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RESEARCH ARTICLE

Pygoscelis antarcticus feathers as bioindicator of trace element risk in marine environments from Barton Peninsula, 25 de Mayo (King George) Island, Antarctica

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Abstract We report the contents of elements in feathers of Chinstrap penguin (*Pygoscelis antarcticus*), which had not been informed up to now, such as silver and bromine and others listed as hazardous by the United States Environmental Protection Agency as arsenic, cobalt, chromium, and mercury. Analyses of the element concentrations in feathers, adult and chicken, from Barton Peninsulas at 25 de Mayo (King George) Island, South Shetlands, were made by Instrumental Neutron Activation Analysis. Samarium, lanthanum a, thorium, and uranium concentrations in Chinstrap penguin feathers were below 0.1 mg/kg. This suggests that the elements in feather do not come from atmospheric particles surface deposition. Arsenic (0.120 ± 0.050 mg/kg) and cobalt (0.030 ± 0.020 mg/kg) concentrations were lower than the reports for other colony of Chinstrap penguins, and essential elements as iron (26 ± 12 mg/kg), zinc (78.0 ± 5.3 mg/kg), and chromium (0.51 ± 0.27 mg/kg) were in the same range while Se (2.90 ± 0.65 mg/kg) content were the lowest reported. Mercury (0.43 ± 0.21 mg/kg), chromium (0.210 ± 0.060 mg/kg), and silver (0.083 ± 0.003 mg/kg) in chicks tended to be lower than in adults. Iron, cobalt, and arsenic concentrations in feathers found in this study were the lowest compared to measurements were in several penguin species in Antarctica. These results confirm to feathers like effective indicators for the trace elements incorporated in the penguins and it provide a data set which can adds to the baseline for bioindication studies using feathers.

Keywords Non-invasive method · Biomonitoring · Marine ecosystem · Chinstrap penguin

Introduction

The presence of certain elements contaminant in the environment presents a real threat to the quality and sustainability of the ecosystems. Terrestrial and aquatic ecosystems receive contaminants through accidental discharges, waste dumping, atmospheric fallout, leaching, and weathering of soils (Burger and Gochfeld 1992; Furness 1993) among other sources. Chemical elements are highly persistent, non-biodegradable, with long biological half-lives and ubiquitous (Burger et al. 2007, 2008). Among these, several can be biomagnified through the food chain (i.e., mercury in organic forms), and this represents a threat to the species at the top in the trophic web (Kojadinovic et al. 2007).

Seabirds are good bio-indicators of the presence of heavy metals in marine ecosystems because of their long cycle life, cross great distances searching for food, and their diet includes different trophic levels (Walsh 1990). The changes in marine environments have been reflected for instance in the penguin populations. According to estimations by Boersma (2008), the population of the largest colony of Patagonian penguin

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(*Spheniscus magellanicus*) has been decreasing 10% per decade, and it was associated to the climate change, oil pollution, and food availability.

Antarctica, despite of isolation and hostile environment for humans, is under the pressure of human pollution from both the specific local settlements and the impact of global contaminants. The Antarctic Treaty goals include the resource protection through the Antarctic Protocol which establishes principles for planning and conducting of all human activities in Antarctica. Also, several Antarctic ecosystems have been designated as Antarctic Specially Protected Areas (ASPA) with the purpose of preserving these environments due to their high sensitivity to disturbances (UNEP 2007). International organizations have established guidelines for the levels of environmental contamination from different sources in Antarctica during the last years (Bargagli 2005, 2008). Nevertheless, regional and global impacts are inescapable and must be monitored.

Penguins have a potential to be standard biological indicators for Antarctic monitoring programs since they have a permanent ecological niche within the South Polar Circle and represent an important part of the avian biomass in Antarctica.

Numerous organs and tissues can be used as monitor such as the liver, muscle, blood, and feathers. The feathers were considered by Hahn et al. (1993) suitable for monitoring contamination from atmospheric deposition; nevertheless, the elements present in blood can be incorporated during its growth and reflect the internal exposure (Metcheva et al. 2006; Monteiro et al. 1996, 1999). The biomonitoring with penguin feathers allows a simplified and non-invasive method of evaluating the pollution levels providing a retrospective study of at least 1 year because the molt is once a year.

