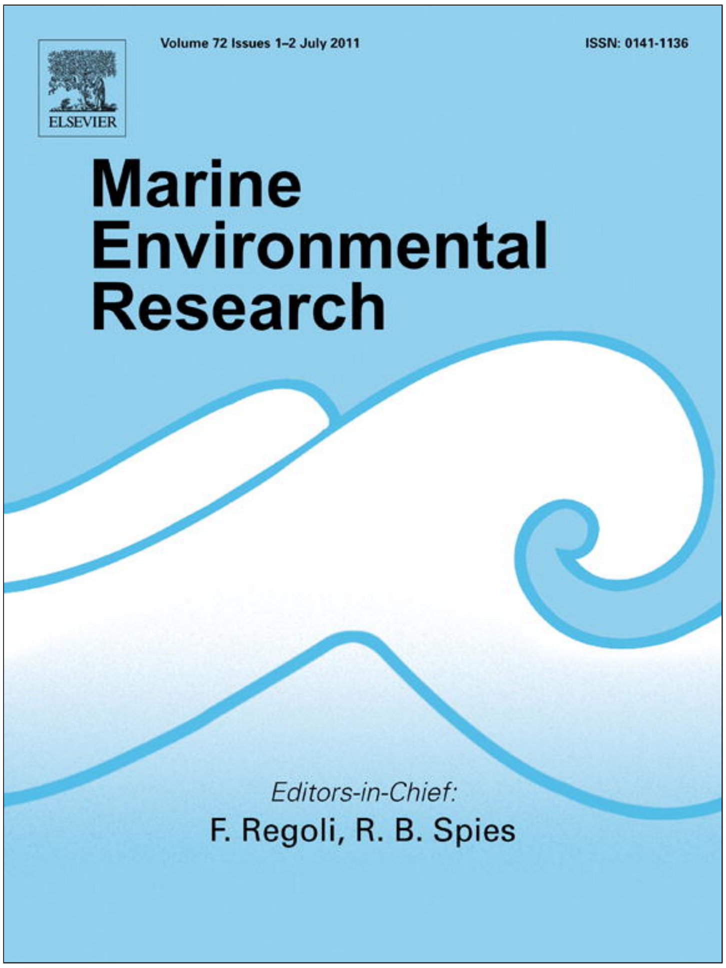
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Trace metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) in feathers of Black-browed Albatross *Thalassarche melanophrys* attending the Patagonian Shelf

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ABSTRACT

We investigated the concentrations of cadmium, chromium, copper, iron, nickel, lead and zinc among feather tissues in sexes of Black-browed Albatross *Thalassarche melanophrys* killed in longliners off Argentina in 2005. We found no different metal concentration with sex for cadmium, copper, iron, lead and zinc in feathers of adult birds, though there were significant body-size differences between sexes. However, the concentrations of trace metals differed significantly among the type of feather within individual bird. The mean concentrations of copper, iron, and zinc in breast feathers of *T. melanophrys* were lower than those reported for the species from Georgias del Sur/South Georgia, the southern Indian Ocean and for other seabirds' worldwide. While cadmium fall within the known range of concentrations for bird feathers lead were not. Our results may be indicating that level of pollution in Patagonia may not be as negligible as previously thought at least for some trace metals.

1. Introduction

Seabirds, and in particular albatrosses, have been widely used for monitoring the concentrations of contaminants in diverse marine regions as they feed far away from land and occupy high trophic levels in marine food webs, thus making them susceptible to the bioaccumulation of pollutants (Burger et al., 1994; Wolfe et al., 1998). Accordingly, monitoring of seabird species has proved to be an important method for assessing concentrations and effects of chemical contaminants in the aquatic environment (Gard and Hooper, 1995; Burger and Gochfeld, 2004; Mallory et al., 2010), and a growing number of studies are currently available for monitoring pollution (Honda et al., 1990; Elliot et al., 1992; Hindell et al., 1999; Burger and Gochfeld, 2000a; Savinov et al., 2003; Borga et al., 2006). Nevertheless, it has to be stressed that trace metal concentrations in seabirds depend on a variety of features such as their life history traits, breeding cycle, behavior and physiology, diet composition and the intensity and timing of exposure in foraging areas (Honda et al., 1986; Elliot et al., 1992; Nygård et al., 2001).

Previous published studies report trace metals concentrations for a number of South Atlantic albatross and petrel species (e.g. Muirhead and Furness, 1988, and Thompson and Furness, 1989a,b from Gough Island, and Becker et al., 2002; González-Solís et al., 2002, and Anderson et al., 2010 from Islas Georgias del Sur/South Georgia Islands). It is noteworthy to stress that the majority of the studies were conducted in feather tissues, and that for some metals (e.g. lead and mercury) the concentrations in feathers are strongly and positively correlated to the levels in blood (Burger and Gochfeld, 1990; Monteiro and Furness, 2001). Moreover, feather

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samples have been used extensively for evaluating trace metals exposure on various seabird species due to several methodological advantages they bring over other tissues (e.g. feathers provide easily obtainable and non-invasive matrices, they also provide retrospective time series analyses, and endangered species can be resampled systematically and released without substantial harm) (see Goede and De Bruin, 1986; Burger, 1993; Pilastro et al., 1993; Monteiro et al., 1998; Burger and Gochfeld, 2004, 2009). This is particularly relevant considering that all albatross species are globally threatened with extinction (ACAP, 2009; BirdLife International, 2010).

