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LEAD USE IN HUNTING

Regulations on lead ammunition adopted in Europe and evidence of compliance

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Abstract The transition to non-lead ammunition has been enforced by regulations on use and possession of lead shot and rifle bullets. Here we review the scientific and technical literature about this regulatory process in Europe and give some notes of its effectiveness to reduce this source of lead contamination in aquatic and terrestrial environments. Presently, lead shot use has been legally restricted in 23 European countries. Two, Denmark and The Netherlands, have a total ban of lead gunshot use in all types of habitats, 16 countries have a total ban in wetlands and/or for waterbird hunting, and 5 have a partial ban implemented only in some wetlands. The legal regulation of lead bullets is limited to some German regions. This review also highlights the need to know the level of compliance with the ban on lead ammunition and the subsequent benefits for the susceptible species and for game meat safety.

Keywords Bullet · Compliance · Contamination · Game meat · Lead poisoning · Shot pellet

INTRODUCTION

Lead is a relatively abundant and cheap metal with good ballistic properties for hunting that has not been replaced by other materials for several centuries despite the technological advances and the development of new materials as occurred with other lead uses (Oltrogge 2009), possibly because the evidence of the toxicological impact of this use has not been known until recent times (Pain et al. 2015).

There is a huge amount of information about lead toxicity and the health and environmental impacts associated with its uses since antiquity (Stroud 2015). The balance between the benefits of the use of this metal and its risk for life has led to its substitution by other materials (ECHA 2017). Such replacement was overcome for uses in plumbing or as a component of paints, petrol and even fishing weights, but many users and manufacturers are still opposed to the substitution of lead in ammunition despite the accumulated evidence of its negative environmental impacts (Thomas et al. 2015; Kanstrup et al. 2019). The introduction of new generations of non-lead shot types has been a driver for the advance in the regulation and elimination of lead in ammunition, as well as the wider understanding of the risks of dispersed of lead shot in ecosystems (Oltrogge 2009; Thomas 2013, 2015; Kanstrup 2019). The non-toxic properties of both the new materials and the final commercial products are another important issue that must be considered for the regulation of the new types of ammunition (Thomas 2016, 2019).

Here we summarize the status of the regulation of the use of lead ammunition for hunting in the different European countries and their compliance and effectiveness. In this review, we have updated previous reviews of the regulations adopted in Europe (Mateo 2009; Stroud 2015) with the most recent regulatory changes adopted in different European countries (AEWA 2018; ECHA 2018; VCF 2018) and other decisions made within with the framework of international agreements (UNEP/CMS 2014; IUCN/WCC 2016). The aim of this review is to compile the information about this regulation in order to highlight the differences between countries and the need of harmonization as ECHA (2017) proposed for the countries within the European Union (EU). We also want to highlight the scarcity of information in the scientific literature about the compliance with regulations or about the effects of these bans on the reduction of lead exposure in the vulnerable avian species.

ROLE OF INTERNATIONAL AGREEMENTS IN THE REGULATORY PROCESS

Individual European countries have implemented national regulations based on the evidence of the environmental impact of lead ammunition in their territories and/or because of the ratification of international treaties that have obligated the parties to make progress in the ban of lead ammunition (Stroud 2015; Kanstrup et al. 2019). However, the effect of these international policy statements has not yet been translated into effective regulations in many countries.

As a summary of the international instruments concerning lead poisoning and wildlife, in 1991 the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) was the first to recommend phasing out lead shot use in wetlands or for waterfowl hunting. By the time of the adoption of the UN-African-Eurasian Migratory Waterbird Agreement (AEWA) in 1995, awareness of the dangers of lead gunshot was well appreciated. As a result, the AEWA Action Plan contained a firm obligation for Parties to endeavour to phase out lead shot for hunting in wetlands by 2000. Insufficient implementation in the majority of Contracting Parties in 2008 resulted in a resolution to establish a new deadline for 2017, and this resolution included the need to evaluate the effectiveness of national measures already taken to phase out the use of lead shot and to phase in non-toxic alternatives in wetlands (AEWA 2012). This is an important aspect because the information about the compliance of these regulations will help the countries to decide policy measures and requirements to enforce the law (Mateo et al. 2014; Cromie et al. 2015; Kanstrup and Balsby 2018, Kanstrup 2019). Parties to the more global Convention on the Conservation of Migratory Species of Wild Animals (UNEP/CMS; Bonn Convention), the "mother" convention to AEWA, adopted in 2014 a resolution whose appended guidelines requested a phase out of the use of lead ammunition across all habitats (wetlands and terrestrial) by 2017 (UNEP/CMS 2014). While this target has not yet been met, various steps have been made towards this, including the establishment of the UNEP/CMS Lead Task Group in 2017. More recently, the World Conservation Congress adopted a resolution in 2016 that calls for action from the IUCN Director General and Commissions along with governments and all IUCN member organizations to work towards the phase out of lead ammunition following the guidelines of the 2014 UNEP/CMS Resolution (IUCN/WCC 2016). In the same line, the United Nations Environment Assembly adopted in 2017 a resolution on Environment and Health which calls for member States and the Executive Director to raise awareness of the dangers to the environment of lead in ammunition, and to encourage research regarding alternatives (UNEA 2017).