Penguin feathers have already been used to monitor the levels of metals which are connected directly to human activities, such as mercury (Hg), lead (Pb), and chromium (Cr). The feathers are not a standard sentinel "tissue"; however, they proved to be useful as early warning for monitoring certain elements such as nickel (Ni) and copper (Cu) (Szefer et al. 1993). In addition, the composition and content of Hg, aluminum (Al), and vanadium (V) proved a useful tool for identifying locations with different contamination degrees in the marine food webs (Monteiro et al. 1996, 1999).

This work is focused on chinstrap penguin from Barton Peninsula, 25 de Mayo (King George) Island, South Shetland Islands, Antarctica. The penguin colony sampled is isolate to the scientist bases and human settlement. We analyzed the elemental composition of penguins' feathers in two maturity stages: adult and chick. In order to gather preliminary data for a subsequent biomonitoring study using feathers, we tested the procedures for specimen conditioning and analysis by instrumental neutron activation analysis (INAA) using goose feathers to avoid excessive sampling of penguin feather. Elements which have not been informed up to now were included, such as silver (Ag), bromine (Br), and antimony (Sb); some elements listed by the U.S. Environmental Protection Agency (EPA), as the metals of major interest in bioavailability studies, namely Sb, arsenic (As), cadmium (Cd), Cr, Hg, and selenium (Se); and also, other metals selected due to their increment for the human exposure and health risk, i.e., Ag, barium (Ba), cobalt (Co), sodium (Na), and zinc (Zn) (John and Leventhal 1995; Mc Kinney and Rogers 1992). The elemental composition of the Chinstrap penguin feathers was compared with several penguin species from Antarctica; bibliographic information includes the same specie analyzed in this study.

Materials and methods

Study area

Narębski Point is located on the southeast coast of Barton Peninsula; this is a small peninsula separated from the Marian and Potter Coves at the southwest end of 25 de Mayo Island, South Shetland Islands, Antarctica (site 1 in Fig. 1). The total size of the area is approximately 1 km^2. Under the Korea Antarctic Research Program, scientists have visited the area regularly since the 1980s in order to study its fauna, flora, and geology. The area is extensively covered by mosses and lichens. There are large numbers of chinstrap penguin and gentoo penguin (*Pygoscelis papua*) and the breeding areas of other seven species of birds, including the southern giant petrel (*Macronectes giganteus*). The high diversity of the landscape and coastal forms is given by the presence of different geologies and a prominent system of fractures, in addition to an extensive and varied vegetation cover, which provides an unusual scenic diversity in the Antarctic environment.

The climate is humid and relatively mild because of a strong marine effect. Colonies of penguins are distributed on the rocks, inclines, and hill crests of Narębski Point. The chinstrap penguin is the most abundant specie that nests at the site, with a total of 2961 pairs observed in 2006/07 (Kokubun et al. 2010; http://ats.aq/documents/recatt/att551_e.pdf).

The area also includes watershed systems, such as lakes and creeks, where dense microbial and algal mats with complex assemblages of the species are frequently found. The high biodiversity of the terrestrial vegetation with complexity of habitats enhance the potential value of the area to be protected. In recent years, however, Narębski Point has been frequented by visitors from the nearby stations with other purposes than the scientific research.

