumers.
6-Global and Regional Action
We suggest that a maximum level (ML) for lead in human foodstuffs derived from wild-shot game animals be included in the next iteration of the Codex Alimentarius General Standard for Contaminants and Toxins, and that this be set at a similar level to the ML set for the meat of cattle, pigs, sheep and poultry (0.1 mg/kg wet weight; Codex Alimentarius, 2019).
We suggest that regional action be taken setting MLs, such as inclusion in European Commission Regulation EC 1881/2006 on setting MLs for certain contaminants in foodstuffs.

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REFERENCES

AB-711. (2013). *Assembly Bill 711, Rendon. Hunting: Nonlead ammunition. Chapter 742. An 706 act to amend Section 3004.5 of the Fish and Game Code, relating to hunting*. Available at: http://leginfo.707legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB711

ACOG. (2019). Lead screening during pregnancy and lactation. Committee Opinion No. 533. *Committee on Obstetric Practice. American College of Obstetricians and Gynecologists,* 120, 416-420. https://doi.org/10.1097/AOG.0b013e31826804e8

AESAN. (2012). *Report of the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) in relation to the risk associated with the presence of lead in wild game meat in Spain. AESAN-2012-002. Report approved by the Scientific Committee on plenary session, February 22, 2012*. Available at: http://aesan.msssi.gob.es/AESAN/docs/docs/evaluacion_riesgos/comite_cientifico/PLOMO_CAZA.pdf

AEWA. (2018). 7th session of the Meeting of the Parties (MOP7). *National Reports*. Available at: https://www.unep-aewa.org/en/documents/national-reports

Ahmadi, S., Maman, S., Zoumenou, R., Massougbodji, A., et al. (2018). Hunting, sale, and consumption of bushmeat killed by lead-based ammunition in Benin. *International Journal of Environmental Research and Public Health,* 15(6), 1140. https://doi.10.3390/ijerph15061140

ANSES. (2018). *AVIS de l'Agence nationale de sécurite´ sanitaire de l'alimentation, de l'environnement et du travail relatif au ''risque sanitaire lie´ a` la consommation de gibier au regard des contaminants chimiques environnementaux (dioxines, polychlorobiphe´nyles (PCB), cadmium et plomb)''. Avis de l'ANSES Saisine n.2015-SA-0109* [*OPINION of the National Agency for Food, Environmental and Occupational Health Safety relating to the ''health risk associated with the consumption of game with regard to environmental chemical contaminants (dioxins, polychlorinated biphenyls (PCBs)), cadmium and lead)''. Opinion of ANSES Request n.2015-SA-0109*]. Maisons-Alfort Cedex: ANSES. Available at: https://www.anses.fr/fr/content/consommation-de-gibiersauvage-agir-pour-r%C3%A9duire-les-expositions-auxcontaminants-chimiques

Arnemo, J. M., Andersen, O., Stokke, S., Thomas, V. G., et al. (2016). Health and environmental risks from lead-based ammunition: Science versus socio-politics. *EcoHealth,* 13(4), 618-622. https://doi.10.1007/s10393-016-1177-x

ATSDR. (2008). The potential for ingestion exposure to lead fragments in venison in Wisconsin. *Agency for Toxic Substances and Disease Registry, Division of Health Assessment and Consultation, US Department of Health and Human Services*. Atlanta, Georgia.

ATSDR. (2020.) Toxicological profile for lead. *US Department of Health and Human Services. Agency for Toxic Substances and Disease Registry*, CS274127-A, pp. 583.