Within the EU, the directive on the conservation of wild birds aimed member states to phase out lead shot in wetlands by 2009 (Stroud 2015). More recently, the process of Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) in the EU by means the European Chemicals Agency (ECHA) has offered the appropriate framework to adopt the necessary regulatory actions on lead ammunition. This has led to propose a restriction of the use of lead gunshot in or over wetlands (ECHA 2017). This proposal states that (1) lead and lead compounds shall not be used in gunshot for shooting with a shot gun within a wetland or where spent gunshot would land within a wetland, and (2) lead gunshot shall not be in the possession of persons in wetlands. At the time of writing this review, the European Commission must adopt a decision about the support to this restriction. In 2018, ECHA also published an investigation report "reviewing the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle" (ECHA 2018). This report concluded that (1) lead gunshot in terrestrial areas poses a risk to both human health and the environment, and (2) the consumption of game shot with lead-based ammunition (including lead-rifle bullets) can result in exposure to consumers and as lead is considered a non-threshold toxicant, this consumption results in risks to humans. Also, dispersal of lead from fishing tackle was included in this additional ECHA (2018) initiative. A wider restriction proposal based on this report is anticipated in time and following this report, a group of 54 European scientists from 17 countries have already encouraged the European Commission to prepare a proposal for further measures to restrict the use of all lead ammunition and anglers' lead weights (European Scientists 2018).

CURRENT REGULATION OF LEAD AMMUNITION IN EUROPE

By 2018, the regulation of lead ammunition has been already adopted by 23 European countries as detailed in the following section. Figure 1 shows the increase in the number of countries with regulations of lead ammunition since the first partial regulation was implemented in Denmark in 1981.

Lead shot

There are at present 23 countries in Europe in which lead shot has been totally or partially banned (Fig. 2). All these countries, except Norway and Switzerland, are within the EU, but there are still six EU countries without any

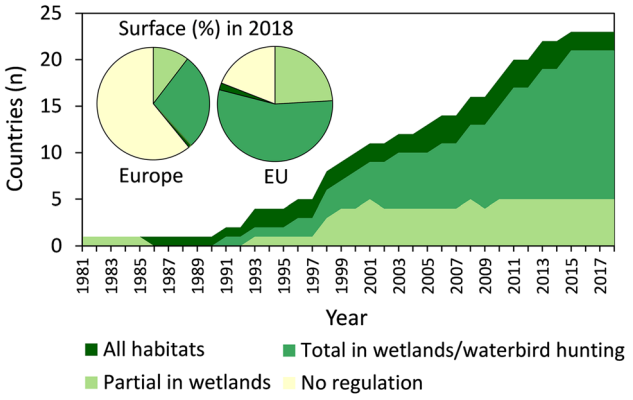

Fig. 1 Trend over time of the number of European countries with a ban on the use of lead shot in wetlands and/or for waterbird hunting (partial in specific wetlands or total) and also including terrestrial habitats (all habitats). Pie charts based on the total surface (area) of countries with and without regulations. The total surface of the left pie (Europe) includes the European parts of Azerbaijan, Kazakhstan, Russia and Turkey

regulation of lead ammunition according to the information submitted to international agreements (i.e. Greece, Ireland, Lithuania, Poland, Romania and Slovenia) (AEWA 2015, 2018; ECHA 2017). The regulations adopted in the European countries varied from those with a total ban in all the territory and habitats (i.e. Denmark and Netherlands) to those with a national ban on the use in all wetlands or for waterbird hunting (16 countries) or in some specific wetlands of international importance (5 countries) (Fig. 2). Another four countries (i.e. Albania, Malta, Moldova, Lithuania) have implemented a ban on waterbird hunting or a moratorium in important areas for waterbirds. The outcome of ECHA/REACH restriction proposal is currently awaited but would seek to harmonize regulation across the EU, which would eliminate these differences among countries (ECHA 2017).

Fig. 2 Lead shot regulations in Europe. Regulations are partial in some specific wetlands of international importance (Ramsar sites, Special Protection Areas for Birds), total in all wetlands or total in all types of habitats

Lead bullets

The use of lead bullets has been banned only in some regions, sites or National Parks in Germany, Italy and Spain in order to avoid contamination of game meat and/or to protect raptors from lead poisoning (ECHA 2017; Martin et al. 2017; VCF 2018). In Germany, the white-tailed eagle (*Haliaeetus albicilla*) has been found to be affected by lead poisoning due to the ingestion of lead bullet fragments present in carcasses and offal left by large-game hunters (Krone et al. 2009). The adoption of this measure in Germany to protect the white-tailed eagle from lead poisoning contrasts with the lack of regulation in other countries where lead poisoning in this species has been also detected, e.g. Sweden (Helander et al. 2009), Finland (Isomursu et al. 2018) and Poland (Kitowski et al. 2017). Similarly, the regulation of the use of lead bullets is practically absent in countries in Southern and Central Europe where lead poisoning has been detected in griffon vulture (*Gyps fulvus*) (Carneiro et al. 2016; Mateo-Tomás et al. 2016), cinereous vulture (*Aegypius monachus*) (Rodríguez-Ramos et al. 2009), bearded vulture (*Gypaetus barbatus*) (Berny et al. 2015) and Egyptian vulture (*Neophron percnopterus*) (Gangoso et al. 2009). There are only a few sites where the protection of the bearded vulture has promoted local regulations. In Italy, the use of lead bullets has been restricted in Sondrio Province since the season 2012/13; lead bullets can still be used provided that hunters bury the offal of killed ungulates (Bassi et al. 2014; ECHA 2018; VCF 2018). In Stelvio National Park and in many other protected areas where hunting is not allowed, the use of lead-free bullets is mandatory in case of interventions to control wild ungulates. A regional regulation made in 2017 by Emilia-Romagna region established the use of lead-free ammunition when the game meat is intended for market sale (ECHA 2018), but this regulation was withdrawn later in 2018. In Spain, the region of Valencia has recently banned the use of lead bullets in the Maestrazgo mountains, where a reintroduction project of bearded vultures is being carried out (VCF 2018). In Austria, the use of non-lead bullets is being promoted in the Hohe Tauern National Park with some incentivations for hunters (i.e. free check of the calibre and weapon as well as free advice from the rifle master, free chemical cleaning of the weapon by the rifle master, 1 free pack of lead-free ammunition and 25% discount on purchase of each additional package (up to a maximum of 5) of lead-free ammunition) (VCF 2018). In France, similar pilot voluntary initiatives are being developed in the Cévennes National Park, the French Alps in Haute Savoie and the French Pyrenees (VCF 2018).

