Widening the problem of lead poisoning to a South-American top scavenger: Lead concentrations in feathers of wild Andean condors

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a b s t r a c t

Lead poisoning is not a new threat for wild birds, but it is now playing an important role in shaping raptor populations. Studies have been focused mainly on Europe, North-America, and Japan, but little is known about the situation in South-America. Lead is a serious threat for wildlife, especially for long-lived species. Nevertheless, no information is available for wild Andean condor (Vultur gryphus) populations. This species, which lives throughout the Andes Mountains, is endangered mainly in the north though it is having problems throughout its distribution. We evaluated lead exposure in the Andean condor by a non-destructive method using feathers. We determined lead concentration from 152 feathers, collected in 15 communal roosts distributed throughout almost all condor's range in Patagonia (ca. 1500 km north–south). We also looked for the origin of this lead through the analysis of lead isotope composition of feathers and ammunition. We present here the first reference data on lead concentration for a raptor population from Argentina. Lead concentrations were generally low, however, some individuals had concentrations several times above the overall mean (up to 21 1g/g). Our results suggest that lead might come from a mix of two types of ammunition sources, one used for big game and another for hare hunting. Andean condors are at the top of the food chain, thus all the other medium-to-large sized scavengers and predators from this area can be also exposed to this threat. We highlight the need to change hunting policies in Argentina, and in other South-American countries, including the banning of lead ammunitions to protect carnivores consuming hunted animals.

1. Introduction

Lead poisoning in wild species as well as in humans is not a new problem (Demayo et al., 1982; Watson et al., 2009; Lambertucci et al., 2010). There are different sources of lead in the environment, but hunting is currently an important source of this metal for birds. Poisoning by ingestion of lead objects is common in wild birds, being waterfowl and raptors the most affected groups (Fisher et al., 2006; Guillemain et al., 2007; Friend et al., 2009). Raptors can face severe conservation problems due to lead ingestion since lead bullets can be both ingested from carcasses of hunted individuals, as well as from live individuals which did not die after receiving a shot (Fisher et al., 2006; Pain et al., 2009). These bullets may be regurgitated, retained for some time and/or dissolved in raptors stomachs. The retention time of lead, along with other factors related to the exposed species, determines the degree of poisoning (Pattee and Pain, 2003; Fisher et al., 2006; Pain et al., 2010).

Almost all the studies of lead exposure in raptors come from Europe, North-America and Japan (see reviews in Fisher et al., 2006; Pain et al., 2009). Several raptors species from those parts of the world have been found with medium-to-high levels of lead (e.g., Pain et al., 1995, 2005; Mateo et al., 1997, 2003; Donázar et al., 2002; Gangoso et al., 2009). In particular, scavengers that feed near cities or in hunting areas could be highly exposed to lead concentrations. Among vultures, there are records of lead poisoning for the four species living in Europe (Mateo, 2009). In North-America the main conservation threat to the critically endangered California condor (Gymnogyps californianus) is lead (Wiemeyer

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et al., 1988; Finkelstein et al., 2010). Indeed, several birds have been found dead with high levels of this metal. Reintroduced condors are routinely recaptured and tested for the concentration of lead in the blood, and birds which have more than 40 lg/dl lead concentration in blood are maintained in captivity for treatment to reduce these concentrations (Hall et al., 2007). In this species, the most common origin of lead are shots found in hunted animals (Church et al., 2006; Hunt et al., 2006; Finkelstein et al., 2010).

In South-America studies on lead concentration in raptors are lacking (Saggese et al., 2009). However, in areas where hunting occurs (e.g., deer or hare hunting), the risk of consuming traces of lead from carcases is high (Church et al., 2006). Trophy, commercial, illegal and subsistence hunting have increased in the last decades in Argentine and other regions of South-America (Saggese et al., 2009). Apart from foreign hunters, there are an unknown number of local sports hunters and poachers pursuing prey for commercial reasons or subsistence (Saggese et al., 2009; Lambertucci et al., 2010). Thus, lead may be a potential problem for scavengers and predators in this area. Particularly, in Argentine Patagonia during the last two centuries several exotic species have been introduced mainly for hunting purposes (Grigera and Rapoport, 1983; Novillo and Ojeda, 2008). Among them, the red deer (Cervus elaphus), the wild boar (Sus scrofa), and Lagomorphs including the European hare, (Lepus europaeus), and rabbit (Oryctolagus cuniculus), have notably increased in number (Novaro et al., 2000; see Novillo and Ojeda, 2008 for a review). All of these species, but particularly red deer and hare, are currently a substantive part of the diet for most top predators and scavengers from Patagonia (Hiraldo et al., 1995; Donázar et al., 1997; Travaini et al., 1998; Novaro et al., 2000; Lambertucci et al., 2009a).

