Environmental Pollution 384 (2025) 127010

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Inaccurate and misleading terminology may impede the protection of people and wildlife from adverse effects of lead ammunition☆

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ARTICLE INFO

Keywords:
Lead toxicity
Non-toxic
Ammunition
Sinkers
Regulation
Terminology
Misleading interpretation

ABSTRACT

Inaccurate terminology and misinformation about lead (Pb) ammunition's toxicity may obstruct proposed regulation requiring use of non-lead substitutes. Elemental lead of anthropogenic origin in the environment is often confused with naturally-occurring lead ore compounds in the scientific literature, leading to suggestions that its use cannot be regulated. Inaccurate and misleading statements about the composition of substitutes for lead ammunition and fishing weights can cause public misunderstanding about their use and hinder proposals to end the use of lead-based products. It is necessary to clarify the composition of lead substitutes in nationally/internationally-approved lists of non-toxic products and to make them publicly available. Suitable products already exist but need to be adopted in most countries' legislation, especially if a broad transition to lead substitutes for all hunting ammunition and fishing weights is to be adopted. These concerns apply especially to the European Union, the United Kingdom, and other countries in which much scientific evidence supports the use of non-lead substitutes.

1. Introduction

The introductions to some scientific papers about lead (Pb) exposure and toxicity occasionally contain generalized, but imprecise, statements (e.g. Stalwick et al., 2023; Eleftheriou and Schuler, 2024; Fernández et al., 2021). Simplified terminology and familiar language may be used in attempts to make complex scientific information intelligible to those who do not have scientific training and experience with a specific topic. Consequently, the precision of the language used and its perceived meaning may be jeopardized and the message distorted. The exposure of wildlife and humans to ingested metallic lead from spent ammunition and lost/discarded fishing weights is now well documented in the scientific literature (Kanstrup et al., 2019), and transitions to the use of substitutes are progressing in many jurisdictions (Katzner et al., 2024). However, the transition to their use is resisted by much of the ammunition and gun manufacturing industry (e.g. AFEMS/WFSA, 2015) and by hunting communities defiant of advisories to use non-lead gunshot (Green et al., 2023, 2025a,b). This paper presents examples of how some of the language used can provide a basis for misinformation and provides guidance on the regulation of non-lead products.

2. Confusion of elemental lead with lead compounds

Some scientific papers begin with a statement similar to *'Lead is a naturally-occurring metal .'; Lead (Pb) occurs naturally in the environment … '; 'Lead (Pb) is a natural component in the environment.'*; or *'Elemental lead is a heavy metal naturally present in the earth's crust.'* (e.g. Couture et al., 2012; Fillion et al., 2014; Stalwick et al., 2023). As written, these statements can be misleading.

Metallic, elemental lead occurs rarely in nature, but lead is a major constituent of over 200 minerals of which galena (lead sulphide, PbS) is the primary form in nature. While natural weathering of rocks, igneous activity, and radioactive decay of naturally-occurring radon release lead to the earth's surface, the vast majority of lead in both remote and urban environments derives from human activities (Flegal and Smith, 1992). Where elemental lead is found it is generally of anthropogenic origin, as in discharged lead-based ammunition, discarded lead batteries, lead water delivery pipes, and lost fishing weights. Lead compounds occurring naturally in soil and lead ores are rarely implicated in lead exposure and toxicosis of wildlife, but elemental lead derived from spent shotgun and rifle ammunition is a major contributor to both exposure and

☆ This paper has been recommended for acceptance by Philip N. Smith.

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https://doi.org/10.1016/j.envpol.2025.127010
Received 8 July 2025; Received in revised form 15 August 2025; Accepted 18 August 2025
Available online 22 August 2025

toxicosis in wildlife and humans (Kanstrup et al., 2019). The failure to distinguish elemental lead from lead compounds such as lead ores, has promoted the view that *'because lead occurs naturally in the environment it cannot be regulated or banned'* .[1] What this view overlooks is that it is the *use* of elemental lead in ammunition and sinkers that is to be, and should be, banned. Should this succeed, it simultaneously reduces its presence in all terrestrial and aquatic environments of wild species and humans.