The area was designated as an Antarctic Specially Protected Area (ASPA-171; http://www.ats.aq/documents/recatt/att551_e.pdf) to protect its ecological, scientific, and esthetic values from human interference. Long-term protection and monitoring of diverse range of species and assemblages will contribute to the development of appropriate regional and global conservation strategies for the species. Also, these studies could provide

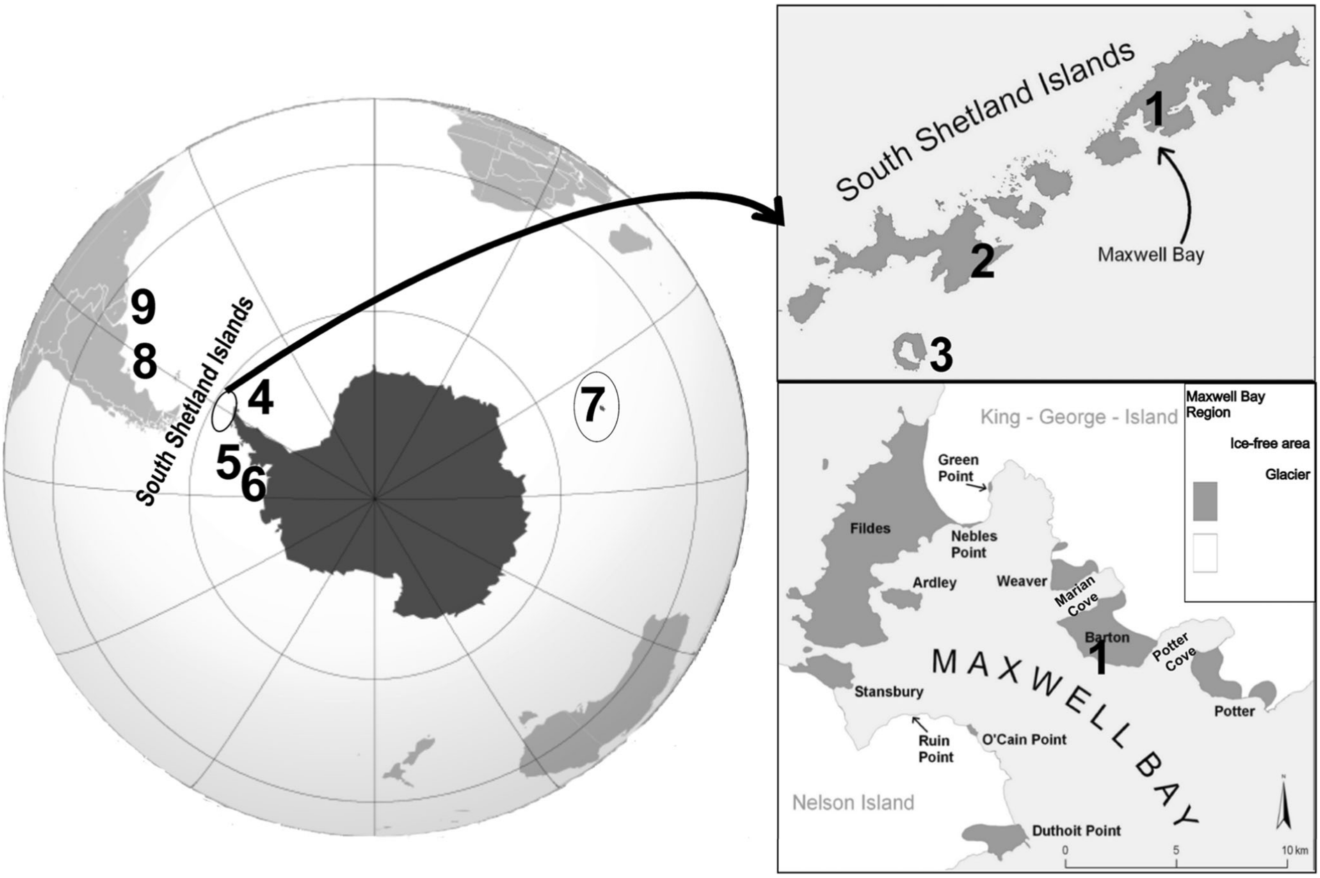

Figure 1 Location of sites in *1* sampling site of this work, Barton Peninsula, 25 de Mayo (King George) Island and *2* to *9* the location of the bibliographic references

reference information for comparisons with other regions of the continent.

Sampling

Several feathers per individual were carefully removed from the skin of the neck of the animals because this body sector is the cleanest and relatively easy to extract. The feathers were extracted by hand using gloves; it was not cut. Then, samples were placed individually in polyethylene bags and kept frozen at −20 °C until they were processed.