The Patagonian Shelf off Argentina and its shelf-break is an important ecosystem whose diversity of species and level of endemism is accompanied by a great biomass and abundance of food for a large number of marine vertebrates (fish, turtles, birds and mammals) most of which are migratory species from distant areas such as Antarctica, Australasia and Western Africa (Croxall and Wood, 2002; Acha et al., 2004; Favero and Silva Rodríguez, 2005). Several authors suggested that the Patagonian Shelf is an area where local pollution by trace metals is neglible or non-existent (Stewart et al., 1999; González-Solís et al., 2002; Barbieri et al., 2007). However, more robust information from the region is still needed for understanding contaminant concentrations and defining biological indicators in this important ecosystem.

This article presents novel data on concentrations of cadmium, chromium, copper, iron, lead, nickel and zinc in feathers of Black-browed Albatross *Thalassarche melanophrys* (herein BBA), coming from individuals incidentally killed while attending commercial longliners operating in the Patagonian Shelf off Argentina. Black-browed albatrosses breed in several subantarctic islands and archipelagoes in the Southern Ocean chiefly at the Malvinas/Falkland Islands and other island groups off southern Australia, Chile, and New Zealand and off south-eastern South Africa. Approximately 67% of the global population (estimated at ca. 602,000 breeding pairs) breeds in Malvinas/Falkland Islands (ACAP, 2009), just 400 km of the Argentine mainland. The majority of the Malvinas/Falkland Islands BBAs are resident on the Patagonian Shelf throughout the year, remaining largely within the core area of incubating birds (ca. within 3500 km), and in shelf and shelf-break waters (see Grémillet et al., 2000; Huin, 2002). Birds from adjacent colonies (e.g. Georgias del Sur/South Georgia Islands) migrate primarily to the east, reaching the Benguela Current area, with small numbers wintering on the Patagonian Shelf or around Australia (Prince et al., 1998; Phillips et al., 2005).

We focused on BBA given that: (1) it is the most important Procellariiform bird in Argentinean waters in terms of biomass (Favero and Silva Rodríguez, 2005), (2) it shows a strong interaction with commercial fisheries, and as such is the most commonly incidentally taken albatross species in Argentine waters (Favero et al., 2003; Gandini and Frere, 2006; Gómez-Laich et al., 2006; Seco Pon et al., 2007; Favero, 2008), and (3) it is listed as Endangered by the International Union for the Conservation of Nature (IUCN, BirdLife International, 2010). The overall objective of this study was to 1) to establish baseline trace metal concentrations against which to measure changes in elemental concentrations over time, and 2) to test hypotheses of no difference in the trace metal concentrations in BBA feathers coming from (a) different parts of the body, and (b) individuals of different sex.

2. Materials and methods

2.1. Sample collection

All of the birds sampled in this study were incidentally captured in the Kingclip *Genypterus blacodes* demersal longline fishery operating in waters of the Patagonian Shelf, Argentina chiefly between 42°S and 47°S and 59°W to 63°W. The longline systems used by this fishing industry has been previously described (Gandini and Frere, 2006; Gandini and Seco Pon, 2007). Overall, 50 adult BBAs incidentally captured during spring and summer 2005 were analyzed. Although a larger number of BBA carcasses were retrieved from longline operations at that period (see Seco Pon et al., 2007), only those birds without evidence of predation while they had been immersed on the longline were used in this study. Some of the birds were processed aboard fishing vessels while others were deep frozen and later transferred still frozen to the Centro de Investigaciones de Puerto Deseado, Argentina. After biometric measurements were made (Appendix A), birds were classified as juveniles or adults based on plumage characteristics and bill coloration (Prince et al., 1993). Sex was determined by visual inspection of gonads in the laboratory. The last grown primary feather (P10) (see Prince et al., 1993) was systematically obtained from the right wing of each sampled individual as a random pinch of feathers was plucked from the right side of the breast of the same individual. Given the difficulty in handling and weighing single feathers, multiple breast feathers were grouped and placed in envelopes. Although there may be some variation in metal concentrations among breast feathers, by using several feathers the differences are generally averaged (Bond and Diamond, 2008). Primary feathers were stored apart from breast feathers.

2.2. Element analysis

P10 and breast feathers were washed vigorously (at least three times) in deionized water alternated with acetone to remove loosely adherent external contamination (Burger et al., 1994), and then dried at 60 °C. All materials associated with trace metal extraction were thoroughly acid-cleaned and rinsed with deionized water before use (Clesceri et al., 1998). Samples were digested in a mixture of concentrated acids, according to methods described by Marcovecchio and Ferrer (2005). About 250 mg were removed from the outermost (distal) segment of each feather and mineralized with a 1:3 perchloric-nitric acid mixture in a thermostatic bath (at 120 ± 10 °C) up to minimum volume. Solutions were made up to 10 ml with 0.7% nitric acid. Each feather segment was sectioned, and each section digested separately to ensure the reproducibility of the method.