The Andean condor (Vultur gryphus) is a large scavenging bird (13 kg mass, 3 m wingspan, 1.3 m height, Ferguson-Lees and Christie, 2001), that feeds mainly on carcasses of medium- to-large sized vertebrates (del Hoyo et al., 1994; Lambertucci et al., 2009a). This species is Near Threatened worldwide, though it is critically endangered in the northern end of its distribution, is listed in CITES Appendix I, and is negatively affected by human disturbances (Lambertucci, 2007; BirdLife International, 2008; Speziale et al., 2008; Lambertucci et al., 2009b). A century ago in Argentine Patagonia, condors fed mainly on the carcasses of guanacos and lesser rheas, but currently they depend almost exclusively on exotic (wild and domestic) species (Lambertucci et al., 2009a). While these exotic species represent a huge food source, they are associated with new problems for the conservation of scavengers (Lambertucci et al., 2009a). Poisoning with lead bullets has been observed in captive Andean condors, a species which is very sensitive to this metal (Locke et al., 1969; Pattee et al., 2006), however, until now the occurrence of lead in wild populations is unknown. In particular, the Andean condor is an interesting species to study the risk of lead exposure because it is at the top of the food chain, consumes two of the main hunted species in Patagonia, has a very low reproductive rate, and depends on a very high survival rate to maintain a stable population, making it very sensitive to the threat of lead (Lambertucci, 2007; Lambertucci et al., 2009a).

The purpose of this work is to evaluate whether lead represents a threat to one of the largest, and probably one of the healthiest,

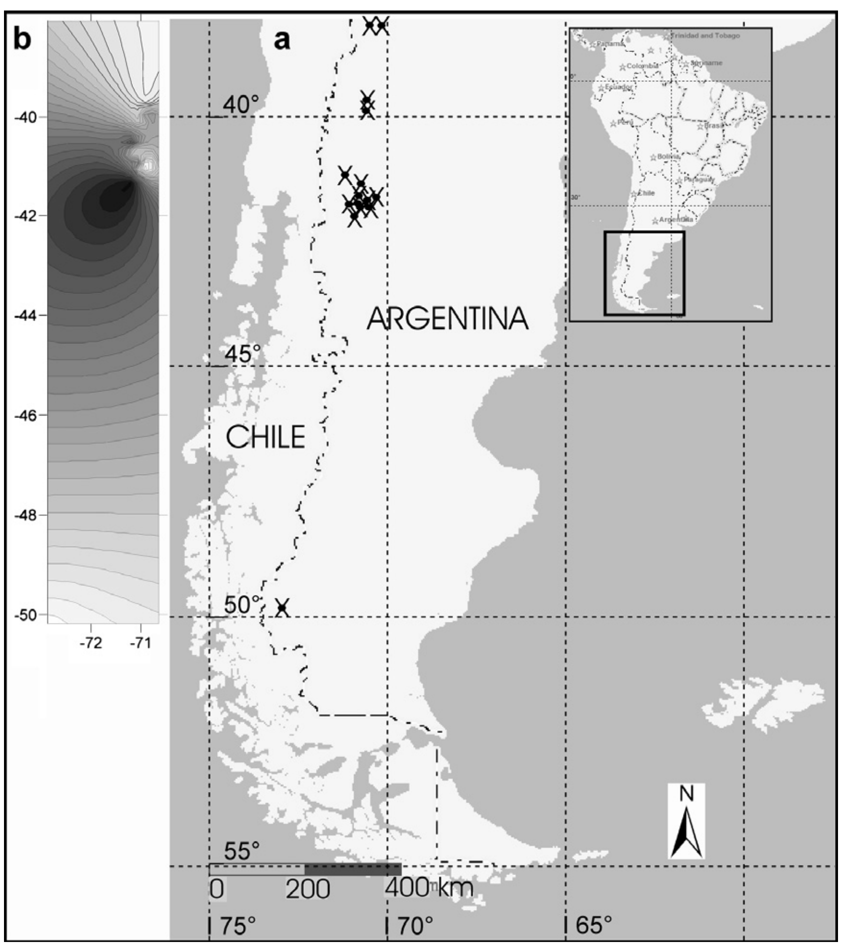

Fig. 1. (a) Study area in Patagonia, Argentina, showing the 15 locations (black crosses = Andean condor communal roosts) surveyed; (b) An isoline map modeling the spatial variation of the mean lead concentration in the condor's feathers along the study area (for more detail see main text).