A total of 30 chinstrap penguins were sampled, adults and chicks; the feathers were collected from individuals from the colony located in the ASPA-171 in two summer campaigns between January and March, 2015 and 2016. Two kinds of samples were carried out weighing several feathers of each individuals to completed approximately 100 mg. Pooled samples were done with equal amounts of feathers from three individuals, and single samples from one animal. The feathers were placed into SUPRASIL quartz ampoules and sealed.

Sample preparation

We used a solution of Na(OH) to clean the feathers. Since the technique of elemental analysis to be used is instrumental neutron activation analysis (INAA), and due to its well known interferences to the presence of Na in this technique, the Na interferences using goose feathers was tested. In the laboratory, three sets of goose feathers were submerged in NaOH (0.25 M) solution followed by a rinse with ASTM grade 1 water. Three other groups were rinsed only with ASTM grade 1 water. All samples were dried at room temperature in a laminar flow hood till constant weight. Thereafter, they were sealed in quartz ampoules for analyses.

Elemental analysis

Elemental concentrations were determined by INAA. The SUPRASIL quartz ampoules were irradiated during 20 h in the RA-6 research nuclear reactor, Centro Atómico Bariloche, Argentina (ϕ_{th} E1.5 × 10^{13} n cm^{-2} s^{-1}; ϕ_{epi} E7.1 × 10^{11} n cm^{-2} s^{-1}). Two gamma ray spectra, with different decay times, were collected using an intrinsic HPGe detector

30% relative efficiency and a 4096 multichannel analyzer, whereas the spectra were analyzed by using the GAMANAL routine included in the GANAAS package, distributed by the International Atomic Energy Agency (IAEA). The elemental concentrations were determined using the absolute parametric method. Analytical errors were computed as the propagation of the uncertainties associated with the nuclear parameters, and the efficiency of the gamma ray detection system. Reference materials NRCC-DORM-2 Dogfish Muscle and IAEA 336-Lichen were analyzed together with the samples for analytical quality control (QC), showing good agreement with the certified values. The QC analyses are reported in Table 1. The detection limits for INAA method is specific for each element, and it is at least one order of magnitude lower than the reported concentrations. The measured elements were Sb, As, Ba, Br, Cd, cesium (Cs), calcium (Ca), Cr, Co, gold (Au), hafnium (Hf), Fe, lanthanum (La), Hg, molybdenum (Mo), potassium (K), Rb, samarium (Sm), scandium (Sc), Se, Ag, Na, thorium (Th), uranium (U), and Zn.

Data analysis

Descriptive statistical analysis was performed with XLSTAT program (copyright 1995–2009 Addinsoft). The minimum, maximum, average, standard deviation, and coefficient of variation were calculated. The differences among samples were checked by Wilcoxon test and Kruskal-Wallis test; the significance level considered in statistical tests was $(\alpha) \leq 0.05$.

Results

Previous works performed with penguin feathers suggested the use of a non-ionic detergent or cleansing solution of NaHO to remove natural oil over the stiff part of the feathers (Parrish et al. 1983; Franca et al. 2010; Moreno et al. 2011). The activation product of Na (^{24}Na) has a high specific activity and emits energetic gamma rays (1.37 and 2.1 MeV) and interferes with the determination of some elements, such as As and K. The pooled

Table 1 Element concentration ranges in reference materials expressed in milligrams per kilograms of dry weight (mg/kg d.w.)