Element concentrations were determined using a Perkin–Elmer AA-2380 atomic absorption spectrophotometer with air/acetylene flame. Analytical grade reagents were used to build up the relevant blanks and calibration curves, and the analytical quality (AQ) was tested against reference materials (mussel tissue flour, R M N°6) provided by the National Institute for Environmental Studies (NIES) from Tsukuba (Japan). All elements were analyzed in dry mass tissue. Percentages ranges of recovery in the analysis of reference materials to assess analytical quality were between 91 and 101% for all the considered metals. The obtained values from the analysis of the reference materials were within the range of certified ones. The analytical precision expressed as coefficients of variance are $< 10\%$ for all the metals based on replicate analysis. Instrumental detection limits ($\mu g\ g^{-1}$) were: cadmium: 0.20, lead: 1.50, copper: 0.77, zinc: 0.88, iron: 2.73, nickel: 1.54 and chromium: 0.29.

2.3. Data analysis

Elements with mean concentrations below limits of detection (LOD), such as nickel and chromium, were reported in the summary statistics but excluded from further considerations or statistical analyses (see Anderson et al., 2010). Among the remaining elements, concentrations in some samples were below the limits of detection (maximum 48% and 24% of samples for cadmium in P10 and breast feathers respectively, 36% and 42% of samples for lead in P10 and breast feathers respectively). In these cases, a value equal to one-half the LOD limit for the type of feather sampled was assigned. Where element concentrations were below the limits of detection in >40% of samples overall for a particular type of feather those elements were also included in summary statistics but excluded from subsequent statistical analyses.

To analyze the relationship of metal concentrations with type of feather and sex, we employed general linear mixed models (GLMM) with normal error structure and identity link function (Crawley, 2007). This analysis was performed using GLMM to consider the non-independence of the type of feather within an individual bird. The relationship between the metal concentrations and type of feather and sex was modeled with individual identity as a random effect and type of feather and sex as fixed effect (Crawley, 2007). We also examined the covariation among elements in type of feathers of male and female birds using Pearson correlations. To run the GLMM and the Pearson, data were transformed using $\log_{10}$ (x) when necessary to accomplish assumptions of normality and variance homoscedasticity (Zar, 1999). Both arithmetic and geometric means are given to facilitate comparisons with other studies in literature. Statistical analysis of the data was performed using R software, Version 2.5.1. (R Development Core Team, 2004). In all cases, differences were considered significant where P was $\leq$0.05. Due to the small number of juvenile birds analyzed in this study ($n = 6$), statistical analyses were conducted in adult birds only. Metal concentrations (μg g^{-1} dry mass) are presented as means ± one SD.

3. Results

The mean concentration of cadmium, copper, iron, lead and zinc in the last grown primary and breast feathers of BBA are given in Table 1. Using GLMM, we found no significant interaction between feather type and sex for any of the metals analyzed (GLMM, all $P > 0.49$). However, the cadmium (GLMM: $F_{1,43} = 35.08$, $P < 0.001$), copper (GLMM: $F_{1,43} = 72.43$, $P < 0.001$), iron (GLMM: $F_{1,43} = 39.80$, $P < 0.001$), lead (GLMM: $F_{1,43} = 19.48$, $P < 0.001$), and zinc (GLMM: $F_{1,43} = 122.73$, $P < 0.001$) concentrations differed significantly among the type of feather within individual BBA. Breast feathers had significantly higher concentrations of cadmium, copper and lead than primary feathers, whilst primary feathers had significantly higher concentrations of iron and zinc than breast feathers.

Correlations among trace metal concentrations within feather type from birds of a particular sex were in general non significant, although there were some significant relationships. We found a significant positive correlation between copper and zinc concentrations in breast feathers of both male and female BBAs. Cadmium and copper, and iron and lead concentrations were correlated in the last grown primary feathers of male birds (Table 2).

4. Discussion

Overall, variation in the concentration of some metals (e.g. cadmium, cooper, iron and zinc) resulted as a function of the type of feather (either breast or primary) of individual BBA considered. Black-browed albatrosses moult their primary feathers biennially during the non-breeding period (Prince et al., 1993). This takes place from late April to early September – early October in the South Atlantic (Tickell, 2000). Like most small albatrosses, BBA replace its flight feathers seasonally in ordered sequences: the primaries outward and the secondaries inwards (Prince et al., 1993), but not all flights feathers are moulted in a single year (Onley and Scofield, 2007). Moreover, albatrosses have more flight feathers than any other group of birds, and based on pattern of feather replacement in North Pacific albatrosses, Edwards and Rohwer (2005) suggested that other species of albatross such as BBA may have multiple moult series throughout their wings. Because birds are able to eliminate a substantial portion of their body burden of certain trace metals via feather moulting, the concentration of certain metals may be not constant along this period (Dauwe et al., 2003). However, we lack information on the moulting sequence of birds retrieved dead from longline operations. Hence, comparisons and conclusions in this study are drawn exclusively from body feathers given that there are known to be most representative of concentrations in plumage as a whole (Furness et al., 1986; Lewis and Furness, 1991; Burger and Gochfeld, 2004).