Elemental lead (such as from spent lead ammunition), having been released to the environment, reacts with oxygen and carbon dioxide, especially in low pH environments, to produce lead oxide and lead carbonate:

$$2\ Pb + O_2 \ggg 2\ PbO$$

$$2\ PbO + 2\ CO_2 \ggg 2\ Pb\ (CO_3)_2$$

These compounds occur on the surface of spent lead gunshot and fishing weights, and when such objects are ingested by wildlife, the lead compounds and the underlying metallic lead dissolve in the acid environment of the foregut. Thus:

$$Pb + 2HCl \ggg PbCl_2 + H_2$$

$$PbO + 2\ HCl \ggg Pb\ Cl_2 + H_2O$$

$$2\ Pb\ (CO_3)_2 + 4\ HCl \ggg 2\ Pb\ Cl_2 + 2\ CO_2 + 2\ H_2O$$

$$Pb\ Cl_2 \ggg Pb^{++} + 2\ Cl^-$$

It is the lead ion, Pb^{++}, that is absorbed into the blood and exerts its toxicity.

Lead concentrations in shooting range soils can be extremely elevated, but the solubility of secondary minerals that form a crust around bullets that are corroding in soils limits the activity of Pb^{2+}in solution (Vantelon et al., 2005; Alasmary, 2025). Nonetheless, physicochemical properties of the soil and organic matter content significantly influence the bioavailability of the Pb from ammunition (Alasmary, 2025) and studies carried out in recent decades show that the uptake of Pb by plants growing in shooting ranges is a growing environmental concern (Dinake et al., 2021) alongside the potential for increasing Pb exposure in food webs. Military and recreational shooting ranges should practice spent ammunition metal removal and recycling to avoid corroded metal (as from Zn, Cu, Pb, Fe) interactions and leaching into the soil.

3. Confusion regarding absorption of metallic lead into the human body

A confusion related to elemental lead was created by the European Arms and Ammunition Manufacturers Association (AFEMS) and the World Forum on Shooting Activities (WFSA), when they stated in defence of the continued manufacture and use of lead-based ammunition that:

> *' … metallic lead in ammunition has no significant impact on human health and the environment as compared to other forms of lead. Lead fragments in game meat, if ingested, cannot be directly absorbed by the human body because they are in metallic form.'* (AFEMS/WFSA, 2015).

While this statement is correct in saying that metallic lead is not absorbed into the bloodstream, it overlooks the fact that the solubility of metallic lead increases at low pH values. Consequently, lead ingested by humans and animals from either bullet fragments or lead gunshot can be dissolved in the acid medium of the stomach or gizzard. The extent to which this happens will be related to the surface area to volume ratio of lead particles ingested, retention time in the intestine and other factors. While the exact mechanisms of gastro-intestinal Pb absorption remain unknown, both active transport and/or diffusion across the epithelia could occur, involving Pb ions and/or Pb complexes with bile acids (ATSDR, 2020). Cooking of game meat killed with Pb ammunition can enhance the dissolution and uptake of Pb into the body, especially when low pH marinades or sauces are used (Mateo et al., 2011). Once absorbed into the blood, Pb exerts its toxicity. Good evidence for this is from a controlled experiment on pigs in which metallic lead fragments derived from rifle bullets included in their diets led to clear elevation of the concentration of lead in the blood (Hunt et al., 2009). An experimental study of rats, in which metallic lead powder of 6–197 μm in size was included in the diet, found that a higher proportion of Pb is absorbed from small than large particles (Barltrop and Meek, 1979). Furthermore, lead particles of <20 μm and sometimes <10 μm in diameter were frequently detected in ballistic gel, used to simulate game animal tissue, into which bullets had been fired (Leontowich et al., 2022). Although not experimental, it has also been shown that dogs fed scraps from the wound channels of wild-shot game have elevated blood lead concentrations (Fernández et al., 2021). Attempting experiments on humans similar to those conducted on pigs and rats is considered to be unethical because lead is well known to be toxic. However, it would be remarkable if humans did not absorb ammunition-derived lead from the diet in much the same way as other mammals. Less strong, but still convincing, corroborative evidence that the same applies to humans comes from correlative studies in which blood lead levels of humans were found to be linearly related to their intake rates of meat from animals killed using lead ammunition (Green and Pain, 2012) and from the similarity of the stable isotope composition of lead in humans who eat game to that of lead ammunition (Tsuji et al., 2008).

The statement of the AFEMS and WFSA is an example of the type of information that could be accepted at face value and misinterpreted by those unfamiliar with lead chemistry or studies of the number and size distribution of lead fragments in game meat (as described in Green and Pain, 2019, 2024; Pain et al., 2025). It could be used to obstruct any transition to substitutes for lead-based ammunition.