Element	IAEA 336		DORM-2	
	Measured values	Certified values	Measured values	Certificate values
Sb	0.067–0.078	0.063–0.083		
As	0.62–0.78	0.55–0.71	18.5 ± 1.8	18 ± 1.1
Ba	8.4–8.5	5.3–7.5		
Br	13–14	11–15		
Cd	0.10–0.13	0.13–0.19	<1.0	0.043 ± 0.0080
Ca (wt%)	0.19–0.30	0.26–0.31		
Cs	0.095–0.110	0.10–0.11		
Zn	31–35	27–34	24 ± 3.4	26 ± 2.3
Co	0.28–0.32	0.24–0.34	0.23 ± 0.024	0.18 ± 0.031
Cr	1.6–2.3	0.89–1.20	33.5 ± 3.4	35 ± 5.5
Sc	0.17–0.21	0.15–0.19		
Sr (mg/g)	0.082–0.10	0.092–0.12		
Hf	0.058–0.071	0.053–0.063	4.85 ± 0.66	4.6 ± 0.26
Fe	385–458	380–480	148.5 ± 22	142 ± 10
La	0.71–0-96	0.56–0.76		
Hg	0.17–0.25	0.16–0.24		
Ag	0.018–0.024	0.016–0.027		
K (%)	0.19–0.21	0.16–0.20		
Rb	1.9–20	1.5–2.0	0.048 ± 0.018	0.041 ± 0.013
Sm	0.11–0.13	0.092–0.12		
Se	0.24–0.26	0.18–0.26	1.45 ± 0.14	1.4 ± 0.090
Ta	0.015–0.020	0.014–0.017		
Tb	0.014–0.016	0.012–0.016		
Th	0.15–0.16	0.12–0.16		
Na	320–367	280–360		
U	0.055–0.063	0.026–0.048		

samples of goose feathers cleaned with NaHO showed higher Na content than the pooled samples cleaned with ASTM grade I water. However, the cleaning procedure did not affect the elemental composition since no significant differences were found between element contents of each set of samples (Wilcoxon test, $p < 0.05$). The value ranges are presented on Table A (complementary data). According to these results, the preparation of the penguin feather samples was made by cleaning only with ASTM grade 1 water.

Table 2 shows the average (standard deviation) and the variation coefficient of the analysis of the individual feather samples, adult and chick, as well as pooled feather samples. The elemental contents of all the penguin feather samples are shown on Tables B and C (complementary data). The elements Ba, Cs, Mo, K, Sm, Th, U, and Au (<2; 0.002; 1; 0.20; 0.007; 0.002; 0.09 mg/kg d.w.; and 5 μg/kg d.w.) were not included for the analysis due to these data were below the detection limits for INAA method. Their limits are at least one order of magnitude lower than the reported concentrations in Table 3. The differences among pooled and individuals samples, of adults and chicks, were not significant (Kruskal-Wallis; $p < 0.05$).

The elemental contents for the feathers are shown on Table 3 together with the reported values found in the scientific literature of the last 10 years. Cadmium was below LOQ in all cases, spreading from 1 to 10 mg/kg. The elements which can be associated to the geologic particulate, such as Sm, La, Th, and U, were lower than all other trace elements. Silver, Cr, and Hg tended to be higher in adults compared with chicks, while As, Rb, Zn, and La were lower (Tables 2 and 3 and Tables B and C complementary data).

Mercury in penguin feathers is the element most frequently reported in the scientific literature; it has been studied in different species of penguins and sites (Table 3). The lowest concentrations were observed in Antarctic sites; all species have Hg contents in the range (0.11–5.7 mg/kg) for adults and (0.05–2.5 mg/kg) for chicken. The highest contents were for gentoo penguin (5.4 ± 2.5 mg/kg) of the Kerguelen Island from the Sub Antarctic Sea and magallanes penguins (5.7 ± 3.7 mg/kg) of Rio Grande do Sul from Southern Brazil. Also, Hg concentration increases with the age in all cases.

