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Essays and Perspectives

A review of lead contamination in South American birds: The need for more research and policy changes

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ABSTRACT

Lead contamination is a worldwide problem that affects the health of several bird species and can cause biodiversity loss. However, in South America there is little information about this problem and the species affected. The aim of this study is to compile existing knowledge about lead contamination in South American bird species and propose actions to mitigate this problem. Through a literature search, we found 39 scientific articles on this topic studying 68 bird species. Most studies came from Argentina and Brazil (71.7%), but also from Chile (7.7%), Venezuela (7.7%), Colombia (5.1%), Bolivia (2.6%), Ecuador (2.6%) and Peru (2.6%). Almost all the articles were published between 2001 and 2017. Waterbirds and birds of prey were the avian guilds more studied. Seventy percent of the studies show individuals with lead concentrations that exceed established thresholds levels. The few available articles suggest that lead contamination may be a continental-scale problem produced by different sources like fuels, mining, industries and hunting ammunition. However, lead ammunition seems to be an underestimated source of lead which is producing the highest toxic levels in bird species from South America. To our knowledge, there are regulations about different lead sources but not for lead ammunition in any country, except for some regions in Argentina. The progressive banning of lead from all sources and particularly from hunting ammunition is the main and most effective way to reduce the risk for wildlife. Current obstacles must be overcome through a combined effort of governments, wildlife managers and local communities.

Introduction

Lead contamination is a worldwide problem that affects a great variety of bird species and can potentially lead to death, population declines and biodiversity loss (Haig et al., 2014). In this sense, lead is one of the most toxic metals known affecting the health of different bird species (De Francisco et al., 2003; Haig et al., 2014). Millions of birds die annually as a consequence of lead poisoning around the world, reaching 3,000,000 deaths only in USA (De Francisco et al., 2003). Lead toxicity has been studied in several bird groups such as waterfowl, upland birds, raptors and scavengers, among others (Bellrose, 1959; Fisher et al., 2006; Kendall et al., 1996). Nowadays, it is affecting a great number of terrestrial and waterbirds worldwide (Ferreyra et al., 2014; Fisher et al., 2006; Mateo et al., 2007; Pain et al., 2009). Moreover, this toxic metal is considered one of the most important threats for several species of conservation concerns (Fisher et al., 2006; Pain et al., 2005; Rideout et al., 2012; Wiemeyer et al., 2017).

The primary exposure pathway to lead is ingestion (De Francisco et al., 2003; Haig et al., 2014; Pain et al., 2005, 2009). Once ingested, digestion enables the absorption of lead in the gut and then it enters to the blood stream and reaches different organs and tissues (De Francisco et al., 2003). The toxic impacts of lead range from subtle hematologic changes to serious and lethal pathologic alterations, according to the lead concentrations reached in different organs and tissues (De Francisco et al., 2003; Ferreyra et al., 2015; Haig et al., 2014). Low concentrations of lead produce harmful effects on bird's health like inhibition of enzymes that are important for

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metabolic functions (Espín et al., 2015). Yet as lead levels increase, it affects numerous systems (nervous, reproductive, immune, urinary and digestive) (Burger, 1995; Burger and Gochfeld, 1994; Haig et al., 2014; Kendall et al., 1996; Pain et al., 2009). This leads to clinical alterations like weakness, weight loss, diarrhoea, incoordination, anaemia, reproductive alterations, immune system dysfunctions, behaviour abnormalities, migratory movement variations, bone mineralization disruptions and even death (Álvarez-Lloret et al., 2014; Burger, 1995; De Francisco et al., 2003; Ecke et al., 2017; Kendall et al., 1996). Of note that lead toxicity and health impacts can vary at the individual and species levels due to differences in gastrointestinal physiology, environmental temperature, weather, diet composition (Kendall et al., 1996; Lindblom et al., 2017), and combination with other stressors like infection (Paskova et al., 2011).

Birds can be exposed to lead by different sources like fishing sinkers, paint, rubish and atmospheric pollution (De Francisco et al., 2003; Haig et al., 2014; Pain et al., 1995; Plaza and Lambertucci, 2017). However, at a global scale the current primary source of lead for birds is ingested lead shot or bullet fragments (Burger, 1995; Fisher et al., 2006; Mateo et al., 2016; Pain et al., 1995, 2009). Consequently, several countries in Europe, North America, Asia and Oceania have implemented policies to regulate this source (Avery and Watson, 2009). However, in many countries and some large regions of the world there are no policies to control this threat. This may be because lead toxicity is not a priority for government, but also because in some places there is little information about the ecosystem impacts that lead contamination produces. This seems to be the case for South America, and thus putting this problem in context for this region is timely and necessary. In this study, we review existing scientific knowledge about lead contamination in bird species from South America. We particularly focus on the location of the existing studies, presumed origin of the lead, type of sample used to diagnose lead contamination, type of laboratory methodologies, lead concentrations found in the different samples, and species studied. We then discuss the need to evaluate this problem at broader spatial and temporal scales, determining potential geographic areas where the risk of lead contamination is high and times of the year when the risk of lead contamination increases. Finally, we analyze needed actions conducive to mitigating this problem.

Material and methods

We compiled information available on lead contamination and poisoning in birds from South America until 15 March 2018 by searching in Google Scholar and Scopus. We used different combinations of relevant terms without restriction on the year of publication. First we performed two general searches with the following terms (1) “lead” OR “Pb” AND “birds” OR “Aves” AND “toxicity” OR “contamination” OR “poisoning” AND the name of each South American country and (2) “Bird lead poisoning” AND the name of each South American country. Then we performed additional searches with multiple combinations of the following terms (bird lead poisoning, bird lead exposure, bird lead contamination, bird trace metals concentrations, and bird heavy metal concentrations, coupled with each name of the South American country). We reviewed the returns of each search until we were sure the results were not related to the search criteria (every paper in Scopus; and up to a maximum of 350 returns of each search for every South American country in Google Scholar). We then checked all the selected articles that studied lead contamination or poisoning in birds in those countries to corroborate they were pertinent. Finally, we looked at the references of the articles we reviewed for additional reports not found in our searches. We excluded articles that did not inform lead concentrations, articles referred to poultry or pet birds and grey literature. From each paper we extracted information about geographic location, year of publication, presumed or confirmed lead sources, type of sample used to analyze lead concentrations, type of laboratory methodologies, concentration of lead reported, species studied, and season of the year when sampling occurred to evaluate associations with hunting. To compare lead concentrations found in the articles we reviewed, we converted all the results reported to mg/kg dry mass (1 μg/g = 1 ppm = 1 mg/kg). To convert wet mass into dry mass we used the following correction factors: 1 μg/g wet mass equals approximately to 4.6 μg/g dry mass for blood, 3.1 μg/g dry mass for liver, 4.3 μg/g dry mass for kidney, and 1.2 μg/g dry mass for bone (Franson and Pain, 2011).