Avery, D. and Watson, R. T. (2009). Distribution of venison to humanitarian organizations in the USA and Canada, in R. T. Watson, M. Fuller, M. Pokras and W. G. Hunt (eds), *Ingestion of lead from spent ammunition: Implications for wildlife and humans* (pp. 157-160). Boise, Idaho; The Peregrine Fund. https://doi.10.4080/ilsa.2009.0114

BASC. (2020). *A joint statement on the future of shotgun ammunition for live quarry shooting*. Available at: https://basc.org.uk/a-joint-statement-on-the-future-of-shotgun-ammunition-for-live-quarry-shooting

Bierkens, J., Buekers, J., Van Holderbeke, M. and Torfs, R. (2012). Health impact assessment and monetary valuation of IQ loss in pre-school children due to lead exposure through locally produced food. *Science of the Total Environment,* 414, 90-97. https://doi.org/10.1016/j.scitotenv.2011.10.048

Bjermo, H., Sand, S, Nälsén, C., Lundh, T., et al. (2013). Lead, mercury, and cadmium in blood and their relation to diet among Swedish adults. *Food and Chemical Toxicology,* 57, 161-169. https://doi.org/10.1016/j.fct.2013.03.024

Bjerregaard, P., Johansen, P., Mulvad, G., Pedersen, H. S. and Hansen J. C. (2004). Lead sources in human diet in Greenland. *Environmental Health Perspectives,* 112(15), 1496-1498. https://doi.org/10.1289/ehp.7083

Bressler, J. M., Yoder, S., Cooper, S. and McLaughlin, J. (2019). Blood lead surveillance and exposure sources among Alaska children. *Journal of Public Health Management and Practice,* 25(Number 1 Supplement), S71-S75. https://doi.org/10.1097/PHH.0000000000000877

Brysse, P. N. (2019). Lead elimination for the 21st century. *Journal of Public Health Management and Practice,* 25(Supplement1), S3-S4. https://doi.10.1097/PHH.0000000000000867

Cartró-Sabaté, M., Mayor, P., Orta-Martínez, M. and Rosell-Melé, A. (2019). Anthropogenic lead in Amazonian wildlife. *Nature Sustainability,* 2, 702-709. https://doi.org/10.1038/s41893-019-0338-7

CDC. (2012). Low level lead exposure harms children: A renewed call for primary prevention. *Centers for Disease Control and Prevention, Advisory Committee on Childhood Lead Poisoning Prevention*. Atlanta, GA, USA.

CDC. (2021a). *Blood lead levels in children*. Available at: https://www.cdc.gov/nceh/lead/prevention/blood-lead-levels.htm

CDC. (2021b). *Blood lead reference value*. Available at: https://www.cdc.gov/nceh/lead/data/blood-lead-reference-value.htm (Accessed: 31 October 2021).

CFT. (2021). *Country food trust. Guidance on lead*. Available at: https://www.thecountryfoodtrust.org/wp-content/uploads/2021/01/Country-Food-Trust-LEAD-FORM.pdf (Accessed: 22 October 2021).

CIC. (2021). *International Council for Game and Wildlife Conservation (CIC). Partners*. Available at: http://www.cic-wildlife.org/partners

CMS. (2020). Preventing poisoning of migratory birds. *UNEP/CMS/Resolution 11.15 (Rev.COP13)*. Available at: https://www.cms.int/sites/default/files/document/cms_cop13_res.11.15_rev.cop13_e.pdf

CMS. (2021). Terms of reference for the intergovernmental task force on phasing out the use of lead ammunition and lead fishing weights. *UNEP/CMS/StC52/Doc.16*. Available at: https://www.cms.int/sites/default/files/document/cms_stc52_doc.16_draft-tors_intergovernmental-task-force-on-lead_e.pdf

Codex Alimentarius Commission. (2021). *Joint FAO/WHO Food Standards Programme CODEX Committee on Contaminants in Foods. 14th Session (virtual 3-7 and 13 May 2021. Revision of The Code of Practice for the Prevention and Reduction of Lead Contamination in Foods (CXC 56-2004)*.