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Andean condor populations located in the NW Patagonia (Lambertucci, 2010). For this purpose lead exposure and its possible sources, such as ammunition used for hunting, were evaluated in Andean condor by a non-invasive method based on the use of feathers. To achieve our goal, lead concentrations and isotope composition were determined in feathers from different age–sex condors. The information on lead poisoning in condors will be essential for the conservation of this and other species that take advantage of the same food source.

2. Methods

2.1. Study area and population

We studied condors in Argentine Patagonia in the southern tip of South-America (in a ca. 1500 km north–south following the Andes range, between latitude 36–50° S and longitude 70–73° W, Fig. 1). In this area, Andean condors select cliffs used as communal roosts, to overnight every day (Lambertucci et al., 2008). The population in the northwestern of Patagonia consists of about 300 individuals (Lambertucci, 2010), but the population is unknown in the rest of the area. The area consists of a gradient that encompasses two major biogeographic units the austral forest and the steppe, and the transition region between them, denominated the forest-steppe ecotone (León et al., 1998). The ecotone and the steppe areas have mainly been used for extensive livestock ranching since the last century, and are also one of the regions in Argentina with the greatest amount of alien mammal introductions (Baldi et al., 2001; Novillo and Ojeda, 2008). Red deer and European hare populations have increased to the detriment of native megaherbivores, such as guanacos and lesser rheas (Novaro and Walker, 2005). Hunting has also increased in recent years in the entire area. Hares are hunted throughout Patagonia, and Red deer hunting takes place mainly in the center of the study area (Sanguinetti pers. comm.; F. Méndez Guerrero pers. comm.), which was sampled intensively.

2.2. Sampling

We analyzed 152 molted Andean Condor feathers collected in January and April 2007 from 15 communal roosts (Fig. 1). We collected the feathers from the base of the cliffs used to roost, to analyze their lead concentrations. We took samples mainly from the center of the study area (13 communal roosts) in Patagonia were both red deer and European hare are hunted. We also took samples from two extremes in the area, north (two communal roosts) and south (one communal roost) where the red deer has not been introduced, and has not arrived yet; hence hunting pressures are lower and mainly focused on hares. We used differences in plumage patterns to distinguish among age-classes. Juvenile and immature birds (up to 6 years old) have a matte brown–gray plumage, whereas adults (from 6 years old) are black and white (secondary wing feathers) with pure-white coverts on the upper wing and a white collar (del Hoyo et al., 1994; Lambertucci, 2007). All feathers were collected in communal roosts, saved in plastic bags and treated in the same manner. We also include data on lead concentrations found in raptors from Europe and the USA which are threatened due to lead, by way of comparison (see Table 1).

2.3. Laboratory analyses

2.3.1. DNA extraction and molecular sexing of feathers

The feathers used for this study are the same from Alcaide et al. (2010), who detailed the molecular sexing analyses of feathers and differentiation of individuals.

2.3.2. Analysis of lead concentration

We extracted the base of the feather, not including the rachis, above the afterfeather. The vanes were separated from the shaft of each feather with a quartz knife. Before the analysis, feathers were rinsed down to reduce possible contamination from external sources. Samples were washed alternately with acetone and deionised water in an ultrasonic bath, then were left at 40 °C overnight in order to obtain a constant dry weight. Approximately 200 mg of each feather was digested in Teflon vessels in acid medium with 0.5 ml of HNO_3 69% (Trace Pur, Merck) and H_2O_2 at 100 °C for 6 h. The digested samples were diluted to a final volume of 10 ml with Milli-Q water. Lead concentrations were determined with Atomic Absorption Spectroscopy. The instrument was a longitudinal AC Zeeman AAS equipped with a transversely heated graphite atomizer (Perkin Elmer model AAnalyst 600). Quantification was performed using the standard addition method. All samples were analyzed in batches with blanks and certified reference material. A reference sample of human hair (CRM No. 13, National Institute for Environmental Studies, Japan) with certified levels of Pb (4.6 ± 0.4 1g/g dry weight) was analyzed. Recovered concentrations of the certified samples were within 5% of the certified values.