In 2023, the European Food Safety Authority updated EU Regulation (EU) 2023/915 (EU, 2023) on maximum levels (MLs) for certain contaminants, including lead, in food. However, they continued not to set an ML for lead in game meat. This absence of setting an EUML for lead in game meat was despite the long-standing MLs for lead throughout the EU and UK for most other types of meat from farmed animals and some wild non-game animals, such as shellfish, only commonly eaten by subsets of the population, in order to protect the health of European Union (EU) citizens, including the most at-risk population groups, such as children and pregnant women (Pain et al., 2025). A digest of up-to-date evidence that a lead ML for game meat would be appropriate was available to them (Thomas et al., 2020). We do not know if they considered this evidence when reaching their decision not to set an ML.

4. Distinctions among 'lead-free', 'non-lead', 'does not contain lead', and 'non-toxic'

The term 'lead-free' should carry the caveat that it does not contain more than a legally-specified level of Pb. In the USA and Canada this is no more than 1 % by mass when used as gunshot for hunting waterfowl (USFWS, 1997). Given the analytic capacity to measure Pb in parts per million and below, and given that removing all lead is practically impossible for commercial ammunition and sinkers, it is best to specify a maximum permissible level of Pb, as has been done in existing and proposed EU and UK regulation (e.g., EU, 2021; 2025; Defra, 2025). This provides guidance to manufacturers and provides the basis for enforcement.

The terms 'lead-free' and 'does not contain lead' do not necessarily imply that ammunition is 'non-toxic' as it could comprise mainly other elements that pose a toxic risk to wildlife, as in the case of zinc (Zn). Zn shot was demonstrated to be toxic to waterfowl (Levengood et al., 1999) and is not approved as a legal substitute for lead shot for waterfowl

[1] Unattributed personal communication to V.G. Thomas.

hunting in North America, although Zn and other metal coatings of approved non-toxic shot types have been approved (CFR, 2025). However, Zn gunshot is sold in Europe (Fäith and Göttlein, 2019) and Zn shot has been recovered from carcasses of wild-shot common pheasants in two studies in the UK (Green et al., 2024; Green et al., 2025a,b). Zn is also a commonly-used metal for fishing weights both in Europe and North America due to its density. Use of the terms 'non-lead' and 'does not contain lead' on a box of shotgun cartridges could be mistakenly interpreted to mean 'non-toxic'. This could reassure those wishing to use lead shot substitutes, but who do not delve into the product's actual composition, and who are not familiar with the topic of ingested metal toxicity. The terms 'non-lead' or 'non-toxic' best describe substitutes for lead-based ammunition and sinkers, provided that they contain the caveat 'containing less than 1 % Pb and no other metals toxic to wildlife singly or in combination at the levels contained'. These terms could be included in any regulation used to accompany a transition to the use of lead-based substitutes.

5. Providing context to the statement that *'substitutes for lead ammunition are toxic to wildlife, but less toxic than lead'*

The terms 'essential' and 'non-essential' element require definition. An essential element is required for animal metabolism, whereas non-essential elements play no such rôle. Copper (Cu) and zinc (Zn) are essential elements at low concentrations but can become toxic at high concentrations. However, Pb is non-essential and is toxic even at low concentrations (Lanphear et al., 2024). While it is strictly accurate that most metals (and their compounds) used as lead substitutes in ammunition can be toxic if exposure levels are sufficiently high, their toxicity varies considerably. Unqualified, this statement reinforces the determination of those reluctant to forego the use of lead ammunition. Statements such as *'Most of the metals used as alternatives to lead in ammunition are heavy metals that, dependent on dose, are toxic to living organisms'* (Kanstrup, 2024) can be misinterpreted when taken alone. Just because many essential and non-essential heavy metals can be toxic, under certain circumstances and at certain levels of exposure, does not mean that they are toxic when used as lead shot substitutes.

In the USA, the US Fish and Wildlife Service is legally required to undertake a detailed toxicological evaluation of a candidate lead shot substitute in order for it to receive legal approval for use. This Three-Tiered process requires controlled laboratory experimental testing of the candidate metal on captive waterfowl over two generations. It evaluates the effects (if any) upon blood parameters, levels of the metal in organs and tissues, effects on survivorship, reproductive output, and development of progeny (USFWS, 1997; 2013). The testing procedure also evaluates the effects of a given environmental spent shot loading upon water quality, aquatic species, and soil parameters. Consequently, any legally-approved lead shot substitute is considered to be non-toxic to both animals and the environment under these testing criteria (Table 1 in Thomas, 2019). Moreover, both lead shot and iron (steel) gunshot are used as experimental control comparisons with a candidate shot type in the Three-Tier testing procedures enabling a direct comparison to be made.