Codex Alimentarius. (2004). Code of practice for the prevention and reduction of lead contamination in foods. *CAC/RCP 56-2004*. Available at: http://www.codexalimentarius.org/standards/list-of-standards/

Codex Alimentarius. (2019). General standard for contaminants and toxins in food and feed CXS 193-1995. Adopted 1995. Revised 2009. Amended in 2019. *Food and Agriculture Organisation*. Available at: https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B193-1995%252FCXS_193e.pdf

Cornatzer, W. E., Fogarty, E. F. and Cornatzer, E. W. (2009). Quantitative and qualitative detection of lead bullet fragments in random venison packages donated to the Community Action Food Centers of North Dakota, 2007, in R. T. Watson, M. Fuller, M. Pokras and W.G. Hunt (eds), *Ingestion of lead from spent ammunition: implications for wildlife and humans* (pp. 154-156). Boise, Idaho: The Peregrine Fund. https://doi.org/10.4080/ilsa.2009.0111

DEFRA. (2021). *Press release. Plans announced to phase out lead ammunition in bid to protect wildlife*. Available at: https://www.gov.uk/government/news/plans-announced-to-phase-out-lead-ammunition-in-bid-to-protect-wildlife (Accessed: 22 October 2021).

Dignam, T., Kaufmann, R. B., LeStourgeon, L. and Brown, M. J. (2019). Control of lead sources in the United States, 1970-2017: Public health progress and current challenges to eliminating lead exposure. *Journal of Public Health Management and Practice,* 25(Supplement1), S13-S22. https://doi.10.1097/PHH.0000000000000889

Dobrowolska, A. and Melosik, M. (2008). Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). *European Journal of Wildlife Research,* 54, 231-235. https://doi.10.1007/s10344-007-0134-y

E.C. (2006). European Commission Regulation EC 1881/2006. Setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Union EC 1881/2006*. L364/365-L364/324. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1442063437890&uri=CELEX:32006R1881

ECHA. (2019). *Request from the European Commission to the European Chemicals Agency to prepare a restriction proposal on the placing on the market and use of lead in ammunition (shotgun and bullets) and of lead in fishing tackle conforming to the requirements of Annex XV to REACH. 16 July 2019*. Available at: https://echa.europa.eu/documents/10162/13641/rest_lead_ammunition_COMrequesten.pdf./f607c957-807a-3b7c-07ae-01151001d939

ECHA. (2021). Annex XV Restriction Report-Lead in outdoor shooting and fishing. Version 2; 24 March 2021. 404 pp and Annex to the XV Report. 560 pp. 24. March 2021. *European Chemicals Agency, Helsinki, Finland*. Available at: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e1840159e6

EFSA. (2010). European Food Safety Authority. EFSA Panel on Contaminants in the Food Chain (CONTAM). Scientific opinion on lead in food. *EFSA Journal,* 8, 1570. https://doi.10.2903/j.efsa.2010.1570

EFSA. (2012). European Food Safety Authority. Lead dietary exposure in the European population. *EFSA Journal,* 10, 28831. https://doi.org/10.2903/j.efsa.2012.2831

European Union. (2017). *2017/C 361/01*. Available at: https://www.eurofoodbank.org/represent-our-membership-at-european-and-international-level/

European Union. (2021). Commission Regulation (EU) 2021/57. *Official Journal of the European Union*. Available at: https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32021R0057&from=EN

Fachehoun, R. C., Lévesque, B., Dumas, P., St-Louis, A., et al. (2015). Lead exposure through consumption of big game meat in Quebec, Canada: Risk assessment and perception. *Food Additives and Contaminants*: *Part A*, 32, 1501-1511. https://doi.org/10.1080/19440049.2015.1071921

FIBL. (2021). *European organic market grew to 40.7 billion euros in 2018*. Available at: https://www.fibl.org/en/info-centre/news/european-organic-market-grew-to-40-7-billion-euros-in-2018.html (Accessed: August 2021).

FSA. (2012). Risk to human health from exposure to lead from lead bullets and shot used to shoot wild game animals. Foods to avoid in pregnancy. *Food Standards Agency. National Health Service*.