2.3.3. Analysis of lead isotopes

Ammunition was obtained at retail stores and from private hunters in San Carlos de Bariloche (main city inside the study area). We assumed that these stores represent a reasonable source of ammunition used by hunters in Patagonia and therefore a plausible source of spent ammunition to which condors in this area may be exposed. We took samples from seven different types of ammunition, five used mainly to hunt small game as hare (four types of .22 bullets from four different manufacturers and a 20 gauge shotgun) and two used for big game (two types of rifle from two manufacturers) to obtain their stable isotope ratios. We also obtained the stable isotope ratios of nine condor feathers with low level of lead (<1 1g/g), and six samples with high level of lead (>4 1g/g) to compare $^{207}Pb/^{206}Pb$ ratios. For this analysis, all feather samples used come from the NW of Patagonia (ca. 41° S; Fig. 1).

Table 1
Comparison of lead concentration in feathers of six raptor species from Europe and America. Lead concentrations are expressed in 1g/g.

	Mean	Maximum	Minimum	Number of feathers	Place	Source
Andean condor	1.17	21.24	<0.01	152	Patagonia, Argentina	This study
Bearded vulture	0.77	1.95	0.04	8	Huesca, Spain	Roscales et al. (2009)
California Condor[1]	7.07*	14.0	1.9	58	California, USA	Wiemeyer et al. (1986)
Osprey	1.04*	8.08	<0.21	82	Delaware Bay, USA	Rattner et al. (2008)
Spanish imperial eagle	4.5	13.84	0.41	66	Andalucía, Spain	Roscales et al. (2009)
Spanish imperial eagle	NA	45–50	2.15	41	Andalucía, Spain	Pain et al., 2005
Turkey vulture	2.38*	6.4	0.27	16	California, USA	Wiemeyer et al., 1986

NA = not available.
* Estimates as the original source had some data on lead concentration of feathers grouped and expressed by means. Thus, they represent the mean of several means.
[1] Feathers collected mainly among 1977–1980 when condor was near to be extinct in the wild.

Lead isotopic determination was carried out following the chemical and instrumental analytical procedures for Pb isotopic determination recently implemented at the Geochronology and Isotope Geochemistry Research Facility of the University of the Basque Country (Spain) (Santos Zalduegui et al., 2004). Ammunition weighing about 1 mg was milled in an agate mortar and then dissolved with 6 N HNO_3; organic matter from the feathers was oxidized with H_2O_2 prior to feather dissolution in HNO_3. Ammunition and feather samples were conditioned with HCl 3 N before chemical separation of Pb in Teflon® (Savillex®) columns with AG1X8 Dowex resin with a HBr treatment (Smith et al., 1992). Pb was loaded onto outgassed Re single filaments with 3 1l of silica gel. The measured ratios, given as an average of 10 blocks of 10 scans, were obtained using a Finnigan MAT 262 Thermal Ionization Mass Spectrometer (TIMS) in static collection mode. The data obtained were corrected for mass fractionation by comparison with replicate analyses of the Pb NBS-981 standard (Woodhead et al., 1995). The incertitude for individual measurements under the same conditions of NBS-981 standard was always <0.005 for $^{207}Pb/^{206}Pb$ and <0.027 for $^{208}Pb/^{206}Pb$.

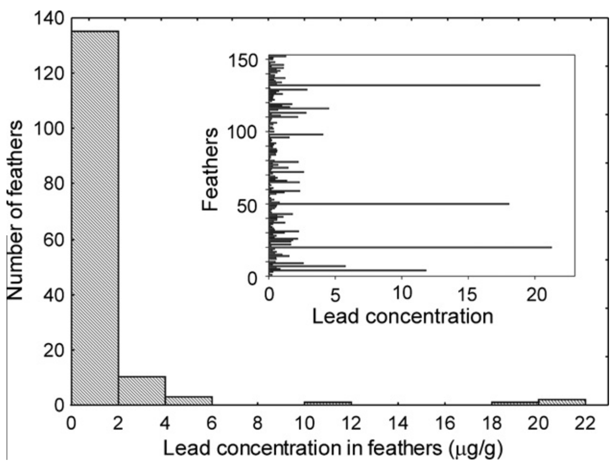

Fig. 2. Frequency distribution of lead concentration in feathers from wild Andean Condors from Patagonia, Argentina (n = 152). We also show the values of lead in each feather (inset graph).