Other than the USA and Canada, no country has legal toxicity testing requirements for gunshot used in waterfowl hunting. As if by default, other countries appear to accept the USA legally-approved lead substitutes, as, for example, steel shot. Perhaps it is the absence of such testing procedures that allows the unsubstantiated views that approved lead shot substitutes are also toxic, albeit less so, to proliferate. Zn shot is an example of an unapproved shot type that has a toxic effect when ingested by waterfowl (Levengood et al., 1999; Fäith and Göttlein, 2019), and this could give rise to the 'less toxic' view. Zn, when used as a shot coating and comprising 1 % of the shot mass is permitted under US regulation, but not as the entire mass of a shot. This concern emphasizes the need for an approval process to be introduced at national and multi-national levels, and especially by the European Union. A ban across the European Union on the use and carrying while hunting of shot containing ≥1 % by weight of lead in and within 100 m of wetlands came into force in February 2023 (EU, 2021). In February 2025, the European Commission published a draft regulatory amendment proposing a restriction on the placing on the market and use of lead-based shotgun and rifle ammunition for hunting, and various other uses, and lead fishing weights (with derogations and phase-in periods; EU, 2025). In July 2025 the UK government announced its intention to ban the placing on the market and use of shot containing ≥1 % lead and of large calibre lead bullets containing ≥3 % lead (by weight) for live quarry shooting, along with various other restrictions, in Britain, with a 3-year phase-in period (with derogations; Defra, 2025).

The use of lead fishing weights of >0.06 g and <28.35 g has been banned in the UK since 1986 (UK Statutory Instrument, 1986) and lead hunting bullets have been banned in California State, Denmark, and, to a limited extent, elsewhere (Katzner et al., 2024). However, to the best of our knowledge, regulations approving types of rifle ammunition and fishing weights based upon their chemical composition do not exist in any jurisdiction, whether in North America or Europe. In the USA and Canada, this is because only waterfowl hunting is a federal jurisdiction: all other categories of hunting and angling fall under state or provincial jurisdiction. Should the European Commission decide in favour of a transition to hunting and angling with lead substitutes the need for a regulated approval process arises. This could be the legal recognition of the approved metals that have already undergone a rigorous experimental approval analysis elsewhere. Metals approved for use in gunshot could also be recognized as approved metals for making fishing weights and rifle bullet cores. The list of approved metals to be used as lead substitutes is unlikely to increase in future, given concerns about ballistic efficiency, availability, ease of manufacture, costs of production, and non-toxicity. Thus, an existing experimental approval system is the most expedient to introduce and enforce. It would also provide guidelines to national manufacturers and import agencies, and then assurances to the public using the substitutes.

6. Conclusions

Metallic lead from ammunition clearly presents health risks to people and wildlife that ingest it, as it can be dissolved in the intestine and absorbed into the blood stream. These risks were recently and comprehensively reviewed in the United Kingdom and European Union as part of their respective chemicals regulatory processes (UK REACH and EU REACH). In both cases, the risk assessments and socio-economic analyses conducted resulted in recommendations for restrictions on the placing on the market use of lead ammunition (with derogations), and in regulatory amendments being drafted (Defra, 2025; EU, 2025).

The inaccuracies and/or misunderstandings described above provide the basis for jurisdictions proposing a transition to non-lead hunting and angling products to define, explicitly, in regulations what are acceptable non-toxic products. This should be complemented by advisories issued to the hunting and fishing communities. This would avoid much ignorance and misinformation about non-toxic materials in ammunition, assure users of their safety, and speed up the phase-out of the use of lead ammunition. These concerns apply especially to the European Union and Great Britian where draft regulatory amendments have been published proposing various bans on the placing on the market and use of lead shotgun ammunition and bullets for hunting and certain other purposes (Defra, 2025; EU, 2025). As these texts were in draft form at the time of writing, we encourage the relevant authorities to explicitly define non-toxic substitute materials, or how these are to be identified, in any final regulatory text. These concerns also apply to Australia and Canada in which the rationales for a regulated transition to non-lead, non-toxic substitutes have been identified (Hampton et al., 2018; Thomas, 2025).

Substitutes for lead ammunition are widely available, especially in North America and Europe. They are effective in hunting all species of game, whether as shotgun shot (Pierce et al., 2015) or rifle bullets (Kanstrup et al., 2016). A simple, helpful, step would require that the term 'non-lead' be printed not only on the packages of non-lead ammunition and fishing weight, but on individual shotgun cartridges. This could enhance compliance and enforcement.

CRediT authorship contribution statement

Vernon G. Thomas: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Rhys E. Green:** Writing – review & editing, Validation, Conceptualization. **Deborah J. Pain:** Writing – review & editing, Conceptualization.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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