Gerofke, A., Ulbig, E., Martin, A. C., Müller-Graf, C., et al. (2018). Lead content in wild game shot with lead or non-lead ammunition: Does state of the art consumer health protection require non-lead ammunition? *PLoS ONE,* 13, e0200792. https://doi.org/10.1371/journal.pone. 0200792

Green, R. E. and Pain, D. J. (2012). Potential health risks to adults and children in the UK from exposure to dietary lead in gamebirds shot with lead ammunition. *Food and Chemical Toxicology,* 50, 4180-4190. https://doi.org/10.1016/j.fct.2012.08.032

Green, R. E. and Pain, D. J. (2015). Risks of health effects to humans in the UK from ammunition-derived lead, in R. J. Delahay and C. J. Spray (eds), *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health* (pp. 27-43). The University of Oxford, UK; Edward Grey Institute.

Green, R. E. and Pain, D. J. (2019). Risks to human health from ammunition-derived lead in Europe. *Ambio Special Issue,* 48(9), 954-968. https://doi.org/10.1007/s13280-019-01194-x

Green, R. E., Taggart, M. A., Pain, D. J., Clark, N. A., et al. (2022). Effectiveness of actions intended to achieve a voluntary transition from the use of lead to non-lead shotgun ammunition for hunting in Britain. *Conservation Evidence Journal*, 19, 8-14. https://doi.org/10.52201/CEJ19/SAFD8835

Gulson, B. L., Mizon, K. J., Korsch, M. J., Palmer, J. M. and Donnelly, J. B. (2003). Mobilization of lead from human bone tissue during pregnancy and lactation—A summary of long-term research. *Science of the Total Environment,* 303, 79-104. https://doi.org/10.1016/S0048-9697(02)00355-8

Hampton, J. O., Laidlaw, M., Buenz, E. and Arnemo, J. M. (2018). Heads in the sand: Public health and ecological risks of lead-based bullets for wildlife shooting in Australia. *Wildlife Research,* 45, 287-306. https://doi.org/10.1071/WR17180

Hernberg, S. (2000). Lead poisoning in a historical perspective. *American Journal of Industrial Medicine*, 38, 244-254. https://doi.org/10.1002/1097-0274(200009)38:3<244::AID-AJIM3>3.0.CO;2-F

Hunt, W. G., Watson, R. T., Oaks, J. L., Parish, C. N., et al. (2009). Lead bullet fragments in venison from rifle-killed deer: Potential for human dietary exposure. *PLoS ONE,* 4(4), e5330. https://doi.10.1371/journal.pone.0005330

IFAN. (2020). *Independent Food Bank Emergency Food Parcel Distribution in the UK. Comparing February–April 2019 with February–April 2020*. Available at: https://uploads.strikinglycdn.com/files/4a18c39c-c550-4496-8779-98d4d05bd7f3/IFAN%20Report%2003.06.20%20V2.pdf

Iqbal, S., Blumenthal, W., Kennedy, C., Yip, Y., et al. (2009). Hunting with lead: Association between blood lead levels and wild game consumption. *Environmental Research,* 109(8), 952-959. https://doi.org/10.1016/j.envres.2009.08.007

Johansen, P., Asmund, G. and Riget, F. (2004). High human exposure to lead through consumption of birds hunted with lead shot. *Environmental Pollution,* 127(1), 125-129. https://doi.org/10.1016/S0269-7491(03)00255-0

Juric, A. K., Batal, M., David, W., Sharp, D., et al. (2018). Risk assessment of dietary lead exposure among First Nations people living on-reserve in Ontario, Canada using a total diet study and a probabilistic approach. *Journal of Hazardous Materials,* 344, 55-63. https://doi.org/10.1016/j.jhazmat.2017.09.035

Kanstrup, N. (2012). Lead in game birds in Denmark: Levels and sources. *Danish Academy of Hunting*, Article, 2012-02-1.