Results

We found 39 scientific articles that mentioned lead contamination in wild birds from South America and reported lead concentrations. Almost seventy two percent were articles from Brazil (38.4%) and Argentina (33.3%); the rest were conducted in Chile (7.7%), Venezuela (7.7%), Colombia (5.1%), Bolivia (2.6%), Ecuador (2.6%) and Peru (2.6%). All the articles we found were published between 2001 and 2017 (Fig. 1). The different sources of lead suspected by the articles included ammunition (7 studies) and pollution generated by other human activities (32 studies) such as mining, fishing, motorboats, waste disposal, and chemical–petrochemical industries (Fig. 2). We did not find any study addressing the relationship between hunting seasons and lead levels in bird tissues.

To diagnose lead contamination, studies used different sample types, laboratory techniques and concentration units. Sample types included: liver (n = 20), kidney (n = 15), feathers (n = 14), bone (n = 7) and blood (n = 8). Some studies also included samples of muscle (n = 4), brain (n = 4), eggs (n = 1), gonads (n = 1), lung (n = n = 2), spleen (n = 1), heart (n = 1) and faeces (n = 1). The laboratory methodologies used to measure lead concentrations were highly variable, but studies mainly using atomic absorption spectrophotometer, graphite furnace atomic absorption spectrometry, and inductively coupled plasma optical spectrometry (Table S1). The concentrations of lead reported included multiple units ranging from individuals with undetectable levels to highly affected birds (Table S1) and almost three quarters of the studies we found (70.0%, 27/39) showed individuals with concentrations above known threshold levels, which are the minimum levels of lead where deleterious effects begin to appear (Espín et al., 2015) (Tables S1 and S2). Of the different bird species studied, some individuals of the Brazilian teal (*Amazonetta brasiliensis*), and the fulvous whistling-duck (*Dendrocygna bicolor*) showed the highest lead concentrations values, reaching concentrations above 380 mg/kg dm in bone (Ferreyra et al., 2014) (Fig. 3, Table S1). These highest reported lead levels were associated with lead ammunition from hunting.

Published studies included information on 68 bird species, one of which is Critically Endangered, two are classified as Endangered, seven are Near Threatened and six are Vulnerable (IUCN, 2018) (Table S1). From all the species that were evaluated for lead contamination in South America, 50% were waterbirds belonging to orders Anseriformes, Podicipediformes, Sphenisciformes, Procellariiformes, Suliformes, Pelecaniformes, and Charadriiformes, 29.5% were birds of prey belonging to orders Cathartiformes, Accipitriformes and Falconiformes, and the rest (20.5%) were different species belonging to the following orders Tinamiformes, Columbiformes, Apodiformes and Passeriformes (Table S1).

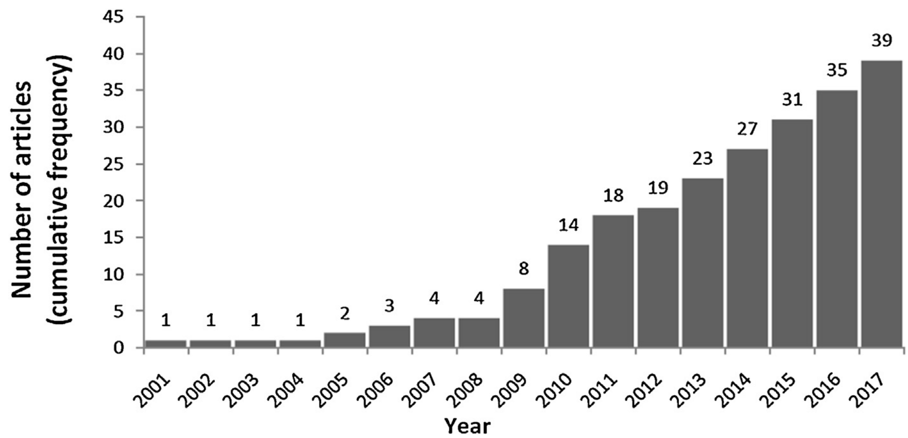

Figure 1. Cumulative number of articles published between the years 2001 and 2017. Note that most articles were published since 2008.

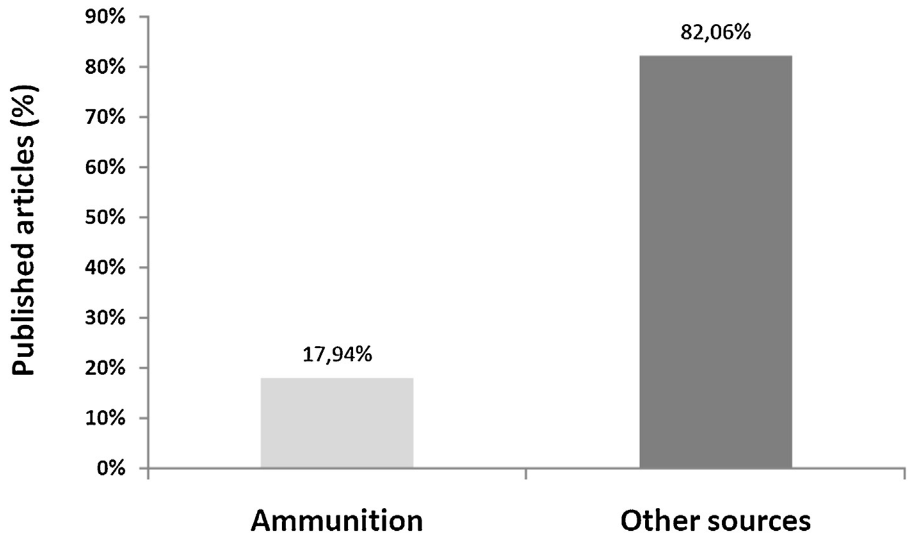

Figure 2. Percentage of articles reviewed according to presumed lead source.