Feather samples presented on Table 3 did not show any significant differences in the elemental concentrations among the species (Kruskal-Wallis test, $p < 0.05$). Selenium (2.90 ± 0.65 mg/kg) and Cr (0.51 ± 0.27 mg/kg) in our results were lower than those from Brazil (Se: 5.2 ± 2.8 mg/kg) and from the Antarctic Peninsula (Cr: 1.5 ± 0.82 mg/kg). Furthermore, our Co (0.03 ± 0.02 mg/kg), As (0.12 ± 0.05 mg/kg), and Fe (26 ± 12 mg/kg) data were lower than those found in

Table 2 Elemental composition of individual and pooled feather samples, from adults and chick penguins. All concentrations are in milligrams per kilograms of dry weight (mg/kg d.w.) except (*) % d.w. and (**) μg/kg d.w

Elements	Pooled adults feathers		Individual adult feathers		Pooled chicken feathers		Individual chicken feathers	
	Average (SD)	CV	Average (SD)	CV	Average (SD)	CV	Average (SD)	CV
Sb	0.017 (0.0085)	50	0.0210 (0.0084)	40	0.0110 (0.0017)	15	0.0140 (0.0032)	20
As	0.13 (0.074)	60	0.36 (0.01 [#])		0.180 (0.041)	20	0.250 (0.069)	30
Ba	1.4 (0.88)	60	5.4 (7.5)	1.5	1.10 (0.064)	6	2.0 (1.2)	60
Br	66.0 (6.1)	10	66.0 (4.1)	6	69.0 (8.5)	10	71 (15)	20
Ca*	0.130 (0.024)	20	0.160 (0.037)	20	0.130 (0.038)	30	0.120 (0.037)	30
Cs	0.0035 (0.0013)	35	0.0041 (0.0018)	45	0.0032 (0.0003)	10	0.0017 (0.0010[a])	
Zn	78.0 (5.3)	7	79.0 (6.2)	8	99 (19)	20	111 (24)	20
Co	0.033 (0.019)	60	0.030 (0.016)	55	0.024 (0.011)	50	0.031 (0.014)	45
Cr	0.51 (0.27)	50	0.49 (0.33)	70	0.210 (0.055)	30	0.33 (0.10)	30
Sc	0.0071 (0.0027)	40	0.0050 (0.0025)	50	0.0110 (0.0043)	40	0.0110 (0.0033)	30
Hf	0.0070 (0.0071)	100	0.0045 (0.0013)	30	0.0034 (0.0011)	30	0.0038 (0.0014)	40
Fe	26 (12)	45	26 (15)	60	30 (12)	40	30 (11)	35
La	0.30 (0.19)	60	0.65 (0.59)	90	0.37 (0.28)	75	0.310 (0.099)	30
Hg	0.62 (0.11)	20	0.71 (0.34)	50	0.43 (0.21)	50	0.230 (0.055)	25
Au**	2.4 (1.7)	70			2.5 (2.1)	85	2.80 (0.11[#])	
Ag	0.17 (0.16)	90	0.083 (0.003)	4	0.110 (0.023)	20	0.088 (0.035)	40
K			0.061 (0.018)	30			0.050 (0.014)	30
Rb	0.170 (0.027)	15	0.240 (0.048)	20	0.21 (0.06)	30	0.210 (0.062)	30
Se	2.90 (0.65)	20	3.9 (1.8)	45	2.10 (0.53)	25	1.80 (0.65)	35
Na	4660 (490)	10	5210 (590)	10	3590 (860)	25	4140 (990)	25

[a] Uncertainty

Table 3 Comparison of elemental concentration in adult penguin feathers from different sites. The reported values for chicks are in gray. All concentrations are expressed in milligrams per kilograms of dry weight (mg/kg d.w.)

Sampling data		Element concentrations							
Sites	Penguin species	Hg	Se	As	Cr	Zn	Co	Fe	Cd
King George Island[1]	Chinstrap	0.62±0.11	2.90±0.65	0.120±0.050	0.51±0.27	78.0±5.3	0.030±0.020	26±12	<1-<10
		0.43±0.21	2.10±0.53	0.160±0.040	0.210±0.060	99±19	0.020±0.010	30±12	<1-<11
King George Island[2,6]	Gentoo				0.68±0.030			17±0.050	
	Chinstrap				0.09±0.050			30 ±29	
	Adelie				0.97			15	
Antarctic Peninsula. Palmer Arc[2;4]	Gentoo				0.73±0.36	33± 4			0.050±0.070
					1.50±0.82	64±11			0.21±0.28
Antarctic Peninsula[4]	Adelie	0.11±0.22							
Ross Sea[2]	Adelie	0.53±0.080							
Deception Island[6.8]	Chinstrap				0.60±0.15			20±13	
Avian Island[6.8]	Adelie				0.31±0.050			4.30±0.47	
Livingston Island[6.8]	Chinstrap		<0.80	0.45±0.20		87±6	0.190±0.030		
	Gentoo		2.0±0.43	0.88±0.30	0.17±0.050	92±4.6	0.25±0.070	47±9.2	0.21±0.10
Kerguelen Island[3]	King	2.1±0.59							
		1.1± 0.16							