Kanstrup, N. (Ed). (2009). CIC Workshop Report. Sustainable Hunting Ammunition. *CIC Workshop, Aarhus, Denmark 5-7 November 2009. The International Council for Game and Wildlife Conservation (CIC)*.

Kanstrup, N. and Thomas, V. G. (2020). Transitioning to lead-free ammunition use in hunting: Socio-economic and regulatory considerations for the European Union and other jurisdictions. *Environmental Science Europe,* 32, 91. https://doi.org/10.1186/s12302-020-00368-9

Kanstrup, N., Hansen, H. P., Balsby, T. J. S. and Mellerup, K. A. (2021). Non-lead rifle ammunition: Danish hunters' attitudes. *Environmental Sciences Europe,* 33, 41. https://doi.10.1186/s12302-021-00485-z

Kanstrup, N., Swift, J., Stroud, D. A. and Lewis, M. (2018). Hunting with lead ammunition is not sustainable: European perspectives. *Ambio,* 47(8), 846-857. https://doi.org/10.1007/s13280-018-1042-y

Kanstrup, N., Thomas, V. G. and Fox, A. D. (eds). (2019). Lead in hunting ammunition: Persistent problems and solutions. *Ambio Special Issue,* 48(9), 923-1098. https://doi.org/10.1007/s13280-019-01220-y

Knutsen, H. K., Brantsæter, A. L. Alexander, J. and Meltzer, H. M. (2015). Associations between consumption of large game animals and blood lead levels in humans in Europe: The Norwegian experience, in R. J. Delahay and C. J. Spray (eds), *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health* (pp. 44-50). The University of Oxford, UK; Edward Grey Institute.

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

Kwan, M. K. H. (2018). A significant dietary source of lead to Nunavik Inuit: Ptarmigan hunting. *Nunavik Research Centre, Kuujjuak, Quebec*. Available at: https://www.researchgate.net/publication/323691577

LAG. (2022). *Lead Ammunition Group*. Available at: http://www.leadammunitiongroup.org.uk/policies/ (Accessed: 15 February 2022).

Lanphear, B. P., Hornung, R., Khoury, J., Yolton, K., et al. (2005). Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. *Environmental Health Perspectives,* 113(7), 894-899. https://doi.org/10.1289/ehp.7688

Lenti, A., Menozzi, A., Fedrizzi, G., Menotta, S., et al. (2021). Lead levels in wild boar meat sauce (Ragù) sold on the Italian market. *International Journal of Environmental Research and Public Health,* 18, 3989. https://doi.org/10.3390/ijerph18083989

Livsmedelsverket. (2021). *Swedish Food Agency advice on lead in game meat*. Available at: https://www.livsmedelsverket.se/ (Accessed: 23 October 2021).

Madden, J. R. (2021). How many gamebirds are released in the UK each year? *European Journal of Wildlife Research,* 67, 72. https://doi.org/10.1007/s10344-021-01508-z

Magee, A. (2020). Meat trends: A brave new world. *Food Manufacture Newsletter, 25 Feb. 2020*. Available at: https://www.foodmanufacture.co.uk/Article/2020/02/25/Meat-trends-A-brave-new-world (Accessed: 22 October 2021).

Marescotti, M. E., Caputo, V., Demartini, E. and Gaviglio, A. (2019). Discovering market segments for hunted wild game meat. *Meat Science,* 149, 163-176. https://doi.org/10.1016/j.meatsci.2018.11.019

MDA. (2021). Processor participation requirements–venison donation program. *Minnesota Department of Agriculture*. Available at: https://www.mda.state.mn.us/food-feed/processor-participation-requirements-venison-donation-program

Meyer, P. A., Brown, M. J. and Falk, H. (2008). Global approach to reducing lead exposure and poisoning. *Mutation Research,* 659, 166-175. https://doi.org/10.1016/j.mrrev.2008.03.003

NHS. (2020). Foods to avoid in pregnancy. *National Health Service*. Available at: https://www.nhs.uk/pregnancy/keeping-well/foods-to-avoid/ (Accessed: 16 April 2020).