2.4. Statistical analyses

An isoline map was used to model and graphically illustrate the spatial variation of lead concentrations in the study area. For this, we constructed a continuous surface of interpolated data over the total extent of the study area, relating the lead concentration in feathers to the coordinates of each communal roost where they were collected. Contour lines were obtained by the application of a geostatistical technique that uses an estimation of the semivariance of the data to perform interpolations ('kriging': see Matheron, 1963).

We considered lead concentrations as abnormal (far from background level) when they were higher than 4 1g/g a value that is in accordance with the bibliography (Burger and Gochfeld, 1994; Pain et al., 1995; Knopper et al., 2006; Finkelstein et al., 2010), and which represents the mean plus one standard deviation in our data. We used generalized linear mixed models (GLMM; Littel et al., 1996) to relate lead concentration (1g/g) (link function: identity, error distribution: Normal) to sex and age. Models were log-transformed and fitted using a forward stepwise procedure, where significant effects ($p < 0.05$) were retained. To avoid non-independence of the data, all models included 'roost' nested in 'zone' as a random term. Finally, we used non-parametric statistics to compare the lead isotope compositions of feathers and ammunition.

3. Results

3.1. Individual and spatial variation in lead concentration

From the 152 feathers analyzed (47 feathers from females, 73 from males and 32 indeterminates; 92 adults, and 54 juveniles), we found a mean concentration of 1.17 1g/g of lead in feathers for the entire study area. Seven feathers had concentrations of lead of more than 4 1g/g (4.6%), from which 4 (2.6%) had more than

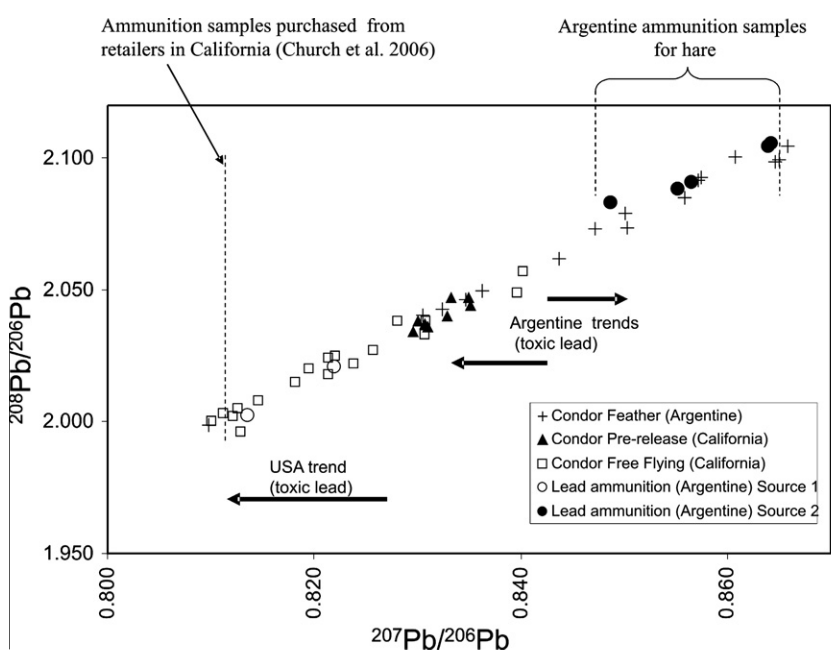

Fig. 3. Lead isotope ratios ($^{208}Pb/^{206}Pb$ vs. $^{207}Pb/^{206}Pb$) in Andean condor feathers from Argentine Patagonia (black plus sign), California condor pre-released and free-living from California, USA (triangles and squares respectively, based on Church et al., 2006) and two sources of lead ammunition from Patagonia. Source 1: Red deer and other big game ammunition; Source 2: hare ammunition.