There is very limited information in the literature on toxic elements apart from mercury in feathers from seabirds attending the Patagonian Shelf (González-Solís et al., 2002; Anderson et al., 2010). However, regional comparisons are possible given that concentrations of some of the metals analyzed in this study are available for the same species from Georgias del Sur/South Georgia, and the southern Indian Ocean (see Kim et al., 1998; Anderson et al., 2010). Since pollution by trace metals in the Patagonian Shelf is presumably non-existent or negligible (Stewart et al., 1999; González-Solís et al., 2002; Barbieri et al., 2007), we expected the concentrations of metals in feathers to be relatively low. In fact, Table 3 draws a parallel between elemental concentrations in feathers of BBA from the Southern Ocean region and related species – all Procellariiformes – from other locations in the world.

Cadmium is a non-essential metal that comes from a variety of anthropogenic sources (Burger, 1993; Furness, 1996). When compared with concentrations in the same tissue, cadmium concentrations in feathers of BBA analyzed in this study were lower than those reported in adult BBA and Grey-headed Albatross *Thalassarche chrysostoma* from Georgias del Sur/South Georgia (Anderson et al., 2010) but higher than those of the same species from the southern Indian Ocean (Kim et al., 1998). In a broader comparison, on average, cadmium fall within the known range of concentrations from bird feathers of related Procellariiformes

Table 1
Mean trace metal concentrations (in μg g^{-1}, dry mass) ± SD in the last grown primary (P10) and breast feathers of adult Black-browed Albatross *T. melanophrys* killed as by-catch in longline fisheries off Argentina in 2005. Geometric means are given in parentheses[1].

	Male ($n = 27$)		Female ($n = 17$)	
	Primary feather	Breast feathers	Primary feather	Breast feathers
Cadmium	0.33 ± 0.32 (0.21)	0.69 ± 0.67 (0.39)	0.33 ± 5.67 (0.24)	0.71 ± 0.64 (0.46)
Chromium	< LOD	< LOD	< LOD	< LOD
Copper	4.86 ± 1.75 (4.54)	9.67 ± 3.22 (9.04)	4.60 ± 1.83 (4.24)	10.02 ± 2.88 (9.66)
Iron	101.73 ± 122.32 (149.12)	21.53 ± 31.91 (38.10)	232.63 ± 355.77 (121.28)	29.65 ± 23.33 (21.87)
Lead	5.71 ± 5.67 (3.35)	3.17 ± 3.34 (1.96)	7.61 ± 12.03 (3.01)	3.35 ± 2.55 (2.56)
Nickel	< LOD	< LOD	< LOD	< LOD
Zinc	102.76 ± 127.37 (152.16)	28.18 ± 67.37 (72.11)	175.35 ± 135.67 (138.67)	72.95 ± 27.31 (69.16)

[1] < LOD below limit of detection.

Table 2
– Interelement concentrations with statistically significance in feathers of males (above the diagonal, $n = 27$) and females (below the diagonal, $n = 17$) Black-browed Albatross recovered from longline operations off Argentina[2].

Element	Cd	Cu	Fe	Pb	Zn
Cd	****************	NS	NS	NS	NS
	****************	NS	NS	NS	NS
Cu	0.523 (0.05)	****************	NS	NS	0.840 (<0.001)
	NS	*****************	NS	NS	NS
Fe	NS	NS	****************	NS	NS
	NS	NS	****************	NS	NS
Pb	NS	NS	NS	****************	NS
	NS	NS	0.510 (0.06)	****************	NS
Zn	NS	0.563 (0.05)	NS	NS	****************
	NS	NS	NS	NS	****************

[2]First row gives values for breast feathers. Second row gives values for the last grown primary feathers.
Comparisons with Pearson correlation (*P* values); NS indicates *P* values > 0.10.

species from different biogeographic areas (see Table 3). Like cadmium, lead is an element that plays no role in metabolic processes of animal organisms. It is an extremely toxic element with a wide range of harmful effects in birds (see review in De Francisco et al., 2003). Normal background concentrations of lead in feather of adult seabirds are in the range of 0.51–1.68 μg g^{-1} dry mass (Mendes et al., 2008; Burger and Gochfeld, 2009). Unfortunately regional comparisons are not possible since lead concentrations in BBA from neighboring waters were below the limit of detection (Anderson et al., 2010). Still, lead concentrations in BBA analyzed in this study were higher than those reported for birds obtained from fishing operations in the Indian Ocean (Kim et al., 1998). Moreover, lead concentrations in BBA feathers examined in the present study tended to be higher than those in any of the seabird species compared (see Table 3).

Copper concentrations in this study were lower than those reported for BBA from Georgias del Sur/South Georgia and the Indian Ocean (Kim et al., 1998; Anderson et al., 2010). Similar pattern was obtained when comparing BBA with related Procellariiformes species from other areas. Iron is a critical element for almost all vertebrates, but can have toxic effects of different magnitude on different bird taxa (Randell et al., 1981). Little information is available for iron concentrations in feather tissues of seabirds. In this study, iron concentrations in feathers were in general lower than those reported in BBA and other three albatross species from Georgias del Sur/South Georgia (Anderson et al., 2010). Zinc, one of the essential elements required for feather formation (Sunde, 1972), showed in this study lower concentrations than those reported for BBA from Georgias del Sur/South Georgia (Anderson et al., 2010), and any of the seabird species compared (see Table 3).