Niewiadomska, K., Kosicka-Gębska, M., Gębski, J., Gutkowska, K., et al. (2020). Game meat consumption—Conscious choice or just a game? *Foods,* 9, 1357. https://doi.org/10.3390/foods9101357

Nkosi, D. V., Bekker, J. L. and Hoffman L. C. (2021). Toxic metals in wild ungulates and domestic animals slaughtered for food purposes: A systemic review. *Foods,* 10, 2853. https://doi.org/10.3390/foods10112853

Pain, D. J., Cromie, R. L, Newth, J., Brown, M. J., et al. (2010). Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS ONE,* 5(4), e10315. https://doi.org/10.1371/journal.pone.0010315

Pain, D. J., Dickie, I., Green, R. E., Kanstrup, N. and Cromie, R. (2019b). Wildlife, human and environmental costs of using lead ammunition: An economic review and analysis. *Ambio Special Issue,* 48, 969-988. https://doi.org/10.1007/s13280-019-01157-2

Pain, D. J., Mateo, R. and Green, R. E. (2019a). Effects of lead from ammunition on birds and other wildlife: A review and update. *Ambio Special Issue,* 48(9), 935-953. https://doi.org/10.1007/s13280-019-01159-0

Pohl, H. R., Ingber, S. Z. and Abadin, H. G. (2017). Historical view on lead: guidelines and regulations, in A. Sigel, H. Sigel and R. K. C. Sigel (eds), *Metal ions in life sciences* (pp. 435-470). https://doi.org/10.1515/9783110434330-013

Schulz, K., Brenneis, F., Winterhalter, R., Spolders, M., Fromme, H., et al. (2021). Marination increases the bioavailability of lead in game meat shot with lead ammunition. *Journal of Nutritional Science,* 10, e24. https://doi.org/10.1017/jns.2021.15

Sevillano-Caño, J., Cámara-Martos, F., Zamora-Díaz, R. and Sevillano-Morales, J. S. (2021). Lead concentration in game migratory upland bird meat: Influence of ammunition impacts and health risk assessment. *Food Control,* 124, 107835. https://doi.org/10.1016/j.foodcont.2020.107835

Sevillano-Morales, J. S., Sevillano-Caño, J., Cámara-Martos, F., Moreno-Ortega, A., et al. (2021). Risk assessment of Cd, Cu, and Pb from the consumption of hunted meat: red-legged partridge and wild rabbit. *Biological Trace Element Research*, 199, 1843-1854. https://doi.org/10.1007/s12011-020-02290-w

Strazdina, V., Jemeļjanovs, A. and Šterna, V. (2013). Nutrition value of wild animal meat. *Proceedings of the Latvian Academy of Science, Sect B*, 67(4/5), 373-377. https://doi.org/10.2478/prolas-2013-0074

Taggart, M. A., Reglero, M. M., Camarero, P. R. and Mateo, R. (2011). Should legislation regarding maximum Pb and Cd levels in human food also cover large game meat? *Environment International,* 37, 18-25. https://doi.org/10.1016/j.envint.2010.06.007

Tammone, A, Caselli, A. E., Condori, W. E., Fernandez, V., et al. (2021). Lead exposure in consumers of culled invasive alien mammals in El Palmar National Park, Argentina. *Environmental Science and Pollution Research,* 28, 42432-42443. https://doi.org/10.1007/s11356-021-13654-7

Thomas, V. G., Kanstrup, N. and Fox, A. D. (2019). The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation. *Ambio Special Issue,* 48(9), 925-934. https://doi.org/10.1007/s13280-018-1132-x

Thomas, V. G., Pain, D. J, Kanstrup, N. and Green, R. E. (2020). Setting maximum levels for lead in game meat in EC regulations: An adjunct to replacement of lead ammunition. *Ambio*, 49, 2026-2037. https://doi.10.1007/s13280-020-01336-6