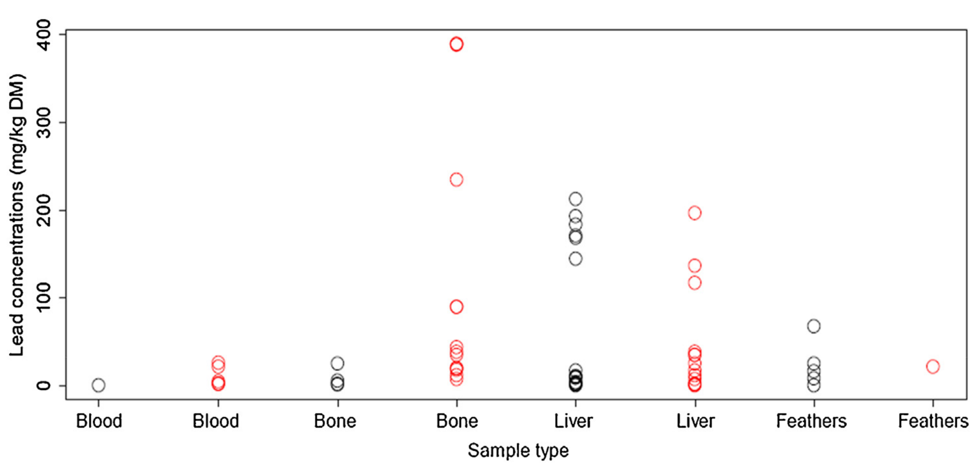

Figure 3. Maximum values of lead concentrations according to the lead source and the samples used to diagnoses lead contamination. Red circles: ammunition; black circles: other sources.

Discussion

Lead contamination in birds from South America

Compared with Europe and North America (Bellrose, 1959; Clark and Scheuhammer, 2003; Fisher et al., 2006; Mateo, 2009), the few publications about lead contamination in birds from South America show that this problem has been poorly studied, and that the efforts are relatively recent and mainly restricted to two countries, Brazil and Argentina. In the 39 studies we reviewed, the suspected source of lead most cited and yet seldom confirmed was pollution generated by mining, fuel or different industries. This is unexpected given that the current most important lead source affecting bird species around the world is ammunition (Fisher et al., 2006; Mateo-Tomás et al., 2016; Pain et al., 1995, 2009). This result could be biased due to researchers having mainly focused on those sources instead hunting. Lead contamination from hunting was mainly studied in bird species associated with wetlands and the Andes mountain range from Argentina (e.g., Ferreyra et al., 2014; Lambertucci et al., 2011; Wiemeyer et al., 2017). In the case of wetlands, the source of lead was spent lead shot ingested by waterfowl (Ferreyra et al., 2009). Similarly, in the Argentine Andes scavenger birds ingested bullet fragments from hunted animal carcasses (Lambertucci et al., 2010, 2011; Wiemeyer et al., 2017). Lead contamination from other sources was studied in mining areas of Bolivia (Garitano-Zavala et al., 2010), near industries in Venezuela and Brazil (Bravo et al., 2005; Martins et al., 2010), in polluted water bodies of Argentina (Cid et al., 2009), and marine coast of Argentina, Brazil, Chile and Ecuador (Celis et al., 2014; Gil et al., 2006; Jiménez-Uzcátegui et al., 2017; Vega et al., 2010). While there are more studies on lead contamination in Argentina and Brazil, it is reasonable to think that similar situations of lead contamination could be happening throughout the entire continent (Wiemeyer et al., 2017). Thus, this problem could be present yet undiagnosed-wise, affecting several bird species and therefore merits additional research.

Different samples types (e.g., blood, bone, feathers, liver, kidney, muscle, brain, gonads, eggs and faeces) were used to assess lead contamination. Some of them, like faeces, are not commonly used for lead contamination diagnosis, are not very useful as a proxy for bioaccumulation and the threshold levels for bird species are not well standardized (Espín et al., 2016). Moreover, there was great variability in units used to express lead concentrations and laboratory analytical methodologies. Therefore, there is a need to reduce the variability in the type of samples analyzed, the laboratory methodologies and the units used to measure lead to allow for a better characterization of the situation and enable comparisons at regional scales (Espín et al., 2016).

Species studied

In South America, the bird species where lead contamination has been studied are mainly waterbirds and birds of prey, particularly scavenging birds (Carvalho et al., 2013; Ferreira, 2010; Ferreyra et al., 2014; Lambertucci et al., 2011). Among species surveyed with some degree of threats, the Andean condor (*Vultur gryphus*), the black browed albatross (*Thalassarche melanophris*), the flightless cormorant (*Phalacrocorax harrisi*), the Galapagos penguin (*Spheniscus mendiculus*), the spectacled petrel (*Procellaria conspicillata*), the white-chinned petrel (*Procellaria aequinoctialis*), and the white-necked hawk (*Buteogallus lacernulatus*) showed lead levels exceeding established thresholds (Carvalho et al., 2013; Ferreira, 2009; Jiménez-Uzcátegui et al., 2017; Lambertucci et al., 2011; Seco Pon et al., 2011; Wiemeyer et al., 2017). However, in the case of pelagic species such as albatrosses, their broad feeding ranges make it difficult to know where they were exposed to lead (Seco Pon et al., 2011).

The species found with higher lead levels in South America (birds of prey and waterbirds) resemble to those reported in other regions of the world (Bellrose, 1959; Fisher et al., 2006; Friend et al., 2009). This may be because those species were specially targeted for lead toxicity studies, and therefore reflect an important sampling bias. However, it could also be due to these species' foraging habits, which could make them more susceptible to lead contamination and poisoning (Finkelstein et al., 2012). For instance, it is widely known that ducks ingest lead pellets by confusing them whit grit or seeds (Bellrose, 1959; Mateo et al., 2000). Thus, this foraging strategy can induce high levels of lead consumption and concentration in tissues, as was found in ducks from Argentina (Ferreyra et al., 2014). Similarly, scavengers commonly ingest ammunition fragments in carcasses of hunted animals (Hunt et al., 2006), and this is also the case in South America (Lambertucci et al., 2010; Wiemeyer et al., 2017). Undoubtedly, more research is needed to increase information on the species known to be more prone to poisoning, as well as on the origin of the lead causing toxicity. Moreover, a random sampling of species and areas will be needed across the continent to have a better representation of the problem.