1 This work; 2 Brasso et al. (2012, 2014); 3 Carravieri et al. (2013); 4 Celis et al. (2012, 2015); 5 Frias et al. (2012); 6 Jerez et al. (2011), Jerez Rodríguez (2012); 7 Kehrig et al. (2015); 8 Metcheva et al. (2006, 2011)

the Livingston Island, and Antarctica (Co, 0.25 ± 0.07; As, 0.88 ± 0.30; and Fe, 47 ± 9.2). The Zn concentration in chicks (99 ± 19 mg/kg) tend to be higher than those from other sites (i.e., Antarctic Peninsula, 64 ± 11 mg/kg; Livingston Island, 92.0 ± 4.6 mg/kg).

Discussion

The wild birds are exposed to metals through the food, water, and also direct ingestion of contaminated sediments (Hargreaves et al. 2011a, b). They have developed a number of homeostatic mechanisms to regulate the levels of essential metals, which typically involve the absorption in the gastrointestinal tract. The metals, once absorbed, are distributed in the body by the circulatory system to a variety of tissues and target organs. The mobilization followed by redistribution for the storage, inactivation or excretion, depend to the rate of absorption respect to the excretion (Metcheva et al. 2011; Burger et al. 2008).

Metals have high affinity for thiol group (−SH) of cysteine residues of the polypeptides and metallothioneins from plasma or membrane proteins and enzymes. Furthermore, tissues rich in protein such as muscle and feathers can predominantly accumulate metals (Sakulsak 2012; Metcheva et al. 2006; Sigel and Sigel 2009). Feathers are epidermal keratin formations attached to the skin. The structure and chemical composition of penguin feathers are almost identical among species. This suggests that the variability in elemental contents among species may be only associated with the contaminant availability around the penguin colonies in the feeding area.

Szefer et al. (1993) evaluated the element contents in several tissues of penguins from Antarctica including feathers, and concentrations were higher than in muscle. This author reported for muscle (Cd, 0.02–0.57; Ag, 0.009–0.01; and Co, 0.09–0.11 mg/kg) which is lower than our data shown on Table 2 (Cd, <1 to <10; Ag, 0.08–0.45; and Co, 0.02–0.25 mg/kg). On the other hand, the feather molt of penguins is complete once a year, and usually occurs after breeding. The new feathers grow under the old ones and these fall when the new feathers are ready. The feather is connected with blood vessels and metals can be incorporated in the keratin structure; metal levels in feathers reflect blood levels during the short period of feather growth (Dauwe et al. 2000). Long-scale studies on the chemical composition of bird tissues, feathers, blood, and guano have revealed changes in environmental pollution of Antarctica (Bargagli 2005). Feathers can play the role of both storing and excretion of metals. Therefore, the elemental composition in the feathers reflects the metals accumulated up to 1 year.

Some authors considered that the elements in the feather could also measure external contamination from atmospheric or aqueous origin (Furness 1993; Hahn et al. 1993; Jaspers et al. 2004). In our work, the elements associated to the soil, which generally are used as geochemical tracers, had values below 0.1 mg/kg (Sm, La, Th, and U on Table 3 and Tables B and C, complementary data). This provides the absence of superficial deposits from air and supported that the penguin feathers removed from the skin of the neck from the animals were effective indicators for the trace elements which are incorporated trough the food web in Antarctic ecosystems.