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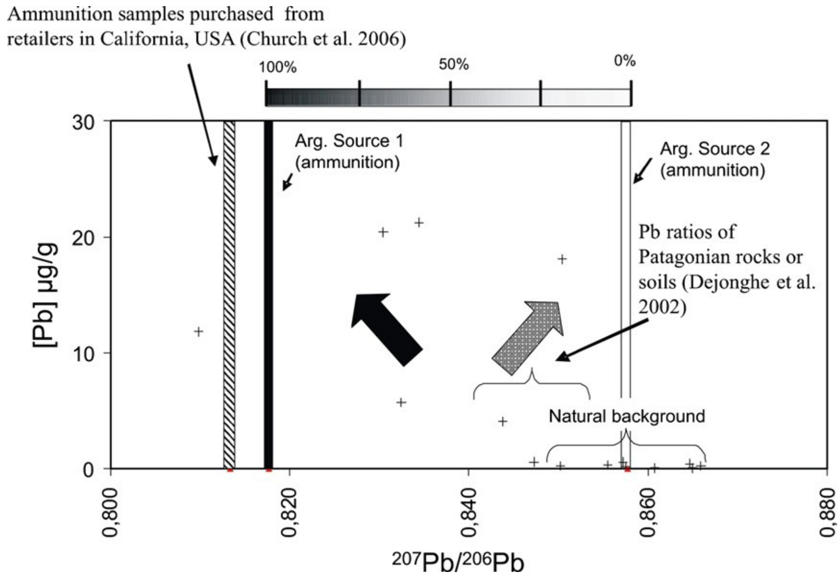

Fig. 4. Lead concentrations and lead isotopic ratios ($^{207}Pb/^{206}Pb$) compositions in Andean condor feathers (plus sign). The mean $^{207}Pb/^{206}Pb$ of the ammunition from California, USA (see Church et al., 2006; black striped bar) and from Argentine Patagonia. The rectangle on the top indicates the approximate composition of isotopic Pb for feathers with high level of this metal. The possible tendency of some intermediate samples (arrows) is also shown. Natural background is based on the feathers with very low level of lead. The $^{207}Pb/^{206}Pb$ ratios for the rocks or soils of this area are indicated (see Dejonghe et al., 2002). Black bar; Source 1: red deer and other big game ammunition, gray bar; Source 2: hare ammunition.

10 1g/g, and 2 (1.3%) had more than 20 1g/g (Fig. 2). Andean condors in our study area showed lower mean concentrations of lead, but higher maximum concentrations than those found in feathers of other raptor species in regions where potential lead threats have been identified (Table 1).

We did not find differences in lead concentration among communal roosts, nor among the three main zones analyzed (GLMM; $p > 0.05$). Although not statistically significant, the mean tended to be higher in the center of the study area compared with the north and the south (mean ± SD; center = 1.26 ± 3.15, North = 0.61 ± 0.31, South = 0.55 ± 0.49; see Fig. 1). This result is influenced by the individuals that had concentrations of lead of >4 1g/g, which were all concentrated in this zone (mean ± SD in the center excluding the seven individuals over 4 1g/g = 0.65 ± 0.68). We did not find differences in lead concentrations between sexes or age-classes ($p > 0.05$). However, six individuals with concentrations of lead over 4 1g/g were adults (two male, two female and two indeterminate) and one was a juvenile (male).

3.2. Lead isotope ratio

Several values of feather samples had lead ratios compatible with lead ammunition (Fig. 3), and indeed, there were no differences between the $^{206}Pb/^{207}Pb$ isotope from the ammunition and the feathers (Mann–Whitney Test, $Z = 0.293$; $P = 0.77$). In Argentine Patagonia, the isotopic lead composition of the ammunition found comes from two sources (Fig. 4). Ammunition used to hunt big game (e.g., red deer or wild boar: rifle) has a different lead isotope composition to that mainly used for hare (.22 bullets and 20 gauge shotgun) (Fig. 3). The ammunition used for big game was similar to the ammunition purchased from retailers in California, USA (mean $^{207}Pb/^{206}Pb$ for USA: 0.813, and for Argentine: 0.817). The isotopic lead composition of ammunition used for hare hunting was higher (mean $^{207}Pb/^{206}Pb$: 0.857). In general, the lead isotopic composition of Andean condor feathers seems to be more compatible with hare ammunition (Fig. 3). Nonetheless, when the lead concentration in feathers was included in the analysis, higher levels of lead come from an intermediate values of lead isotopes ($^{206}Pb/^{207}Pb$; Fig. 4). Hare ammunition was similar in isotope composition to feathers with low concentration of lead, possibly indicating a coincidence with background lead for this area. We found that the lead isotopic ratio ($^{207}Pb/^{206}Pb$) was different between the feathers with low concentration of lead (<4 1g/g) and high concentration (P4 1g/g; M-W U test = $Z = -2.56$; $P = 0.011$; Mean high [Pb] 0.8268; SD = 0.0114; Mean low [Pb] = 0.8553; SD = 0.006). In general, feathers with high concentration of lead show ratios $^{207}Pb/^{206}Pb$ lower than 0.850 (Fig. 4).