REGULATION OF LEAD AMMUNITION BY EUROPEAN COUNTRIES: COMPLIANCE, EFFECT ON HUNTING BAGS AND OBSERVED BENEFITS FOR BIRDS AND GAME MEAT SAFETY

- *Albania (non-EU member)* A 2-year hunting moratorium in wetlands was imposed between March 2014 and March 2016, and a further five-year hunting moratorium was imposed for 2016–2021, but there is no regulation of lead shot use (AEWA 2018).
- *Andorra (non-EU member)* Without regulation of lead ammunition.
- *Armenia (non-EU member)* Without regulation of lead ammunition.
- *Austria (EU member)* Lead shot is not permitted for hunting waterfowl wherever they occur (ECHA 2017). The use of non-lead bullets is being encouraged with some incentives for hunters (VCF 2018).
- *Azerbaijan (non-EU member)* Without regulation of lead ammunition.
- *Belarus (non-EU member)* Without regulation of lead ammunition.
- *Belgium (EU member)* In Flanders, lead shot has been banned for waterfowl hunting in Ramsar sites since 1993, and in 1998 this ban was extended to all EU Bird Directive areas (Beintema 2001). A total ban on the use of lead shot over wetlands in Flanders was adopted in 2003 (AEWA 2005) and the use of lead shot also outside wetlands was banned in 2005 (ECHA 2018). In Wallonia, the restriction applied initially to hunting in wetlands, although coated lead pellets ('cartouches à plomb nickelés') were allowed (AEWA 2008). The total ban of lead shot for waterfowl hunting at less than 50 m from wetlands in Wallonia was established in 2005 (AEWA 2018).
- *Bosnia-Herzegovina (non-EU member)* Without regulation of lead ammunition.
- *Bulgaria (EU member)* The ban of lead shot in wetlands and 200 metres around has been in place since 2008 (MoEW 2007). The prohibition is enforced by the Executive Forestry Board and covers all existing wetlands across the country (AEWA 2015).
- *Croatia (EU member)* A provision forbidding the use of lead shot in wetlands throughout the Republic of Croatia became law when this country entered the EU in 2013 (AEWA 2015).
- *Cyprus (EU member)* Lead shot was banned in wetlands in Cyprus in 2003 with the law on the protection and conservation of game and wild birds (AEWA 2008, 2015).
- *Czech Republic (EU member)* The use of lead shot for waterfowl hunting was banned on 31 December 2010 (AEWA 2015).