Titus, K., Haynes, T. L. and Paragi, T. (2009). The importance of moose, caribou, deer, and small game in the diets of Alaskans, in R. T. Watson, M. Fuller, M. Pokras and W. G. Hunt (eds), *Ingestion of lead from spent ammunition: Implications for wildlife and humans* (pp. 137-143). Boise, Idaho; The Peregrine Fund. https://doi.org/10.4080/ilsa.2009.0312

Trinogga, A. L, Courtiol, A. and Krone, O. (2019). Fragmentation of lead-free and lead-based hunting rifle bullets under real life hunting conditions in Germany. *Ambio Special Issue,* 48(9), 1056-1064. https://doi.org/10.1007/s13280-019-01168-z

Uhart, M., del Valle Ferreyra, H., Romano, M., Muchiutti, A., Alzuagaray, S., Santiago, M.and Caselli, A. (2019). Lead pollution from hunting ammunition in Argentina and current state of lead shot replacement efforts. *Ambio Special Issue,* 48(9), 1015-1022. https://doi.org/10.1007/s13280-019-01178-x

UNEP. (2010). Final review of the scientific information on lead. Version of December 2010. Chemicals Branch, DTIE, Paris, France. *United Nations Environment Programme*.

UNEP. (2018). United Nations Environment Assembly of the United Nations Environment Programme. Third session, Nairobi, 4-6 December 2017. 3/4. Environment and health. *United Nations Environment Programme*. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/31019/k1800154.english.pdf?sequence=3&isAllowed=y

UNICEF and Pure Earth. (2021). *The toxic truth: Children's exposure to lead pollution undermines a generation of future potential*. Available at: http://www.pureearth.org/wp-content/uploads/2021/03/The-Toxic-Truth-Childrens-Exposure-To-Lead-Pollution-UNICEF-Pure-Earth-2020.pdf (Accessed: 22 October 2021).

USDA. (2021). *Food pantry use increased in 2020 for most types of U.S. households*. Available at: https://www.ers.usda.gov/amber-waves/2021/november/food-pantry-use-increased-in-2020-for-most-types-of-u-s-households/#:~:text=Data%20from%20the%20Current%20Population%20Survey%20Food%20Security,pantry%2C%20an%20increase%20from%204.4%20percent%20in%202019.?msclkid=ff1fbc2ba84411ec96410f1da6873b02

Waitrose and Partners. (2021). *Our approach to animal welfare. July 2021*. Available at: https://www.johnlewispartnership.co.uk/content/dam/cws/pdfs/Juniper/ethics-and-sustainability/Our-approach-to-animal-welfare-2021.pdf (Accessed: 23 October 2021).

Wang, G., DiBari, J., Bind, E., Steffens, A. M., et al. (2019). Association between maternal exposure to lead, maternal folate status, and intergenerational risk of childhood overweight and obesity. *Journal of the American Medical Association. Network Open*, 2(10), e1912343. https://doi.org/10.1001/jamanetworkopen.2019.12343

White, P. A. and Belant, J. L. (2015). Provisioning of game meat to rural communities as a benefit of sport hunting in Zambia. *PloS ONE,* 10(2), e0117237. https://doi.org/10.1371/journal.pone.0117237

WHO. (2011). Lead. Pp 162-177, in *Evaluation of certain food additives and contaminants*. Seventy-third report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series 960, WHO Press, Geneva Switzerland.

WHO. (2021). *Lead poisoning facts sheet*. Available at: https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health (Accessed: 22 October 2021).

Wilson, W. A., Harper, R. G., Alexander, G., Perara M. and Fraker, M. (2020). Lead contamination in ground venison from shotgun-harvested white-tailed deer (Odocoileus virginianus) in Illinois. *Bulletin of Environmental Contamination and Toxicology,* 105, 366-371. https://doi.org/10.1007/s00128-020-02967-x