Lead contamination at geographical and temporal scales

The effective mitigation of the risks posed by different contaminants requires knowing their sources and their distribution at spatial and temporal scales (Mateo-Tomás et al., 2016). Therefore, knowing where and when lead contamination is occurring in South America could aid mitigation efforts.

High risk areas

According to our review, some landscapes in South America seem to be more likely sources of environmental lead for bird species, mainly associated to different land uses. Places where industries are present (Bravo et al., 2005), sites where hunting with lead ammunition occurs (Romano et al., 2016; Rubio et al., 2014), polluted marine costal zones (Gil et al., 2006; Vega et al., 2010), places where motorboat sports are regularly practiced (Cid et al., 2009), and mining areas (Garitano-Zavala et al., 2010) can be considered geographical hotspots for lead contamination. Compiling information about potential areas with high probability of lead contamination and producing risk maps could be important to define priority areas for lead toxicity surveillance. Moreover, they could be used to design local policies and interventions to reduce this important threat for birds, other wildlife and humans that live in those areas (Mateo-Tomás et al., 2016; Pain et al., 2010).

High risk seasons

When the source of lead is ammunition, the risk of lead contamination for some bird species (e.g. birds of prey) may vary across the year, and the higher risk periods coincide with the hunting season. This relationship is clear in other parts of the world. For instance, lead blood concentrations in Turkey vultures (*Cathartes aura*) were positively correlated with an increase in wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*) hunting in California (Kelly and Johnson, 2011). The same relationship seems to occur in other bird species such as common ravens (*Corvus corax*) in Yellowstone National Park (Craighead et al., 2009), marsh harriers (*Circus aeruginosus*) in France (Pain et al., 1997), Steller's sea-eagle (*Haliaeetus pelagicus*) and the white-tailed eagle (*Haliaeetus albicilla*) in Japan (Saito et al., 2009), griffon vulture (*Gyps fulvus*) (Mateo-Tomás et al., 2016) and Egyptian vultures (*Neophron percnopterus*) in Spain (Gangoso et al., 2009). We did not find any study that evaluated lead contamination changes between seasons in South America. However, Ferreyra et al. (2009, 2014) found high levels of ingested pellets in ducks during the hunting season. In South America, wildlife hunting seasons are mostly concentrated from March to August. This is relevant for surveys that aim to establish times of the year with greater risks as well as for putting results into context. Moreover, this information can aid wildlife managers in focusing monitoring and mitigation efforts seasonally according to predicted risk.

Sources of lead in South America

Pollution as source of lead contamination in birds

That vast majority of the articles we reviewed show that pollution from fuel, mining activities and different types of industries are the main suspected sources of lead affecting bird species of South America. In the last years regulations to mitigate these sources of lead have been implemented globally (Stroud, 2014). Thus, it is reasonable to expect a reduction in the contamination they produce. However, while in the last 25–30 years environmental policies have increased, mining activities continue to be an important source of contamination and conflict in different countries of South America (Bebbington and Williams, 2008; Hilson, 2000; Urkidi, 2010). The same situation occurs with industries like petrochemicals and acid battery manufactures (UNEP, 2017 – Emerging issues). Therefore, despite current regulations, some of these sources of lead will likely continue to be an environmental problem. In this sense, they should be monitored across the entire continent, especially in sites where they are considered important economic resources.

Ammunition: An underestimated source of lead in South America

We found very few studies focusing on lead contamination from hunting ammunition (but see Ferreyra et al., 2014; Lambertucci et al., 2011; Wiemeyer et al., 2017) (Fig. 2). Notwithstanding, the few available studies linked to ammunition reported the highest lead concentration in birds. This situation contrasts with other parts of the world like North America and Europe where this association has been extensively examined (De Francisco et al., 2003; Haig et al., 2014; Mateo-Tomás et al., 2016; Pain et al., 2005, 2009). This surprising knowledge vacuum may have contributed to the invisibility of this important threat to biodiversity in South America.

Using the number of hunting licenses sold in the continent as a reference, game hunting is widely distributed in South America (Ojasti, 2000), except for Colombia where sport hunting is not allowed (Rey Angel, Dirección de Bosques, Biodiversidad y Servicios Ecosistémicos Colombia com. pers.), and Brazil where in the past was allowed in Rio Grande do Sul (Guadagnin et al., 2007), but not nowadays. For instance, in Argentina, one of the countries with highest sport hunting practices in South America (Ojasti, 2000); there are designated hunting sites for small and large game in the entire country (Novaro, 1995; Romano et al., 2016; Rubio et al., 2014; Saggese et al., 2009). Similarly, in Chile there are areas to practice small and big game hunting and although there is less information from other South American countries, sport hunting occurs in most of them (Ojasti, 2000).

Some species considered agricultural pests (e.g. hares and rabbits) can be hunted without permits or bag limits in some areas of Chile, Uruguay and Argentina (Mann, 1989; Ojasti, 2000; Pautasso, 2003; Walton, 1999). Moreover, illegal and subsistence hunting are widely distributed yet there is a lack of information on the number of animals hunted per area, per day, and how they manage the remains of the hunt that generally contain lead fragments (Chiarello, 2000; De la Montaña, 2013; Pautasso, 2003; Paviolo et al., 2009; Pérez Carusi et al., 2009). It is clear that lead from hunting causes significant environmental contamination (Romano et al., 2016; Rubio et al., 2014). Therefore, while studies exploring impacts of this source of lead were performed only in a few countries of South America, it is reasonable to think that lead contamination from hunting may be extended to the entire continent, producing unknown impacts on ecosystems and bird populations.