The site comparisons considering the same penguin specie showed some differences, i.e., Se content in chinstrap penguin from 25 de Mayo Island was 2.90 ± 0.65 mg/kg while from Livingston Island was below 0.8 mg/kg. Nevertheless, the element contents of all the penguin feathers shown on Table 3 have a wide dispersion among sites, and the differences were not significant. The distribution of penguin species is diverse; all of them live in colonies in the Southern Hemisphere (Bargagli 2005; Boersma 2008; Whitehead et al. 2016; https://seaworld.org/en/animal-info/animal-infobooks/penguin/diet-and-eating-habits). They can migrate up to about 600 km north from their colonies. For example, Penguins adelie, chinstrap, macaroni, and king migrate to the north of the Antarctic continent during winter and stay at sea until the next spring, while rockhopper and magellanic can reach the Southern Brazil. The gentoo penguin is restricted to near their colonies all the year, unless that the ice prevents their access (http://www.penguinworld.com/types/adelie.html).

On the other hand, the released elements mainly to blood supply are linked to the feeding habits, position in the food chain, and state of ocean waters (Metcheva et al. 2006). The diets of the main species penguins are highly dependent on krill, mainly *Euphausia superba*, and also in minor proportion, are common fish and amphipods in certain locations depending on the seasons; for example, king penguins and magellanic penguins have the cephalopods as the main food items (http://www.penguinworld.com/types/adelie.html). It is likely that the similarity of the feeding and the migratory habits between penguin species were the reason of the lack of significant differences in contents of the elements among site and species.

The bioaccumulation is age-dependent of some metals in feathers (Squadrone et al. 2016; Maedgen et al. 1982; Stock et al. 1989; Furness and Camphuysen 1997). Some studies of Cd concentration has shown increasing with age, although Battaglia et al. (2005) showed significant correlations of Cd content between feathers and excretion organs (livers and kidneys) for two bird species. But also, this author showed significant differences of Cd contents between adults and juveniles in all tissues except in the feathers and considered that Cd is accumulated from the diet and excreted through the feathers (Battaglia et al. 2005). But our data of Cd for age, adults and chick, were spreading between 1 and 10 mg/kg.

Mercury is one of the most important environmental contaminants in the food chain and the marine environment, and it has been especially monitored through the sea birds (Ancora et al. 2002; Brasso and Polito 2013; Brasso et al. 2014; Kehrig et al. 2015; Squadrone et al. 2016). Total Hg concentration measured in adult penguin feathers usually was higher than that in chicks (Table 3) as well as in other sea birds (Carravieri et al. 2013, 2014; Catry et al. 2008; Bond and Diamond 2009). Some authors have linked the results with the exposure period; however, Carravieri et al. (2014) attributed the differences to the results of adults feeding their chicks with preys different than those they consume themselves. In addition, in our work, the element contents were lower in chicks than adults, except for Zn (Table 3); similar relationship between concentrations with age was observed in other studies reported in the literature (Kim and Oh 2015).

The element concentrations observed in this studied were the lowest compared to those from other the sites from Antarctica reported in Table 3.

Remarks

In this work, we were able to find a suitable sampling and cleansing procedure to use multi-elemental INAA for biomonitoring studies with feathers. Since there were no significant differences among individual feathers, pooled samples provide good information on the metal burden of feathers. The representative data were done using pooled samples reducing the number of replicas for analysis; this would allow a larger number of sampling sites and extend the study area.

Taking into account the molting, relationship of elemental composition among tissues, and the lack of atmospheric contaminants in the feathers, we consider that those from the neck over the skin are a feasible sentinel tissue. This is an early alert indicator of the metals risk in the food web Antarctic while the use of other tissues can be overlooked.

The variability of contaminants with the age was associated mainly to the feeding habits. The analogous habits, migratory and feeding, among penguin species can be the reason for similar elemental contents but these need more intensive monitoring.

The samples feathers chinstrap penguin of the colony from ASPA-171 of Barton Peninsula allowed provide a data base of elemental content control for the further study.

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