- *Denmark (EU member)* This was the first country in the world that implemented a ban on the use of lead shot, with the exception of the ban in some specific areas of the Mississippi Flyway in USA since 1976 (Anderson et al. 1987). This ban on lead shot use in Denmark was implemented for clay target shooting over wetlands in 1981, for hunting in Ramsar areas and for shooting over ponds with rearing and release of mallards (*Anas plathyrynchos*) for hunting and for clay target shooting in all habitats in 1986 (Kanstrup 2006). Moreover, from 1986, trade of cartridges containing more than 28.5 g of lead was banned (Clausen 1992). Denmark enforced a total ban on the use, trade and possession of lead shot in 1996 (Kuivenhoven et al. 1998, Kanstrup 2006), but there is still no regulation of lead bullets used for large-game hunting (Kanstrup et al. 2016). In Greenland, the use of all lead shot was not banned until 2012.
  In Denmark, compliance of the ban has recently been investigated. Kanstrup and Balsby 2018 found that the majority of shotgun plastic debris collected on Danish shorelines originated from non-lead types. In samples from 2016 and 2017 of pheasants with embedded shot (N = 447), Kanstrup and Balsby 2019 found that 1.8% (in 2016) and 2.2% (in 2017) were killed with lead shot, the remaining with non-lead types, mainly steel shot. The same study showed that among 148 mallards bagged in 2017, 3.1% had lead shot. The high compliance is due to strict regulation of use of lead shot in all habitats combined with a ban of trade and possession of lead shot cartridges. Furthermore, the wide availability of high-quality non-lead ammunition types is a driver for the compliance (Kanstrup 2019).
  Regarding the impact of this regulation on the hunting activity, the number of hunters, the long-term popularity of hunting and the annual hunting bag in Denmark have not been affected by the implementation of lead shot regulations (Kanstrup 2015, 2019). Prevalence of ingested shot is at present subjected to investigation. A sample of 690 mallard gizzards showed a prevalence of ingested shot at c.10%. Of this, the majority was steel shot (Kanstrup, unpublished).
- *Estonia (EU member)* The use of lead shot for hunting in wetlands was banned in 2013 (AEWA 2015).
- *Finland (EU member)* Lead shot was banned for waterfowl hunting (except in Åland Islands) in 1996 (AEWA 2018).
- *France (EU member)* In Tour du Valat Biological Station estate, a 2500-ha natural wetland in the Camargue (Rhone Delta), lead shot was voluntarily banned in 1994 for both terrestrial game and waterbirds (Mondain-Monval et al. 2015). A nation-wide ban on lead shot for hunting in wetlands has been implemented since 2006 (AEWA 2018). Voluntary initiatives by hunters to use non-lead bullets are being developed in the Cévennes National Park, the French Alps in Haute Savoie and the French Pyrenees (VCF 2018).
  Regarding the effect of the regulation, the prevalence of lead shot ingestion in waterfowl in Tour du Valat did not decrease between the period 1995–1999 (n = 297, 13.5%) and the period 2003–2005 (n = 179, 12.3%), but there was a significant increase in the prevalence of steel shot ingestion from 2% to 7.8%, respectively (Mondain-Monval et al. 2015). These authors concluded that the voluntary ban on lead shot ban in Tour du Valat had avoided the contamination of 8% of the ducks foraging in that area during the 11 years of the study.
- *Georgia (non-EU member)* Without regulation of lead ammunition.
- *Germany (EU member)* At a national scale, the German Federal Government and hunter's associations made in 1993 a recommendation to use non-toxic shot for waterfowl hunting in wetlands (Beintema 2001). Presently, several regions of Germany have banned lead shot for hunting waterfowl in waterbodies in line with AEWA resolutions (Gremse and Rieger 2015). The Federal States of Baden-Württemberg, Bavaria, Berlin, Brandenburg, Hesse, Lower Saxony, Mecklenburg-Western Pomerania, North Rhine-Westphalia, Rhineland-Palatinate, Saarland, Saxony-Anhalt, Schleswig-Holstein, and Thuringia have implemented a ban on lead shot for waterbird hunting, comprising 94.5% of Germany's total area (AEWA 2005, 2015). Saxony has banned lead shot use in all types of habitats since 2014. Moreover, the Government of Brandenburg was the first to introduce regulations of the use of any lead ammunition, including lead bullets for game hunting in the federal forests in 2005 (AEWA 2005, Kenntner et al. 2007). Specifically, 3 of 16 German Federal States (Schleswig-Holstein, Baden-Württemberg and Saarland) have totally banned the use of lead-core bullets for hunting. In Schleswig-Holstein, the use of lead bullets and shotgun slugs for hunting was banned first in State Forests in 2013 and then state-wide in 2015. In Baden-Württemberg, the use of lead bullets has been banned for hunting ungulates in the State Forests since 2014 and the rest of the region since 2016. In Saarland, the ban on lead-rifle ammunition was implemented in State Forests in 2011 and became state-wide since 2014, with a grace period granted to phase out their use by 2017. The Federal State of North Rhine-Westphalia is in the process of passing legislation to restrict the use of lead bullets and shotgun slugs in hunting, but there is already a ban on lead ammunition for rifles in State

Forests since 2013. Other German regions have also banned lead-rifle ammunition in State Forests since 2013 (Berlin, Brandenburg, Lower Saxony and Rhineland-Palatinate), 2014 (Mecklenburg-Vorpommem) and 2015 (Hesse) (Gremse and Rieger 2015).
In terms of the effect of the regulation on game meat safety, Martin et al. (2017) found that median concentrations of lead in red deer (*Cervus elaphus*) meat did not differ significantly between lead shot and non-lead shot animals, but the highest concentrations were found in edible parts of animals shot with lead ammunition.

- *Greece (EU member)* Without regulation of lead ammunition.
- *Hungary (EU member)* Lead shot was banned for hunting in Ramsar sites and other wetlands in 2005 (AEWA 2005).
- *Iceland (non-EU member)* Without regulation of lead ammunition.
- *Ireland (EU member)* Without regulation of lead ammunition.
- *Italy (EU member)* The use of lead shot was banned in wetlands under the category of Special Protection Areas (SPAs) and within 150 m from their shores in 2008, which covers about 45% of the overall wetland surface area. However, the possession of lead ammunition inside the SPA wetlands is still allowed, making enforcement of the ban problematic. The use of lead shot is still allowed in wetlands outside SPAs (AEWA 2015). The use of lead bullets has been banned for hunting in Stelvio National Park and Sondrio Province (ECHA 2018; VCF 2018).
- *Kosovo (non-EU member)* Without regulation of lead ammunition.
- *Latvia (EU member)* Lead shot was banned for waterfowl hunting at the Natural Park Lake Engure in 1998 and this was later extended to other nature reserves in 2004 (Beintema 2001; AEWA 2018).
- *Liechtenstein (non-EU member)* Without regulation of lead ammunition.
- *Lithuania (EU member)* Hunting is forbidden in most important wetlands of the country (ECHA 2018), but there is no specific regulation of lead ammunition.
- *Luxemburg (EU member)* The use of lead shot for hunting in wetlands and 30 m around them has been banned since 2011 (AEWA 2015).
- *North Macedonia (non-EU member)* Without regulation of lead ammunition.
- *Malta (EU member)* There are no wetlands where hunting is permitted (ECHA 2018), but there is no specific regulation of lead ammunition.
- *Moldova (non-EU member)* Waterfowl hunting was prohibited during 2014–2015 in the state protected areas, including Ramsar sites where most of the SPAs are located. Hunting of migratory birds was prohibited during 2015–2017. A lead shot ban for hunting in all wetlands of international importance was also implemented during 2014–2016 according to the Association Agreement between Moldova and the EU (AEWA 2015, 2018). Without specific regulation of lead ammunition.
- *Monaco (non-EU member)* Without regulation of lead ammunition, but hunting is banned in all the territory.
- *Montenegro (non-EU member)* Without regulation of lead ammunition.
- *Netherlands (EU member)* The use of lead shot was banned nation-wide in 1993, and possession has been illegal since 1998: enforcement is carried out by the police (Kuivenhoven et al. 1998; Beintema 2001; AEWA 2015). Together with Denmark, it is the only European country with a total ban on lead shot for game. The Netherlands also regulate clay target shooting with lead shot (Thomas and Guitart 2013).
- *Norway (non-EU member)* Lead shot was banned for waterfowl hunting in 1991 (Beintema 2001) and this was extended to all types of hunting in 2005, but in 2015 the Norwegian parliament voted to permit again the use of lead shot for hunting non-wetland species (Knutsen et al. 2015; Arnemo et al. 2016).
- *Poland (EU member)* Without regulation of lead ammunition.
- *Portugal (EU member)* Lead shot has been partially banned for hunting in wetlands since 2010 (AEWA 2018).
- *Romania (EU member)* Without regulation of lead ammunition.
- *Russia (non-EU member)* Without regulation of lead ammunition.
- *San Marino (non-EU member)* Without regulation of lead ammunition.
- *Serbia (non-EU member)* Without regulation of lead ammunition.
- *Slovakia (EU member)* Lead shot has been banned for hunting in wetlands since 2015 (AEWA 2015).
- *Slovenia (EU member)* Without regulation of lead ammunition.
- *Spain (EU member)* The use and possession of lead shot was banned in Ramsar sites and other protected wetlands in 2001, and this was extended in 2007 to all the Natura 2000 wetlands. Before that, the use of lead shot for hunting in wetlands was banned in the regions of the Balearic Islands in 1995 and Castilla-La Mancha in 1999 (Mateo 2009). The use of lead bullets has been banned in Maestrazgo mountains in the region of Valencia (VCF 2018).
The effect of the ban on lead shot was monitored in the Ebro Delta, where lead shot ingestion in waterbirds had