4. Discussion

4.1. Levels of lead concentration in the population

We found high records of lead in a systematic study for a wild population of a South-American raptor species. Therefore, we suggest that the problem of lead for scavengers and predators is also present in parts of South-America. Andean condors had, in general, low levels of lead concentration in their feathers, but some individuals were clearly exposed to this metal. Indeed, the maximum value obtained was one of the highest when compared with raptors species from other regions of the world. Until now the references on lead concentrations published for this species were mainly anecdotal or come from captive birds (e.g., Locke et al., 1969; Pattee et al., 2006; Saggese et al., 2009). The frequency distribution of lead concentrations we found is that commonly observed in birds facing problems due to lead – i.e., low levels in the majority of the birds with some birds having high levels (e.g., Pain et al., 2005, 2007; Gangoso et al., 2009; Hernández and Margalida, 2009). The low lead concentration found in most individuals is probably due to the low level of human disturbance (cars, roads, industry, etc.) in our study area. Concentrations of over 4 1g/g in different tissues have been proposed to generate behavioral, physiological, and nutritional disorders in birds (Burger and Gochfeld, 1994; Pain et al., 1995; Knopper et al., 2006). We found that 4.6% of the studied feathers had lead concentrations higher than this value, and in two cases more than five times this value; this percentage of the population with lead poisoning can be problematic.

Differences in lead concentrations between spatial areas, sex and age-classes were not conclusive. On the one hand, we must consider that these birds fly long distances and can be eating in different areas (Lambertucci, 2007). However, there was a tendency – higher levels of lead in the center of the study area –, which may be influenced both by the higher proportion of data collected in this area, and the fact that the distributions of the main hunted species overlap there. Thus, there is a higher probability of encountering a carcass with lead there than in the extremes of the study area, where deer have not yet arrived. Although we have not found clear differences between age-classes in lead concentrations in this study population, the feathers with highest lead levels come mainly from adults. This can be a serious problem for the survival of a long-lived species such as condors (see Section 4.3).

4.2. Lead isotope composition

Considering that some of the feather samples had lead isotopic ratios compatible with lead shot, it is likely that shot could be the source of lead contamination for this condor population. Inside the study area there is no other obvious source of lead, indeed, large roads, cities, mining, industry, or dumps are few and far away. The areas surrounding the communal roost are mostly sparsely populated (<0.6 inhabitants/km^2) with large farms (see Speziale et al., 2008). Indeed, condors are not used to highly populated areas, and they generally avoid eating close to roads (del Hoyo et al., 1994; Speziale et al., 2008; Lambertucci et al., 2009b). Moreover, in this area the condor's diet mainly consists of a few species of herbivores (Lambertucci et al., 2009b), which do not seem to be exposed to a particular lead source. Consequently, it is very likely that the source of this lead is ammunition. However, future research using non-invasive methods, for example pellet examination (Mateo et al., 2003), and analyses based on invasive methods, are likely to provide further insights on the origin of Pb exposure in this species.

We found that ammunition in Patagonia has two different isotope compositions. The ones used for big game, which is similar to that of the ammunition used in California, USA, and another with higher values of $^{207}Pb/^{206}Pb$ mainly used for hunting hare. The isotopic ratio of the feathers with low level of lead concentration (which may represent natural, background levels) was very similar to some ammunition available in this area. This might show that lead in feathers can come from the bullets, but may also suggest that these bullets and the background lead isotope composition are similar. If this last suggestion is correct the background composition of $^{207}Pb/^{206}Pb$ in Argentina is higher than in USA (see Church et al., 2006). Lead can be also incorporated from soil and dust. A global evaluation of dust from many parts of the Southern Hemisphere, including Patagonia, suggested that this area was characterized by a very variable isotopic composition ($^{207}Pb/^{206}Pb$: 0.80–0.85; De Deckker et al., 2010). However, Dejonghe et al. (2002) reported that the Pb ratio in places close to our study area was similar to those found by us as background level in condor's feathers ($^{207}Pb/^{206}Pb$: 0.84–0.85; see Fig. 4).