There are few studies concerning sex differences in elemental concentrations in birds. Burger (1993) summarized studies of sex-related differences in metal concentrations in feathers of birds and reported differences in three out of eight species studied. For

Table 3
Average (arithmetic mean) trace metal concentrations in feathers (μg g^{-1}, dry mass) of Black-browed Albatross and other seabirds from the literature and from this study.

Species		Location	Cadmium	Copper	Iron	Lead	Zinc	Source
Other seabirds from the Southern Ocean								
Black-browed Albatross	*Thalassarche melanophrys*	Bird Island, Georgias del Sur/South Georgia	0.578	8.613	610.216	< LOD[a]	39.592	Anderson et al. (2010)
		southern Indian Ocean[b]	0.070	10.4	Na	0.426	71.7	Kim et al. (1998)
		Patagonian Shelf[c]	0.200	1.01	1.46	4.31	1.84	This study
Grey-headed Albatross	*Thalassarche chrysostoma*	Bird Island, Georgias del Sur/South Georgia	0.196	5.661	229.219	< LOD[a]	50.115	Anderson et al. (2010)
Wandering Albatross	*Diomedea exulans*	Bird Island, Georgias del Sur/South Georgia	0.317	6.032	166.858	< LOD[a]	58.16	Anderson et al. (2010)
Northern Giant Petrel	*Macronectes halli*	Bird Island, Georgias del Sur/South Georgia	0.083	6.211	103.719	< LOD[a]	67.557	Anderson et al. (2010)
Southern Giant Petrel	*Macronectes giganteus*	Bird Island, Georgias del Sur/South Georgia	0.289	6.877	95.208	< LOD[a]	90.208	Anderson et al. (2010)
White-chinned Petrel	*Procellaria aequinoctialis*	Bird Island, Georgias del Sur/South Georgia	0.138	13.11	262.076	< LOD[a]	77.646	Anderson et al. (2010)
Antarctic Prion	*Pachyptila desolata*	Bird Island, Georgias del Sur/South Georgia	0.059	20.176	1.010.868	< LOD[a]	113.658	Anderson et al. (2010)
Blue Petrel	*Halobaena caerulea*	Bird Island, Georgias del Sur/South Georgia	0.074	8.745	986.705	< LOD[a]	6.953	Anderson et al. (2010)
Flesh-footed Shearwater	*Puffinus carneipes*	Lord Howe and Western Australia, Australia[d]	0.188	14.005	Na	0.493	50.416	Bond and Lavers (2010)
		Kauwahaia and Lady Alice Islands, New Zealand[d]	0.065	14.063	Na	0.419	96.115	Bond and Lavers (2010)
Other Procellariiformes globally								
Black-footed Albatross	*Phoebastria nigripes*	Midway Attol, North Pacific	0.152	Na	Na	0.973	Na	Burger and Gochfeld (2000b)
Laysan Albatross	*Phoebastria immutabilis*	Midway Attol, North Pacific	0.364	Na	Na	0.799	Na	Burger and Gochfeld (2000b)
Bonin Petrel	*Pterodroma hypoleuca*	Midway Attol, North Pacific	0.129	Na	Na	1.35	Na	Burger and Gochfeld (2000d)
Wedge-tailed Shearwater	*Puffinus pacificus*	Midway Attol, North Pacific	0.071	Na	Na	0.478	Na	Burger and Gochfeld (2000d)
Christmas Shearwater	*Puffinus nativitatis*	Midway Attol, North Pacific	0.950	Na	Na	2.38	Na	Burger and Gochfeld (2000d)

[a] < LOD below the limit of detection; Na not analyzed.
[b] Black-browed Albatross, Grey-headed Albatross and White-chinned Petrel combined.
[c] Breast feather of males and females combined.
[d] Values reported in fresh mass.

example, there were no significant differences between sexes for the same array of metals in feathers of adult Laysan Albatrosses *Phoebastria immutabilis* from northern Pacific (Burger and Gochfeld, 2000c). In this study, no different metal concentration with sex was observed for cadmium, copper, iron, lead, and zinc in feathers. Considering that biometric measurements revealed significant body-size differences between sexes in BBA (in line with that reported by Phillips et al., 2004 and Gandini et al., 2009), this finding was unexpected considering that metal concentrations were reported to vary in those species with body-size differences between sexes or differential diets, and also that females can eliminate trace metals by sequestering them in the eggshell or transferred via vitellus or the albumen (Burger, 1993; Furness, 1996; Lacoue-Labarthe et al., 2008; Bond and Diamond, 2009; Burger and Gochfeld, 2009). Other relevant variables (e.g. age, sex-specific foraging strategies, relative proportion of sex and time that birds spend behind fishing vessels, etc.) could play a role in determining metal concentrations. BBA frequently follow fishing vessels, being benefited from discards along the Patagonian Shelf (Croxall and Gales, 1998). Accordingly, BBA is the most abundant Procellariiform species attending national longline vessels, roughly representing 40% of individuals recorded in recent years (Gandini and Seco Pon, 2007). Additional research is needed to address the relative contribution of discards and offal from national longliners in BBA diet and the influence diet has upon metal concentrations in sexes of the species.