been studied before the ban (Mateo et al. 2014). After effective ban starting in the Ebro Delta in 2003, the examination of the gizzards of 937 waterbirds harvested by hunters between 2007 and 2012 revealed a decrease in the prevalence of lead shot ingestion in 4 out of the 9 species studied with respect to the prevalence observed before the ban in 1991–1996. In particular, lead shot ingestion in mallards decreased significantly from a pre-ban value of 30.2% to 15.5% in the post-ban period (Mateo et al. 2014). These results can be explained by the good compliance by hunters of the lead shot ban. Hunted birds with only embedded Pb shot declined from 26.9% in 2007–2008 to < 2% over the following three hunting seasons after ban reinforcement implemented by Environmental Officers by controlling the ammunition carried by hunters in the wetlands. It was also probably important to undertake random monitoring of shot game via X-ray and retrieval and identification of the ammunition used to kill it, the result of which would have consequences for obtaining hunting permits in subsequent years. The partial ban facilitates the focus of enforcement in these important wetlands, but also leaves out of the regulation some important feeding areas around natural wetlands (i.e. rice fields in the case of the Ebro Delta). Regarding other effects of this regulation, there was a benefit in the reduction of the lead concentrations in the meat of hunted waterfowl. Only 2.5% of mallard muscle tissue had Pb levels above European Union regulations for meat (0.1 µg/g wet weight) in the 2008–09 season, when the prevalence of lead shot ingestion was also lowest (5.1%) (Mateo et al. 2014). The hunting bag of waterfowl in the Ebro Delta was similar before and after the ban on lead shot (Mateo et al. 2013).

- *Sweden (EU member)* Lead shot was banned first in Sweden for waterfowl hunting within Ramsar sites, and for all geese and ducks in 1998. In 2002, the Swedish government introduced a ban on lead ammunition intended to be fully implemented in 2008 (for wetlands in 2002, for lead shot everywhere in 2006, and for bullets in 2008) (AEWA 2005), but only the ban on the use of lead shot for hunting in wetlands was implemented on the expected date (AEWA 2018). Clay target shooting with lead shot is regulated (Thomas and Guitart 2013).
- *Switzerland (non-EU member)* A ban on the use of lead shot in shallow water areas and other wetlands was introduced in 1998 (Beintema 2001). In 2012, lead shot use was banned for the hunting of waterfowl in general, and is enforced by cantonal authorities (AEWA 2018).
- *Turkey (non-EU member)* Without regulation of lead ammunition.
- *Ukraine (non-EU member)* There is no regulation of lead ammunition, but a draft law has been prepared for the banning of lead shot use when hunting in wetlands of international importance (i.e. Ramsar sites), and has been submitted to the Ukrainian Parliament (Verkhovna Rada) for adoption (AEWA 2018).
- *United Kingdom (EU member)* Different regulations have been adopted by the different regions. In 1999, England banned shooting with lead shot on or over any area below high-water mark of ordinary spring tides, specific Sites of Special Scientific Interest, for certain waterbird species. The same regulation was adopted by Wales in 2002. Scotland banned lead shot for shooting on or over wetland areas in 2005. In Northern Ireland, there was initially a voluntary ban, but a statutory ban similar to the Scottish model was implemented in 2009 (AEWA 2008, 2015; Stroud 2015).

  The compliance with the ban on lead shot for hunting over wetlands in England has been studied with hunted waterfowl purchased from game dealers between 2002 and 2014. Non-compliance, measured by the presence of embedded Pb shot in the purchased waterfowl during this period, varied between 68 and 77%, denoting low compliance with the ban (Cromie et al. 2015).

