Regulation of some sources of lead poisoning: a brief review

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ABSTRACT

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

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

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

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

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

NARRATIVE

Lead toxicology

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

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

Lead in antiquity

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

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

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

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

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

The onset of industrial exposure to lead

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

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

"Rather than receiving praise for his incisive work, Baker was condemned by the clergy, the mill owners and by fellow physicians: cider was Devon's main export. Baker suffered the fate of many 'early warning' scientists whose inconvenient truths are not welcomed by supporters of the* status quo.*"
(Needleman and Gee 2013).

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

"This mischievous effect from lead is at least 60 years old; and you will observe with concern how long a useful truth may be known and exist, before it is generally received and practiced on."
(Franklin 1818).

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

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

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

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

Lead in paint

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

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

"The consequences of this delay have been disastrous"
(Hernberg 2000).

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

STOP PRESS: A global review of the status of phasing out of lead paint was published by SAICM in September 2015: **http://tinyurl.com/nd8svek**

and Mexico. Thus, 123 years after recognition of this issue, a significant proportion of the world's population still remains at risk to exposure from lead in paint both in industrial and domestic settings (ICCM 2009).

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

"57. Phase out lead in lead-based paints and in other sources of human exposure, work to prevent, in particular, children's exposure to lead and strengthen monitoring and surveillance efforts and the treatment of lead poisoning."
(WSSD 2002).

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

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

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

Lead in petrol

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

REGULATION OF LEAD IN PETROL IN THE USA

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

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

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

"at present there are no good grounds for prohibiting the use of ethyl gasoline … provided that its distribution and use are controlled by proper regulations"
(Needleman and Gee 2013).

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

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

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

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

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

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

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

REGULATION OF LEAD IN PETROL IN THE UK

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

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

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

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

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

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

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

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

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

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

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

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

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

GLOBAL ELIMINATION OF LEAD IN PETROL

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

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

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

Contemporary human exposure to lead

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Regulation of lead in ammunition

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

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

UK REGULATIONS CONCERNING USE OF LEAD GUN-SHOT IN WETLANDS

The UK response to the IWRB initiative was to convene a meeting of interested parties in September 1991 chaired by the Joint Nature Conservation Committee. This became the Lead Shot in Wetland Areas Steering Group which met annually for the next seven years. A Lead in Waterfowl Working Group, chaired by Department of the Environment (DoE), was established and met up to four times a year until 1997 to advise

the Steering Group and government (Table 1). It members formally represented different sectors (footnote 2 to Table 1). With 46 organisations contributing to the Steering Group's deliberations (footnote 1 to Table 1), the advisory process was fully inclusive.