5. Conclusion

The results of this study indicate that the bulk of the toxic elements analyzed in feathers were below the medians of those reported for seabirds worldwide, but lead concentrations were higher than BBA from the Indian Ocean and any of the related Procellariiformes species selected for comparison. Thus, our results may be indicating that level of pollution in Patagonia may not be as negligible as previously thought at least for some trace metals. However, one disadvantage when using pelagic seabirds such as albatrosses to characterize marine environments is the wide feeding range of albatrosses also greatly varying between and within the year (Grémillet et al., 2000; Huin, 2002). Yet, other disadvantage when using feathers to evaluate concentrations of lead, cadmium, and many other elements is that total concentration may be the result of two combined processes: deposition (from the atmosphere onto the surface of feather) or incorporation (from the blood) (Furness and Camphuysen, 1997). For feathers to be maximally useful as tools to assess current body burden or concentrations of metals in internal avian tissues there should be a solid relationship between the concentrations in feathers and other tissues (Burger, 1993). Given that relatively high lead concentrations have been reported in several tissues (e.g. blood, bones, feathers) and vital organs (e.g. liver, kidneys, salt gland) of pelagic seabird species (see Kim et al., 1998; Burger and Gochfeld, 2000c; González-Solís et al., 2002; Metcheva et al., 2006; Anderson et al., 2010), further investigations are needed to study features of lead bioaccumulation in different tissues of Black-browed albatrosses feeding in the Patagonian Shelf, particularly in bone as this is the principal site for long-term storage (De Francisco et al., 2003).

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Appendix A

Biometric data (mean ± SD) of adult Black-browed Albatross *Thalassarche melanophrys* incidentally killed in longliners off Argentina. Kruskall-Wallis one-way ANOVA (*H*) and probabilities (*P*) are also given.

	Male	Female	H (*P*)
	$n = 23$	$n = 17$	
Bill length (cm)	12.02 ± 0.39	12.06 ± 1.19	1.783 (NS)
Bill depth (cm)[a]	2.44 ± 0.97	1.57 ± 1.25	4.361 (0.042)
Nalopsi (cm)[b]	3.37 ± 1.34	2.22 ± 1.78	3.988 (NS)
Head width (cm)	6.35 ± 0.21	6.07 ± 0.28	9.19 (0.05)
Nape (cm)	7.65 ± 0.53	7.04 ± 0.33	12.612 (0.001)
Wing length (cm)	110.02 ± 2.21	109.64 ± 8.44	0.0329 (NS)
Tarsus (cm)	8.05 ± 0.29	8.29 ± 0.33	3.9 (NS)
Weight (g)	4652.63 ± 428.97	3939.58 ± 320.41	24.125 (<0.001)

NS not significant.
[a] Minimum depth at the mid length of the bill.
[b] Distance from the upper mandible to the lower mandibule at the nostril.

References

Acha, E.M., Mianzan, H.W., Guerrero, R.A., Favero, M., Bava, J., 2004. Marine fronts at the continental shelves of austral South America: Physical and ecological processes. Journal of Marine Systems 44, 83–105.
Agreement on the Conservation of Albatrosses and Petrels (ACAP), 2009. The ACAP Species Assessments Available from. http://www.acap.aq/acap-species.
Anderson, O.R.J., Phillips, R.A., Shore, R.F., McGill, R.A.R., McDonald, R.A., Bearhop, S., 2010. Element patterns in albatrosses and petrels: influence of trophic position, foraging range, and prey type. Environmental Pollution 158, 98–107.
Barbieri, E., Garcia, C.A.B., Passos, E.A., Aragão, K.A.S., 2007. Heavy metal concentration in tissues of *Puffinus gravis* sampled on the Brazilian coast. Ararajuba 15, 69–72.
Becker, P.H., González-Solís, J., Behrends, B., Croxall, J.P., 2002. Feather mercury levels in seabirds at South Georgia: influence of trophic position, sex and age. Marine Ecology Progress Series 243, 261–269.
BirdLife International, 2010. Species Factsheet: Thalassarche Melanophrys Available from. http://www.birdlife.org./datazone/speciesfactsheet.php?id=3959.
Bond, A.L., Diamond, A.W., 2008. High within-individual variation in total mercury concentration in seabird feathers. Environmental Toxicology and Chemistry 27, 2375–2377.
Bond, A.L., Diamond, A.W., 2009. Total and methyl mercury concentrations in seabird feathers and eggs. Archives of Environmental Contamination and Toxicology 56, 286–291.
Bond, A.L., Lavers, J.L., 2010. Trace element concentrations in feathers of Flesh-footed Shearwaters (*Puffinus carneipes*) from across their breeding range. Archives of Environmental Contamination and Toxicology. doi:10.1007/s00244-010-9605-3.
Borga, K., Campbell, L., Gabrielsen, G.W., Norstrom, R.J., Muir, D.C.G., Fisk, A.T., 2006. Regional and species specific bioaccumulation of major and trace elements in arctic seabirds. Environmental Toxicology 25, 2927–2936.
Burger, J., 1993. Metals in avian feathers: bioindicators of environmental pollution. Reviews in Environmental Toxicology 5, 203–311.
Burger, J., Gochfeld, M., 1990. Tissue levels of lead in experimentally exposed Herring Gull (*Larus argentatus*) chicks. Journal of Toxicology and Environmental Health 29, 219–233.
Burger, J., Gochfeld, M., 2000a. Effects of chemicals and pollution on seabirds. In: Schreiber, E.A., Burger, J. (Eds.), Biology of Marine Birds. CRC Press, Boca Raton, Florida, pp. 485–525.
Burger, J., Gochfeld, M., 2000b. Metals in albatross feathers from Midway Atoll: influence of species, age and nest location. Environmental Research Section A 82, 207–221.
Burger, J., Gochfeld, M., 2000c. Metals in Laysan albatrosses from Midway Atoll. Archives of Environmental Contamination and Toxicology 38, 254–259.
Burger, J., Gochfeld, M., 2000d. Metals levels in feathers of 12 species of seabirds from Midway Atoll in the northern Pacific Ocean. Science of the Total Environment 257, 37–52.
Burger, J., Gochfeld, M., 2004. Marine birds as sentinels of environmental pollution. EcoHealth 1, 263–274.
Burger, J., Gochfeld, M., 2009. Mercury and other metals in feathers of Common Eider *Somateria mollissima* and Tufted Puffin *Fratercula cirrhata* from the Aleutian chain of Alaska. Archives of Environmental Contamination and Toxicology 56, 596–606.
Burger, J., Nisbet, I.C.T., Gochfeld, M., 1994. Heavy metal and selenium levels in feathers of known-aged Common terns *Sterna hirundo*. Archives of Environmental Contamination and Toxicology 26, 351–355.