CONCLUSIONS

Current regulations on lead ammunition in Europe differ between countries. For EU countries this may be partially reversed by future regulations under REACH. However, the migratory flyways of many of the avian species affected by lead poisoning (primarily waterbirds and raptors) are continental in range. Figures 1 and 2 indicate that protection of birds against lead poisoning from lead shot is limited to a small part of Europe. For wetland species, the regulations are more widespread, but there is a particular lack of protection in several countries of Eastern Europe, where migrating birds of the Black Sea/Mediterranean flyway pass and stage. In the case of lead bullets, regulation is limited to some German Federal States and some specific sites in Italy and Spain, which gives only a partial protection to some large eagles and avian scavengers. Finally, the international agreements (i.e. AEWA and UNEP/CMS) and supranational authorities (i.e. REACH/ECHA) are moving countries to regulate lead ammunition in all forms and for all types of hunting, but the way this ban on lead ammunition is produced (i.e. partial or total) can be a determinant for the compliance and success of the ban. Moreover, in most of the countries the use of lead shot is

still allowed for hunting waterbirds in their feeding sites out of wetlands, which may not reduce the risk of exposure to spent shot. Recent experience in Europe has shown how important is to improve the knowledge about the compliance with bans on lead ammunition, especially in those countries where both non-lead and lead ammunition are available in the market. Compliance can be monitored by direct examination of killed animals to check the type of ammunition used, but it can be also performed by monitoring the reduction of the lead exposure in the vulnerable species. Regulation, by itself, does not secure the protection of birds from lead poisoning unless there is strict law enforcement and a continuous field monitoring to confirm that lead poisoning is no longer an issue.

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REFERENCES

AEWA. 2005. Third Session of the Meeting of the Parties to the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), 23–27 October 2005, Dakar, Senegal. www.unep-aewa.org. Accessed 23 Nov 2018.

AEWA. 2008. 8th Meeting of the Technical Committee, 3–5 March 2006, Bonn, Germany. www.unep-aewa.org. Accessed 23 Nov 2018.

AEWA. 2012. Resolution 5.231. AEWA's Contribution to Delivering the Aichi 2020 Biodiversity Targets. 5th Session of the Meeting of the Parties 14-18 May 2012, La Rochelle, France. http://www.unep-aewa.org/meetings/en/mop/mop5_docs/mop5_final_res.htm. Accessed 23 Nov 2018.

AEWA. 2015. Resolution 6.15. AEWA's Contribution to Delivering the Aichi 2020 Biodiversity Targets and Relevance of the Sustainable Development Goals. 6th Session of the Meeting of the Parties 9–14 November 2015, Bonn, Germany. http://www.unep-aewa.org/sites/default/files/document/aewa_mop6_res15_cntr_aichi_en_0.pdf. Accessed 23 Nov 2018.

AEWA. 2018. 7th Session of the Meeting of the Parties (MOP7). National Reports. https://www.unep-aewa.org/en/meeting/7th-session-meeting-parties-aewa. Accessed 23 Nov 2018.

Anderson, W.L., S.P. Havera, and R.A. Montgomery. 1987. Incidence of Ingested Shot in Waterfowl in the Mississippi Flyway, 1977–1979. *Wildlife Society Bulletin* 15: 181–188.

Arnemo, J.M., O. Andersen, S. Stokke, V.G. Thomas, O. Krone, D.J. Pain, and R. Mateo. 2016. Health and Environmental Risks from Lead-based Ammunition: Science Versus Socio-Politics. *EcoHealth* 13: 618–622.

Bassi, E., M. Ferloni, A. Gugiatti, L. Pedrotti, M. Di Giancamillo, and G. Grilli. 2014. Il rischio di saturnismo negli uccelli necrofagi in relazione alle attuali modalità di caccia degli ungulati. In *Atti XVI Convegno Italiano di Ornitologia. Cervia (RA), 22–25 settembre 2011,* eds. R. Tinarelli, A. Andreotti, N. Baccetti, L. Melega, F. Roscelli, L.Serra, and M. Zenatello, 335–336, Scritti, Studi e Ricerche di Storia Naturale della Repubblica di San Marino.

Beintema, N. 2001. *Lead Poisoning in Waterbirds. International Update Report 2000.* Wageningen, The Netherlands: Wetlands International.

Berny, P., L. Vilagines, J.M. Cugnasse, O. Mastain, J.Y. Chollet, G. Joncour, and M. Razin. 2015. VIGILANCE POISON: Illegal Poisoning and Lead Intoxication are the Main Factors Affecting Avian Scavenger Survival in the Pyrenees (France). *Ecotoxicology and Environmental Safety* 118: 71–82.

Carneiro, M.A., P.A. Oliveira, R. Brandão, O.N. Francisco, R. Velarde, S. Lavín, and B. Colaço. 2016. Lead Poisoning Due to Lead-Pellet Ingestion in Griffon Vultures (*Gyps fulvus*) from the Iberian Peninsula. *Journal of Avian Medicine and Surgery* 30: 274–279.

Clausen, B. 1992. Lead Poisoning Control Measures in Denmark. In *Lead Poisoning in Waterfowl*, ed. D.J. Pain, 68–70. Slimbridge, UK: International Waterfowl and Wetland Research Bureau.

Cromie, R., J. Newth, J. Reeves, M.O'Brien, K.Beckmann, and M. Brown. 2015. The Sociological and Political Aspects of Reducing Lead Poisoning from Ammunition in the UK: Why the Transition to Non-toxic Ammunition is so Difficult. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 104–124. Oxford, UK: Edward Grey Institute, The University of Oxford.