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

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

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

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

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

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

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

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

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

INTERNATIONAL RESPONSES

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

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

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

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

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

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

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

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

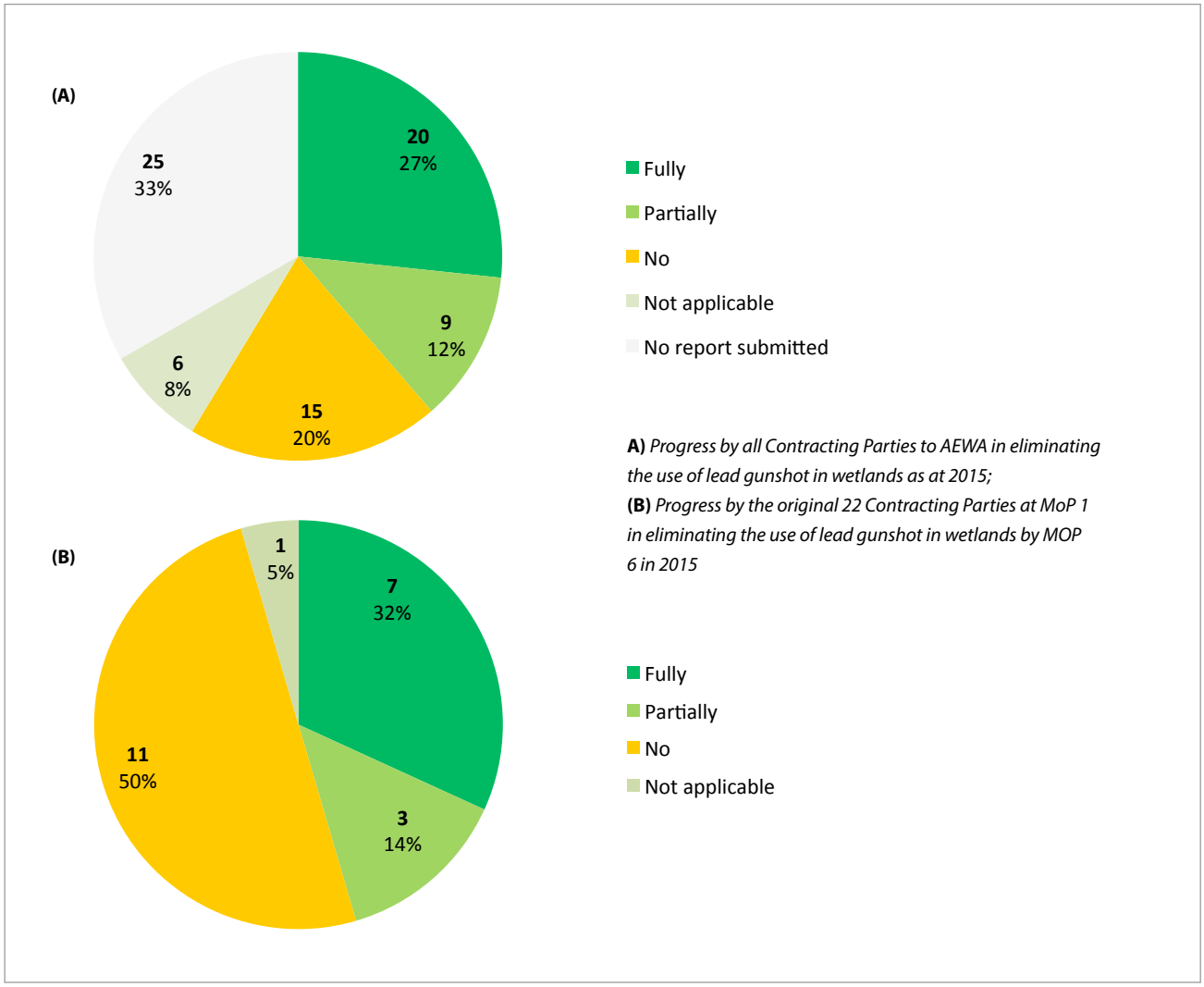
Decision	Content	Comment
African-Eurasian Migratory Waterbirds Agreement		
2002 – Second Meeting of Parties – Resolution 2.2 (AEWA 2002)	*"implementation of … still highly insufficient in the majority of Range States"* *"report to each MoP on progress … in accordance with self-imposed and published timetables"*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

Progress towards phasing out lead gunshot in wetlands

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

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

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



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

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

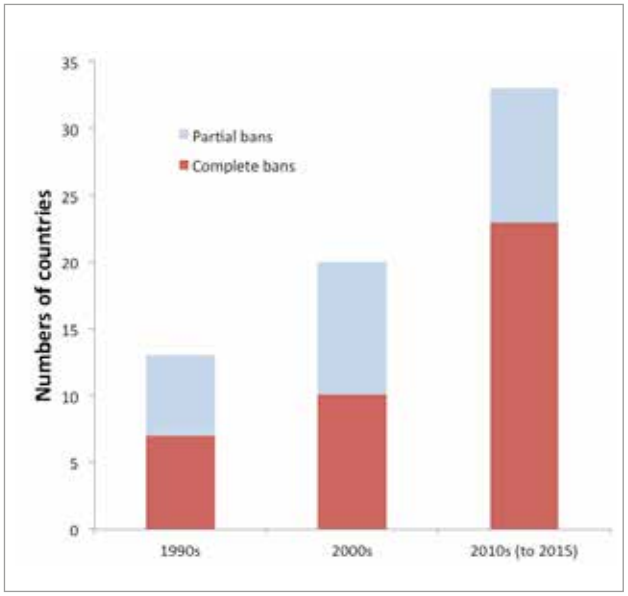


Figure 2: **Progress towards eliminating the use of lead gunshot in wetlands world-wide.** *Partial bans include situations where some progress has been made but a complete national ban has yet to be achieved. Data from Fawcett and van Vessem (1995), Kuivenhoven and Van Vessem (1997), Beintema (2004),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

CONCLUSIONS

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

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

(UNEP 2003)

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

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

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

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

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

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

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

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

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

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

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

ACKNOWLEDGEMENTS

Grateful thanks to Julia Newth, Ailsa Benton, Rachel Stroud and Chris Spray for, variously, the supply of literature and constructive comments on the draft, and to Ruth Cromie for discussions. The views expressed are those of the author alone.

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

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