Regulations about the use of lead in paint and fuel exist worldwide, including South America as explained above (Arnemo et al., 2016; Fujiwara et al., 2011; Kessler, 2014; Mañay et al., 2008). However, there are few regulations limiting lead ammunition use worldwide (Avery and Watson, 2009) and South America is not an exception. This is unfortunate because lead pollution from ammunition is one of the few major environmental problems with a straightforward solution of recognized effectiveness (Anderson et al., 2000; Arnemo et al., 2016).

Banning lead ammunition and promoting its replacement with non-toxic substitutes is essential to decrease lead contamination (Anderson et al., 2000; Arnemo et al., 2016; Samuel and Bowers, 2000; Thomas and Guitart, 2010). There is, however, great resistance to eliminate lead ammunition from hunters around the world, who argue that the availability, price and performance of substitutes are sub-optimum (Kanstrup et al., 2016; Shedden, 1992; Thomas, 2013). It is true that equally effective non-lead options do not yet exist for all types of firearms used in hunting, and that they are currently not manufactured or sold everywhere in the world (Epps, 2014). Nonetheless, these limitations could be solved with policies that generate demand for non-toxic alternatives (Thomas, 2013), as happened in Denmark when lead ammunition was banned (Kanstrup et al., 2016). Regarding the effectiveness of non-toxic substitutes, even the most uncompromising hunting groups have accepted the evidence that substitutes have comparable prices and accuracy to lead ammunition (Arnemo et al., 2016; Epps, 2014; Thomas, 2013; Thomas and Guitart, 2010).

A clear advantage in South America over other areas in the world is that the lack of bans on lead ammunition seems to stem more from lack of information or awareness, than from hunter lobbying and resistance. Where scientific evidence has been made available and technical and social pressure for policies voiced, changes have occurred as it happen in other parts of the world (Kanstrup et al., 2018). For instance, over the past few years some provinces in Argentina have taken pioneer actions to regulate lead ammunition use. In particular, Santa Fe and Cordoba provinces currently prohibit the use of lead ammunition in wetlands (Resolutions 123-2016 and 57-2017 for Santa Fe; Resolution N° 1115-2011 for Córdoba). Furthermore, South American countries which adhere to the Convention of Migratory Species (Argentina, Chile, Brazil, Uruguay, Paraguay, Bolivia, Ecuador and Peru) endorsed resolution PNUMA/CEM N° 11.15 in 2014, which exhorts countries to progressively reduce and eliminate the use of lead ammunition over three years. While this commitment is non-binding, it shows some degree of awareness of the myriad of problems associated to lead ammunition for birds by South American nations. Undoubtedly these types of actions should be imitated by all South American countries to reduce the ecosystem impacts of lead.

Final remarks and conclusion

Despite the fact that information on lead contamination in South American birds has grown in the last years, it is still modest and restricted to some countries and areas. Nonetheless, the articles we found suggest that lead contamination is likely an important, yet poorly documented, threat to the health and survival of several bird groups across the continent. Moreover, it is advisable to unify some aspects in the future research like for instance the type of samples used to diagnoses lead contamination and the units reported. Feathers and blood could be used for live birds and liver, bone and feathers for dead ones. Currently there is evidence of high lead contamination in some waterbirds and birds of prey from South America, including several threatened species. While a number of sources of lead, such as industrial pollution, fuels and mining were identified affecting species above accepted threshold levels (e.g. *Spheniscus mendiculus*), lead from ammunition may remain being an underestimated and non-regulated source associated with high tissue levels in birds from this continent.

According to a previous review (Avery and Watson, 2009) and to our current knowledge, there are no regulations on the use of lead ammunition in South America, with the exception of some provinces in Argentina. Therefore, it is reasonable to expect that lead contamination will continue increasing in the coming years should hunting (sports and subsistence) remain at current levels or increase, especially because of bioaccumulation and lack of biodegradation of this toxic metal (Romano et al., 2016).

Policy changes that aim to mitigate lead contamination and, over time, eliminate anthropogenic lead sources of environmental pollution, are paramount and timely in South America. Even if gaps in scientific knowledge exist, there is enough evidence to support applying the precautionary principle and moving forward now. Notwithstanding, independently-replicated research that both shows the extent of the problem and monitors the evolution of any lead reduction programme will strengthen such actions (Thomas, 2009). Fluent communication between scientists and wildlife managers on such matters will be essential for positive conservation outcomes. We believe that it is time to stop with this important threat to biodiversity.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.pecon.2018.08.001.