ECHA. 2017. Adopted Opinions on Restriction Proposals. Lead compounds – Shot. EC Number: 231-100-4; CAS Number: 7439-92-1. Restriction Report, Opinions of ECHA Committees and Consultation Responses. European Chemicals Agency. https://echa.europa.eu/previous-consultations-on-restriction-proposals/-/substance-rev/17005/term. Accessed 23 Nov 2018.

ECHA. 2018. The European Chemicals Agency (ECHA) Recommends that Measures are Needed to Regulate the Use of Lead Ammunition in Terrestrial Environments in Addition to Those Proposed for Wetlands. https://echa.europa.eu/-/echa-identifies-risks-to-terrestrial-environment-from-lead-ammunition. Accessed 23 Nov 2018.

European Scientists. 2018. An Open Letter from European Scientist on the Risks on Lead Ammunition. http://www.europeanscientists.eu/. Accessed 20 Feb 2019.

Gangoso, L., P. Alvarez-Lloret, A.A. Rodríguez-Navarro, R. Mateo, F. Hiraldo, and J.A. Donazar. 2009. Long-Term Effects of Lead Poisoning on Bone Mineralization in Vultures Exposed to Ammunition Sources. *Environmental Pollution* 157: 569–574.

Gremse, C., and S. Rieger. 2015. Lead from Hunting Ammunition in Wild Game Meat: Research Initiatives and Current Legislation in Germany and the EU. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health,* eds. R.J. Delahay, and C.J. Spray, 51–56. Oxford, UK: Edward Grey Institute, The University of Oxford.

Helander, B., J. Axelsson, H. Borg, K. Holm, and A. Bignert. 2009. Ingestion of Lead from Ammunition and Lead Concentrations in White-Tailed Sea Eagles (*Haliaeetus albicilla*) in Sweden. *Science of the Total Environment* 407: 5555–5563.

Isomursu, M., J. Koivusaari, T. Stjernberg, V. Hirvelä-Koski, and E.R. Venäläinen. 2018. Lead Poisoning and Other Human-Related Factors Cause Significant Mortality in White-Tailed Eagles. *Ambio* 47: 858–868. https://doi.org/10.1007/s13280-018-1052-9.

IUCN/WCC. 2016. International Union for the Conservation of Nature/World Conservation Congress 2016. Resolution 82. https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_082_EN.pdf. Accessed 20 Feb 2019.

Kanstrup, N. 2006. Non-toxic Shot-Danish Experiences. In *Waterbirds Around the World.* eds. C.G. Boere, C.A. Galbraith, and D.A. Stroud, 861. Edinburgh, UK: The Stationery Office.

Kanstrup, N. 2015. Practical and Social Barriers to Switching from Lead to Non-toxic Gunshot—A Perspective from the EU. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 98–102. Oxford, UK: Edward Grey Institute, The University of Oxford.

Kanstrup, N. 2019. Lessons Learned from 33 Years of Lead Shot Regulation in Denmark. In *Lead in Hunting Ammunition: Persistent Problems and Solutions,* eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. https://doi.org/10.1007/s13280-018-1125-9.

Kanstrup, N., and T.J.S. Balsby. 2018. Plastic Litter from Shotgun Ammunition on Danish Coastlines—Amounts and Provenance. *Environmental Pollution* 237: 601–610.

Kanstrup, N., and T.J.S. Balsby. 2019. Danish Pheasant and Mallard Hunters Comply with the Lead Shot Ban. In *Lead in Hunting Ammunition: Persistent Problems and Solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. https://doi.org/10.1007/s13280-019-01152-7.

Kanstrup, N., V.G. Thomas, O. Krone, and C. Gremse. 2016. The Transition to Non-lead Rifle Ammunition in Denmark: National Obligations and Policy Considerations. *Ambio* 45: 621–628. https://doi.org/10.1007/s13280-016-0780-y.

Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2019. Hunting with Lead Ammunition is Not Sustainable: European Perspectives. *Ambio* 47: 846–857. https://doi.org/10.1007/s13280-018-1042-y.

Kenntner, N., Y. Crettenand, H.-J. Fünfstück, M. Janovsky, and F. Tataruch. 2007. Lead Poisoning and Heavy Metal Exposure of Golden Eagles (*Aquila chrysaetos*) from the European Alps. *Journal of Ornithology* 148: 173–177.

Kitowski, I., D. Jakubas, D. Wiącek, and A. Sujak. 2017. Concentrations of Lead and Other Elements in the Liver of the White-Tailed Eagle (*Haliaeetus albicilla*), a European Flagship Species, Wintering in Eastern Poland. *Ambio* 46: 825–841. https://doi.org/10.1007/s13280-017-0929-3.

Knutsen, H.K., A.L. Brantsæter, J. Alexander, and H.M. Meltzer. 2015. Associations Between Consumption of Large Game Animals and Blood Lead Levels in Humans in Europe: The Norwegian Experience. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health,* eds. R.J. Delahay, and C.J. Spray, C.J., 44–50. Oxford, UK: Edward Grey Institute, The University of Oxford.

Krone, O., N. Kenntner, A. Trinogga, M. Nadjafzadeh, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, and R. Zieschank. 2009. Lead Poisoning in White-Tailed Sea Eagles: Causes and Approaches to Solutions in Germany. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G Hunt, 289–301. Boise, Idaho, USA: The Peregrine Fund.