Clesceri, L.S., Greenberg, A.E., Eaton, A.D., 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed.. American Public Health Association, Washington.

Crawley, M.J., 2007. The R Book. Wiley, Chichester, U.K.

Croxall, J.P., Gales, R., 1998. An assessment of the conservation status of albatross. In: Robertson, G., Gales, R. (Eds.), Albatross Biology and Conservation. Surrey Beatty and Sons Ltd, Australia, pp. 46–65.

Croxall, J.P., Wood, A.G., 2002. The importance of the Patagonian shelf for top predator species breeding at south Georgia. Aquatic conservation. Marine and Freshwater Ecosystems 12, 101–118.

Dauwe, T., Bervoets, L., Pinxten, R., Blust, R., Eens, M., 2003. Variation of heavy metals within and among feathers of birds of prey: effects of molt and external contamination. Environmental Pollution 124, 429–436.

De Francisco, N., Ruiz Troya, J.D., Aguera, E.I., 2003. Lead and lead toxicity in domestic and free living birds. Avian Pathology 32, 3–13.

Edwards, A.R., Rohwer, S., 2005. Large-scale patterns of molt activation in the flight feathers of two albatross species. Condor 107, 835–848.

Elliot, J.E., Scheuhammer, A.M., Leighton, F.A., Pearce, P.A., 1992. Heavy metal and metallothionein concentrations in Atlantic Canadian seabirds. Archives of Environmental Contamination and Toxicology 22, 63–73.

Favero, M., 2008. South American perspective: fisheries mortality. In: De Roy, T., Jones, M., Fitter, J. (Eds.), Albatross: Their World, Their Ways. David Bateman Ltd, Auckland, pp. 176–177.

Favero, M., Silva Rodríguez, M.P., 2005. Estado actual y conservación de aves pelágicas que utilizan la plataforma continental Argentina como área de forrajeo. El Hornero 20, 95–110.

Favero, M., Khatchikian, C., Arias, A., Silva Rodríguez, M.P., Cañete, G., Mariano-Jelicich, R., 2003. Estimates of seabird by-catch along the Patagonian Shelf by Argentine longline fishing vessels, 1999-2001. Bird Conservation International 13, 273–281.

Furness, R.W., 1996. Cadmium in birds. In: Beyer, W.N., Heinz, S.H., Redmon-Norwood, A.W. (Eds.), Environmental Contaminants in Wildlife. Lewis Publishers, Boca Raton, Florida, pp. 389–404.

Furness, R.W., Camphuysen, Kees, C.J., 1997. Seabirds and monitors of the marine environment. ICES Journal of Marine Science 54, 726–737.

Furness, R.W., Muirhead, S.J., Woodburn, M., 1986. Using bird feathers to measure mercury in the environment: relationship between mercury content and moult. Marine Pollution Bulletin 17, 27–37.

Gómez-Laich, A., Favero, M., Mariano-Jelicich, R., Blanco, G., Cañete, G., Arias, A., Silva Rodríguez, M.P., Brachetta, H., 2006. Environmental and operational variability affecting the mortality of Black-Browed Albatrosses associated to longliners in Argentina. Emu 106, 21–28.

Gandini, P.A., Frere, E., 2006. Spatial and temporal patterns in the bycatch of seabirds in the Argentinean longline fishery. Fisheries Bulletin 104, 482–485.

Gandini, P., Seco Pon, J.P., 2007. Seabird assemblages attending longline vessels in the Argentinean Economic Exclusive Zone. Ornitología Neotropical 18, 553–561.

Gandini, P., Frere, E., García, M.F., Seco Pon, J.P., 2009. Sexual differences in external measurements of Black-browed albatross *Diomedea melanophrys* incidentally killed during longline operations. El Hornero 23, 43–46.