References

Álvarez-Lloret, P., Rodríguez-Navarro, A.B., Romanek, C.S., Ferrandis, P., Martínez-Haro, M., Mateo, R., 2014. Effects of lead shot ingestion on bone mineralization in a population of red-legged partridge (*Alectoris rufa*). Sci. Total Environ. 466, 34–39.
Anderson, W.L., Havera, S.P., Zercher, B.W., 2000. Ingestion of lead and nontoxic shotgun pellets by ducks in the Mississippi flyway. J. Wildl. Manag. 64, 848–857.
Arnemo, J.M., Andersen, O., Stokke, S., Thomas, V.G., Krone, O., Pain, D.J., Mateo, R., 2016. Health and environmental risks from lead-based ammunition: science versus socio-politics. Ecohealth 13, 618–622.
Avery, D., Watson, R.T., 2009. Regulation of lead-based ammunition around the world. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 161–168.
Bebbington, A., Williams, M., 2008. Water and mining conflicts in Peru. Mt. Res. Dev. 28, 190–195.
Bellrose, F.C., 1959. Lead poisoning as a mortality factor in waterfowl populations. Ill. Nat. Hist. Surv. Bull. 27, 235–238.
Bravo, A., Colina, M., Azuero, S., Salas, R., 2005. Heavy metal levels in plasma and fecal material samples of the black vulture (*Coragyps atratus*). Rev. Cient. 15, 315–319.
Burger, J., 1995. A risk assessment for lead in birds. J. Toxicol. Environ. Health Part Curr. Issues 45, 369–396.
Burger, J., Gochfeld, M., 1994. Behavioral impairments of lead-injected young herring gulls in nature. Toxicol. Sci. 23, 553–561.
Carvalho, P.C., Bugoni, L., Mc Gill, R.A., Bianchini, A., 2013. Metal and selenium concentrations in blood and feathers of petrels of the genus *Procellaria*. Environ. Toxicol. Chem. 32, 1641–1648.
Celis, J.E., Espejo, W., González-Acuña, D., Jara, S., Barra, R., 2014. Assessment of trace metals and porphyrins in excreta of Humboldt penguins (*Spheniscus humboldti*) in different locations of the Northern coast of Chile. Environ. Monit. Assess. 186, 1815–1824.
Chiarello, A.G., 2000. The influence of illegal hunting on mammals and birds in Tabuleiro forest in Espírito Santo state, Brazil. Bol. Mus. Biol. Mello Leitão 11, 229–247.
Cid, F.D., Gatica-Sosa, C., Antón, R.I., Caviedes-Vidal, E., 2009. Contamination of heavy metals in birds from Embalse La Florida (San Luis, Argentina). J. Environ. Monit. 11, 2044–2051.
Clark, A.J., Scheuhammer, A.M., 2003. Lead poisoning in upland-foraging birds of prey in Canada. Ecotoxicology 12, 23–30.
Craighead, D., Bedrosian, B., Watson, R.T., Fuller, M., Pokras, M., Hunt, W., 2009. A relationship between blood lead levels of common ravens and the hunting season in the southern Yellowstone ecosystem. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, Idaho, pp. 202–205.
De Francisco, N., Ruiz Troya, J.D., Agüera, E.I., 2003. Lead and lead toxicity in domestic and free living birds. Avian Pathol. 32, 3–13.
De la Montaña, E., 2013. Cacería de subsistencia de distintos grupos indígenas de la Amazonía Ecuatoriana. Rev. Ecosist. 22, 84–96.
Ecke, F., Singh, N.J., Arnemo, J.M., Bignert, A., Helander, B., Berglund, M.M., Borg, H., Brojer, C., Holm, K., Lanzone, M., et al., 2017. Sub-lethal lead exposure alters movement behavior in free-ranging golden eagles. Environ. Sci. Technol. 51, 5729–5736.
Emerging Issues of Environmental and Concern, 2017. UNEP Frontiers, https://www.unenvironment.org/resources/frontiers-2017-emerging-issues-environmental-concern/ (accessed 15 March 2018).
Epps, C.W., 2014. Considering the switch: challenges of transitioning to non-lead hunting ammunition. The Condor 116, 429–434.
Espín, S., García-Fernández, A.J., Herzke, D., Shore, R.F., Van Hattum, B., Martínez-López, E., Coeurdassier, M., Eulaers, I., Fritsch, C., Gómez-Ramírez, P., et al., 2016. Tracking pan-continental trends in environmental contamination using sentinel raptors—what types of samples should we use? Ecotoxicology 25, 777–801.
Espín, S., Martínez-López, E., Jiménez, P., María-Mojica, P., García-Fernández, A.J., 2015. Delta-aminolevulinic acid dehydratase (δALAD) activity in four free-living bird species exposed to different levels of lead under natural conditions. Environ. Res. 137, 185–198.
Ferreira, A.P., 2010. Trace metals analysis in brown booby (*Sula leucogaster*) collected from Ilha Grande Bay, Rio de Janeiro, Brazil. Rev. Uniandrade 11, 41–54.
Ferreira, A.P., 2009. Avaliação das concentrações de metais pesados no sedimento, água e em *Leucopternis lacernulata* (gavião-pomba). Estudo de caso: Baía de Sepetiba, Rio de Janeiro. Gaia Sci. 3, 23–31.
Ferreyra, H., Beldomenico, P.M., Marchese, K., Romano, M., Caselli, A., Correa, A.I., Uhart, M., 2015. Lead exposure affects health indices in free-ranging ducks in Argentina. Ecotoxicology 24, 735–745.
Ferreyra, H., Romano, M., Beldomenico, P., Caselli, A., Correa, A., Uhart, M., 2014. Lead gunshot pellet ingestion and tissue lead levels in wild ducks from Argentine hunting hotspots. Ecotoxicol. Environ. Saf. 103, 74–81.
Ferreyra, H., Romano, M., Uhart, M., 2009. Recent and chronic exposure of wild ducks to lead in human-modified wetlands in Santa Fe Province, Argentina. J. Wildl. Dis. 45, 823–827.
Finkelstein, M.E., Doak, D.F., George, D., Burnett, J., Brandt, J., Church, M., Grantham, J., Smith, D.R., 2012. Lead poisoning and the deceptive recovery of the critically endangered California condor. Proc. Natl. Acad. Sci. U. S. A. 109, 11449–11454.
Fisher, I.J., Pain, D.J., Thomas, V.G., 2006. A review of lead poisoning from ammunition sources in terrestrial birds. Biol. Conserv. 131, 421–432.
Franson, J.C., Pain, D.J., 2011. Lead in birds. In: Beyer, W.N., Meador, J.P. (Eds.), Environmental Contaminants in Biota: Interpreting Tissue Concentrations. , 2nd ed. CRC Press, Boca Raton, FL, pp. 563–593.
Friend, M., Franson, J.C., Anderson, W.J., 2009. Biological and societal dimensions of lead poisoning in birds in the USA. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 34–60.
Fujiwara, F.G., Gómez, D.R., Dawidowski, L., Perelman, P., Faggi, A., 2011. Metals associated with airborne particulate matter in road dust and tree bark collected in a megacity (Buenos Aires, Argentina). Ecol. Indic. 11, 240–247.
Gangoso, L., Alvarez-Lloret, P., Rodríguez-Navarro, A.A., Mateo, R., Hiraldo, F., Donazar, J.A., 2009. Long-term effects of lead poisoning on bone mineralization in vultures exposed to ammunition sources. Environ. Pollut. 157, 569–574.
Garitano-Zavala, Á., Cotín, J., Borràs, M., Nadal, J., 2010. Trace metal concentrations in tissues of two tinamou species in mining areas of Bolivia and their potential as environmental sentinels. Environ. Monit. Assess. 168, 629–644.
Gil, M.N., Torres, A., Harvey, M., Esteves, J.L., 2006. Metales pesados en organismos marinos de la zona costera de la Patagonia Argentina continental. Rev. Biol. Mar. Oceanogr. 41, 167–176.
Guadagnin, D.L., Perello, L.F.C., Menegheti, J.O., 2007. Current situation of leisure hunting and wetland management in Rio Grande Do Sul State, South Brazil. Neotropical Biol. Conserv. 2, 63–70.
Haig, S.M., D'Elia, J., Eagles-Smith, C., Fair, J.M., Gervais, J., Herring, G., Rivers, J.W., Schulz, J.H., 2014. The persistent problem of lead poisoning in birds from ammunition and fishing tackle. The Condor 116, 408–428.
Hilson, G., 2000. Barriers to implementing cleaner technologies and cleaner production (CP) practices in the mining industry: a case study of the Americas. Miner. Eng. 13, 699–771.
Hunt, W.G., Burnham, W., Parish, C.N., Burnham, K.K., Mutch, B., Oaks, J.L., 2006. Bullet fragments in deer remains: implications for lead exposure in avian scavengers. Wildl. Soc. Bull. 34, 167–170.
IUCN, 2018. Red List of Threatened Species Version 2017-3. www.iucnredlist.org (accessed 15.03.18).