Kuivenhoven, P., J. van Vessem, and E. van Maanen. 1998. Saturnisme des oiseaux d'eau. Rapport d'actualisation internationale 1997. *Bulletin Mensuel de l'Office National de la Chasse* 229: 28–31.

Martin, A., C. Gremse, T. Selhorst, N. Bandick, C. Müller-Graf, M. Greiner, and M. Lahrssen-Wiederholt. 2017. Hunting of Roe Deer and Wild Boar in Germany: Is Non-lead Ammunition Suitable for Hunting? *PLoS ONE* 12: e0185029.

Mateo, R. 2009. Lead Poisoning in Wild Birds in Europe and the Regulations Adopted by Different Countries. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G Hunt, 71–98. Boise, Idaho, USA: The Peregrine Fund.

Mateo, R., N. Vallverdú-Coll, A. López-Antia, M.A. Taggart, M. Martínez-Haro, R. Guitart, and M.E. Ortiz-Santaliestra. 2014. Reducing Pb Poisoning in Birds and Pb Exposure in Game Meat Consumers: The Dual Benefit of Effective Pb Shot Regulation. *Environment International* 63: 163–168.

Mateo, R., N. Vallverdú-Coll, and M.E. Ortiz-Santaliestra. 2013. Intoxicación por munición de plomo en aves silvestres en España y medidas para reducir el riesgo. *Ecosistemas* 22: 61–67.

Mateo-Tomás, P., P.P. Olea, M. Jiménez-Moreno, P.R. Camarero, I.S. Sánchez-Barbudo, R.C.R. Martín-Doimeadios, and R. Mateo. 2016. Mapping the Spatio-Temporal Risk of Lead Exposure in Apex Species for More Effective Mitigation. *Proceedings of the Royal Society B* 283: 20160662.

MoEW (Ministry of Environment and Water). 2007. Biological Diversity Act. State Gazette. No.94/2007. National Assembly. Sofia, Bulgaria.

Mondain-Monval, J.-Y., P. Defos du Rau, M. Guillemain, and A. Olivier. 2015. Switch to Non-Toxic Shot in the Camargue, France: Effect on Waterbird Contamination and Hunter Effectiveness. *European Journal of Wildlife Research* 61: 271–283.

Oltrogge, V. 2009. Success in Developing Lead-Free, Expanding-Nose Centerfire Bullets. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G Hunt, 310–315. Boise, Idaho, USA: The Peregrine Fund.

Pain, D.J., R.L. Cromie, and R.E. Green. 2015. Poisoning of Birds and Other Wildlife from Ammunition-Derived Lead in the UK. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health,* eds. R.J. Delahay, and C.J. Spray, 58–84. Oxford, UK: Edward Grey Institute, The University of Oxford.

Rodríguez-Ramos, J., V. Gutiérrez, U. Höfle, R. Mateo, L. Monsalve, E. Crespo, and J.M. Blanco. 2009. Lead in Griffon and Cinereous Vultures in Central Spain: Correlations between Clinical Signs and Blood Lead Levels. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G Hunt, 235–236. Boise, Idaho, USA: The Peregrine Fund.

Stroud, D.A. 2015. Regulation of Some Sources of Lead Poisoning: A Brief Review. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health,* eds. R.J. Delahay, and C.J. Spray, 8–26. Oxford, UK: Edward Grey Institute, The University of Oxford.

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

Thomas, V.G. 2015. Availability and Use of Lead-Free Shotgun and Rifle Cartridges in the UK, with Reference to Regulations in Other Jurisdictions. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and Minimizing the Risks to Human and Environmental Health,* eds. R.J. Delahay, and C.J. Spray, 85–97. Oxford, UK: Edward Grey Institute, The University of Oxford.

Thomas, V.G. 2016. Elemental Tungsten, Tungsten–Nickel Alloys and Shotgun Ammunition: Resolving Issues of Their Relative Toxicity. *European Journal of Wildlife Research* 62: 1–9.

Thomas, V.G. 2019. Chemical Compositional Standards for Non-lead Hunting Ammunition and Fishing Weights. In *Lead in Hunting Ammunition: Persistent Problems and Solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. https://doi.org/10.1007/s13280-018-1124-x.

Thomas, V.G., and R. Guitart. 2013. Transition to Non-toxic Gunshot Use in Olympic Shooting: Policy Implications for IOC and UNEP in Resolving an Environmental Problem. *Ambio* 42: 746–754. https://doi.org/10.1007/s13280-013-0393-7.

Thomas, V.G., N. Kanstrup, C. Gremse. 2015. Key Questions and Responses Regarding the Transition to Use of Lead-Free Ammunition. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health,* eds. R.J. Delahay, and C.J. Spray, 125–134. Oxford, UK: Edward Grey Institute, The University of Oxford.

UNEA. 2017. Third Meeting of the UN Environment Assembly (UNEA)—Resolution UNEP/EA.3/Res.4. https://papersmart.unon.org/resolution/uploads/k1800154.english.pdf. Accessed 20 Feb 2019.

UNEP/CMS 2014. UN Convention on Migratory Species (CMS) Resolution 11.15—Preventing Poisoning of Migratory Birds. https://www.cms.int/sites/default/files/document/cms_cop12_res.11.15%28rev.cop12%29_bird-poisoning_e.pdf. Accessed 20 Feb 2019.

VCF. 2018. Lead Ammunition Banned from Maestrazgo—Significant Breakthrough in Our Most Recent Bearded Vulture Reintroduction Project. Vulture Conservation Foundation. https://www.4vultures.org/lead-ammunition-banned-in-valencia. Accessed 20 Feb 2019.

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