The distribution of lead concentrations in the feathers shows that high levels of lead come from a particular event, which is consistent with the ingestion of lead ammunition. Moreover, when the Pb concentration increases, the dispersion of the $^{207}Pb/^{206}Pb$ values increase too, also suggesting that these birds are exposed to an anthropogenic source of lead. A plausible explanation may be that the lead isotope composition comes from a mixed source of lead. In this way, condors can be consuming lead from ammunition used for big game and hare hunting, in which case, the values of the isotope ratios from the feathers with high level of lead may represent an intermediate level between those sources. Nonetheless, we must also consider that other $^{207}Pb/^{206}Pb$ compositions can be found in other ammunition we did not sample, and that some bullets can be brought by the hunters from their respective countries.

Bullet fragmentation in large game is typical and its occurrence can affect the distribution of lead contamination levels in scavengers (Watson et al., 2009). When lead shots enter the body of the hunted animal, they spread in small fragments that are easily ingested and dissolved, contributing to the sublethal, but nonetheless dangerous, concentrations of lead in wildlife (Hunt et al., 2006; Knopper et al., 2006). Basal concentrations of lead found in this condor population show that in Patagonia natural lead concentrations seem to be very low. It should be noted however, that small deviations in the concentrations of lead, even lower than some found in this study, might affect populations, weakening individuals and increasing the impact of other diseases (Baos et al., 2006; Gangoso et al., 2009).

4.3. Conservation and management strategies

Hunting pressure in Argentina is high and increasing (Saggese et al., 2009). Millions of hares are hunted and exported every year from this county (Novillo and Ojeda, 2008; Lambertucci et al., 2010). In the study area, hundreds of carnivores, such as foxes, pumas and wild cats, are hunted for control purposes, to reduce predation on livestock, and guanacos and lesser rheas are also hunted to reduce their competition with livestock (Novaro and Walker, 2005). Thousands of red deer are killed for sportive hunting and invasive species for control purposes. Moreover, hunting for the control of problematic species (e.g., the exotic red deer) has increased in the area in public and private lands (Lambertucci et al., 2009a; J. Sanguinetti pers. comm.; F. Méndez Guerrero pers. comm.). At present, condors in Patagonia rely heavily on exotic mammals with near to half of their overall diet being comprised of deer and Lagomorphs (Lambertucci et al., 2009a). In this area, foreign hunters generally take only the head of big game (by way of a trophy) abandoning the rest in the field. Local people also use selected animal body parts, leaving the rest in the field. Hares are consumed in their entirety as is usual for small game, but many of the injured individuals escape and may be finally consumed by scavengers. Thus, Andean condors as well as other species (medium-to-large raptors and carnivore mammals) will most likely be taking advantage of the carcasses left by hunters, and be thus exposed to lead poisoning.

Although the human impact in Patagonia is lower than in other parts of the world, hunting with lead could be an important threat. Our results highlight that lead is not solely a problem for the carnivores from North-America or Europe. Populations of raptor scavengers are extremely sensitive to the availability of healthy food sources, and lead exposure can have severe effects on populations of long-lived species which can only be observed after a long time (e.g., Gangoso et al., 2009; Hernández and Margalida, 2009; Finkelstein et al., 2010). In particular, mortality rates to maintain a population of Andean or California condors should be very low, especially for adults (Mertz, 1971). Consequently, if our results are generalized, lead may have severe consequences for the condor population.

National and provincial, public and private organizations from Argentina devoted to the protection of wildlife should play a key role in endorsing and overseeing the change of lead bullets to an alternative and safer option. In Argentina several provinces promote the hunting within their jurisdictions. Moreover, the Argentine National Park Administration uses lead bullets inside their protected areas to control exotic species of red deer, beavers (Castor canadensis), rabbits, wild livestock, etc. The same Institution manages areas devoted to red deer hunting in Patagonia. Though strategies are needed to control exotic species within every South-American country (Speziale and Lambertucci, 2010), this should be done in a way that is compatible with the conservation of the biodiversity. It would be advisable that National Park Administrations and other organizations start using alternative less toxic bullets (e.g. see, Thomas and McGill, 2008; Knott et al., 2009). Politic decisions take time to be put into practice, thus it is very important to start now to implement regulations to the use of lead bullets. Though other countries already have laws that ban lead bullets, this has yet to be instigated in South-America (Friend et al., 2009; Mateo, 2009). Banning lead bullets does not seem to be problematic; indeed, it would protect both humans and wildlife consuming game meat (Lambertucci et al., 2010), and would consequently help maintain large regions of high conservation value.

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