Jiménez-Uzcátegui, G., Vinueza, R.L., Urbina, A.S., Egas, D.A., García, C., 2017. Lead and cadmium levels in Galapagos penguin *Spheniscus mendiculus*, flightless cormorant *Phalacrocorax harrisi*, and waved albatross *Phoebastria irrorata*. Mar. Ornithol. 45, 159–163.
Kanstrup, N., Swift, J., Stroud, D.A., Lewis, M., 2018. Hunting with lead ammunition is not sustainable: European perspectives. Ambio, http://dx.doi.org/10.1007/s13280-018-1042-y.
Kanstrup, N., Thomas, V.G., Krone, O., Gremse, C., 2016. The transition to non-lead rifle ammunition in Denmark: national obligations and policy considerations. Ambio 45, 621–628.
Kelly, T.R., Johnson, C.K., 2011. Lead exposure in free-flying Turkey vultures is associated with big game hunting in California. PLoS ONE 6, e15350.
Kendall, R.J., Lacker, T.E., Bunck, C., Daniel, B., Driver, C., Grue, C.E., Leighton, F., Stansley, W., Watanabe, P.G., Whitworth, M., 1996. An ecological risk assessment of lead shot exposure in non-waterfowl avian species: upland game birds and raptors. Environ. Toxicol. Chem. 15, 4–20.
Kessler, R., 2014. Lead-based decorative paints: where are they still sold—and why? Environ. Health Perspect. 122, 96–103.
Lambertucci, S.A., Donázar, J.A., Hiraldo, F., 2010. Poisoning wildlife and people with lead: time to stop. Environ. Sci. Technol. 44, 7759–7760.
Lambertucci, S.A., Donázar, J.A., Huertas, A.D., Jiménez, B., Sáez, M., Sanchez-Zapata, J.A., Hiraldo, F., 2011. Widening the problem of lead poisoning to a South-American top scavenger: lead concentrations in feathers of wild Andean condors. Biol. Conserv. 144, 1464–1471.
Lindblom, R.A., Reichart, L.M., Mandernack, B.A., Solensky, M., Schoenebeck, C.W., Redig, P.T., 2017. Influence of snowfall on blood lead levels of free-flying bald eagles (*Haliaeetus leucocephalus*) in the upper Mississippi River Valley. J. Wildl. Dis. 53, 816–823.
Mann, A., 1989. Conservación de la fauna en Chile: Actualidad y proyección futura. Av. en Cienc. Vet. 4. Revistas Universidad de Chile.
Mañay, N., Cousillas, A.Z., Alvarez, C., Heller, T., 2008. Lead contamination in Uruguay: the "La Teja" neighborhood case. Rev. Environ. Contam. Toxicol. 195, 93–115.
Martins, N.R.S., Marques, M.V.R., Dar, V., Resende, J.S., Carvalhaes, A.G., Andrade, E.A.G., Barrios, P.R., 2010. Lead poisoning mortality in wild Passeriformes and its detection in free-range chicken eggs in Southern Minas Gerais, Brazil. Rev. Bras. Ciênc. Avícola 12, 149–152.
Mateo, R., 2009. Lead poisoning in wild birds in Europe and the regulations adopted by different countries. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 71–98.
Mateo, R., Green, A.J., Lefranc, H., Baos, R., Figuerola, J., 2007. Lead poisoning in wild birds from southern Spain: a comparative study of wetland areas and species affected, and trends over time. Ecotoxicol. Environ. Saf. 66, 119–126.
Mateo, R., Guitart, R., Green, A.J., 2000. Determinants of lead shot, rice, and grit ingestion in ducks and coots. J. Wildl. Manag. 64, 939–947.
Mateo, R., Petkov, N., Lopez-Antia, A., Rodríguez-Estival, J., Green, A.J., 2016. Risk assessment of lead poisoning and pesticide exposure in the declining population of red-breasted goose (*Branta ruficollis*) wintering in Eastern Europe. Environ. Res. 151, 359–367.
Mateo-Tomás, P., Olea, P.P., Jiménez-Moreno, M., Camarero, P.R., Sánchez-Barbudo, I.S., Martín-Doimeadios, R.C.R., Mateo, R., 2016. Mapping the spatio-temporal risk of lead exposure in apex species for more effective mitigation. Proc. R. Soc. B, http://dx.doi.org/10.1098/rspb.2016.0662.
Novaro, A.J., 1995. Sustainability of harvest of culpeo foxes in Patagonia. Oryx 29, 18–22.
Ojasti, J., 2000. Manejo de fauna silvestre neotropical. In: Dallmeier (Ed.), Monitoring and Assessment of Biodiversity (MAB) Series No. 5. Smithsonian Institution/MAB Program, Washington, DC, pp. 31–104.
Pain, D.J., Bavoux, C., Burneleau, G., 1997. Seasonal blood lead concentrations in marsh harriers *Circus aeruginosus* from Charente-Maritime, France: relationship with the hunting season. Biol. Conserv. 81, 1–7.
Pain, D.J., Cromie, R.L., Newth, J., Brown, M.J., Crutcher, E., Hardman, P., Hurst, L., Mateo, R., Meharg, A.A., Moran, A.C., et al., 2010. Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. PLoS ONE 5, e10315.
Pain, D.J., Fisher, I.J., Thomas, V.G., 2009. A global update of lead poisoning in terrestrial birds from ammunition sources. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 99–118.
Pain, D.J., Meharg, A.A., Ferrer, M., Taggart, M., Penteriani, V., 2005. Lead concentrations in bones and feathers of the globally threatened Spanish imperial eagle. Biol. Conserv. 121, 603–610.
Pain, D.J., Sears, J., Newton, I., 1995. Lead concentrations in birds of prey in Britain. Environ. Pollut. 87, 173–180.
Paskova, V., Paskerova, H., Pikula, J., Bandouchova, H., Sedlackova, J., Hilscherova, K., 2011. Combined exposure of Japanese quails to cyanotoxins, Newcastle virus and lead: oxidative stress responses. Ecotoxicol. Environ. Saf. 74, 2082–2090.
Pautasso, A.A., 2003. Aprovechamiento de la fauna silvestre por pobladores rurales en la fracción norte de los bajos sub meridionales de la Provincia de Santa Fe, Argentina (incluye aspectos relacionados a la producción y la conservación en este ambiente). Comun. Mus. Prov. Cienc. Nat. Florentino Ameghino 8, 1–62.
Paviolo, A., De Angelo, C., Di Blanco, Y., Agostini, I., Pizzio, E., Melzew, R., Ferrari, C., Palacio, L., Di Bitetti, M.S., Carpinetti, B., et al., 2009. Efecto de la caza y el nivel de protección en la abundancia de los grandes mamíferos del Bosque Atlántico de Misiones. Contrib. Para Conserv. Manejo En El Parq. Nac. Iguazú, 237–254.
Pérez Carusi, L.C., Beade, M.S., Miñarro, F., Vila, A.R., Giménez-Dixon, M., Bilenca, D.N., 2009. Relaciones espaciales y numéricas entre venados de las pampas (*Ozotoceros bezoarticus celer*) y chanchos cimarrones (*Sus scrofa*) en el refugio de vida silvestre Bahía Samborombón, Argentina. Ecol. Austral. 19, 63–71.
Plaza, P.I., Lambertucci, S.A., 2017. How are garbage dumps impacting vertebrate demography, health, and conservation? Glob. Ecol. Conserv. 12, 9–20.
Rideout, B.A., Stalis, I., Papendick, R., Pessier, A., Puschner, B., Finkelstein, M.E., Smith, D.R., Johnson, M., Mace, M., Stroud, R., et al., 2012. Patterns of mortality in free-ranging California condors (*Gymnogyps californianus*). J. Wildl. Dis. 48, 95–112.
Romano, M., Ferreyra, H., Ferreyroa, G., Molina, F.V., Caselli, A., Barberis, I., Beldoménico, P., Uhart, M., 2016. Lead pollution from waterfowl hunting in wetlands and rice fields in Argentina. Sci. Total Environ. 545, 104–113.
Rubio, M., Germanier, A., Mera, M.F., Faudone, S.N., Sbarato, R.D., Campos, J.M., Zampar, V., Bonzi, E., Perez, C.A., 2014. Study of lead levels in soils by weathering of metallic Pb bullets used in dove hunting in Córdoba, Argentina. X-Ray Spectrom. 43, 186–192.
Saggese, M.D., Quaglia, A., Lambertucci, S.A., Bo, M.S., Sarasola, J.H., Pereyra-Lobos, R., Maceda, J.J., 2009. Survey of lead toxicosis in free-ranging raptors from central Argentina. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 223–231.
Saito, K., Watson, R.T., Fuller, M., Pokras, M., Hunt, W., 2009. Lead poisoning of Steller's sea-eagle (*Haliaeetus pelagicus*) and white-tailed eagle (*Haliaeetus albicilla*) caused by the ingestion of lead bullets and slugs. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 302–309.
Samuel, M.D., Bowers, E.F., 2000. Lead exposure in American black ducks after implementation of non-toxic shot. J. Wildl. Manag. 64, 947–953.
Seco Pon, J.P.S., Beltrame, O., Marcovecchio, J., Favero, M., Gandini, P., 2011. Trace metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) in feathers of black-browed albatross *Thalassarche melanophrys* attending the Patagonian Shelf. Mar. Environ. Res. 72, 40–45.
Shedden, C.B., 1992. The British hunter's perspective on lead and steel shot. Int. Waterfowl Wetl. Res. Bur. Publ. 16, 81–85.
Stroud, D.A., 2014. Regulation of some sources of lead poisoning: a brief review. In: Oxford Lead Symposium, pp. 8–25.
Thomas, V.G., 2013. Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. Ambio 42, 737–745.
Thomas, V.G., 2009. The policy and legislative dimensions of nontoxic shot and bullet use in North America. In: Watson, R.T., Fuller, M., Pokras, M., Hunt, W.G. (Eds.), Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, ID, pp. 351–362.
Thomas, V.G., Guitart, R., 2010. Limitations of European Union policy and law for regulating use of lead shot and sinkers: comparisons with North American regulation. Environ. Policy Gov. 20, 57–72.
Urkidi, L., 2010. A global environmental movement against gold mining: Pascua–Lama in Chile. Ecol. Econ. 70, 219–227.
Vega, C.M., Siciliano, S., Barrocas, P.R., Hacon, S.S., Campos, R.C., Do Couto Jacob, S., Ott, P.H., 2010. Levels of cadmium, mercury, and lead in Magellanic penguins (*Spheniscus magellanicus*) stranded on the Brazilian Coast. Arch. Environ. Contam. Toxicol. 58, 460–468.
Walton, O., 1999. Marco legal relativo a la conservación y uso sustentable de aves, mamíferos y reptiles marinos en Chile. Estud Ocean. 18, 5–12.
Wiemeyer, G.M., Pérez, M.A., Bianchini, L.T., Sampietro, L., Bravo, G.F., Jácome, N.L., Astore, V., Lambertucci, S.A., 2017. Repeated conservation threats across the Americas: high levels of blood and bone lead in the Andean condor widen the problem to a continental scale. Environ. Pollut. 220, 672–679.