Gard, N.W., Hooper, M.J., 1995. An assessment of potential hazards of pesticides and environmental contaminants. In: Martin, T.E., Finch, D.M. (Eds.), Ecology and Management of Neotropical Migratory Birds: a Synthesis and Review of Critical Issues. Oxford University Press, New York, pp. 295–310.

Goede, A.A., De Bruin, M., 1986. The use of bird feathers for indicating heavy metal pollution. Environmental Monitoring and Assessment 7, 249–256.

González-Solís, J., Sampera, C., Ruiz, X., 2002. Metals and selenium as bioindicators of geographic and trophic segregation in Giant petrels *Macronectes* spp. Marine Ecology Progress Series 244, 257–264.

Grémillet, D., Wilson, R.P., Wanless, S., Chater, T., 2000. Black-browed albatrosses, international fisheries and the Patagonian Shelf. Marine Ecology Progress Series 195, 269–280.

Hindell, M.A., Brothers, N., Gales, R., 1999. Mercury and cadmium concentrations in the tissues of three species of southern albatrosses. Polar Biology 22, 102–108.

Honda, K., Nasu, T., Tatsukawa, R., 1986. Seasonal changes in mercury accumulation in the Black-eared Kite, *Milvus migrans lineatus*. Environmental Pollution 42, 325–334.

Honda, K., Marcovecchio, J.E., Kan, S., Tatsukawa, R., Ogi, H., 1990. Metal concentrations in pelagic seabirds from the North Pacific Ocean. Archives of Environmental Contamination and Toxicology 19, 704–711.

Huin, N., 2002. Foraging distribution of the black-browed albatross, *Thalassarche melanophrys*, breeding in the Falkland islands. Aquatic Conservation: Marine and Freshwater Ecosystems 12, 89–99.

Kim, E.Y., Goto, R., Tanabe, S., Tanaka, H., Tatsukawa, R., 1998. Distribution of 14 elements in tissues and organs of oceanic seabirds. Archives of Environmental Contamination and Toxicology 35, 638–645.

Lacoue-Labarthe, T., Warnau, M., Oberhänsli, F., Teyssié, J.L., Jeffree, R., Bustamante, P., 2008. First experiments on the maternal transfer of metals in the cuttlefish *Sepia officinalis*. Marine Pollution Bulletin 57, 826–831.

Lewis, S.A., Furness, R.W., 1991. Mercury accumulation and excretion in laboratory reared black-headed gull *Larus ridibundus* chicks. Archives of Environmental Contamination and Toxicology 21, 316–320.

Mallory, M.L., Robinson, S.A., Hebert, C.E., Forbes, M.R., 2010. Seabirds as indicators of aquatic ecosystem conditions: a case for gathering multiple proxies of seabird health. Marine Pollution Bulletin 60, 7–12.

Marcovecchio, J., Ferrer, L., 2005. Distribution and geochemical partitioning of heavy metals in sediments of the Bahía Blanca Estuary, Argentina. Journal of Coastal Research 21, 826–834.

Mendes, P., Eira, C., Torres, J., Soares, A.M.V.M., Melo, P., Vingada, J., 2008. Toxic element concentration in the Atlantic Gannet *Morus bassanus* (Pelecaniformes, Sulidae) in Portugal. Archives of Environmental Contamination and Toxicology 55, 209–503.

Metcheva, R., Yurukova, L., Tedorova, S., Nikolova, E., 2006. The penguin feathers as bioindicator of Antarctica environmental state. Science of the Total Environment 362, 259–265.

Monteiro, L.R., Furness, R.W., 2001. Kinetics, dose-response, and excretion of methylmercury in free-living adult Corýs Shearwaters. Environmental Science and Technology 35, 739–746.

Monteiro, L.R., Granadeiro, J.P., Furness, R.W., 1998. Relationship between mercury levels and diet in Azores seabirds. Marine Ecology Progress Series 166, 259–265.

Muirhead, S.J., Furness, R.W., 1988. Heavy metals concentrations in the tissues of seabirds from Gough island, south Atlantic ocean. Marine Pollution Bulletin 19, 278–283.

Nygärd, T., Lie, E., Røv, N., Steinnes, E., 2001. Metal dynamics in an Antarctic food chain. Marine Pollution Bulletin 7, 598–602.

Onley, D., Scofield, P., 2007. Albatrosses, Petrels and Shearwaters of the World. Princeton University Press.

Phillips, R.A., Silk, J.R.D., Phalan, B., Catry, P., Croxall, J.P., 2004. Seasonal sexual segregation in two *Thalassarche* albatross species: competitive exclusion, reproductive role specialization or foraging niche divergence? Proc. Royal Soc. London Ser. B. Biol. Sci. 271, 1283–1291.

Phillips, R.A., Silk, J.R.D., Croxall, J.P., Afanasyev, V., Bennett, V.J., 2005. Summer distribution and migration of non-breeding albatrosses: individual consistencies and implications for conservation. Ecology 86, 2386–2396.

Pilastro, A., Congiu, L., Tallandini, L., Turchetto, M., 1993. The use of bird feathers for the monitoring of cadmium pollution. Archives of Environmental Contamination and Toxicology 24, 355–358.

Seco Pon, J.P., Gandini, P., Favero, M., 2007. Effect of longline configuration on the seabird mortality in the Argentine semi-pelagic Kingclip *Genypterus blacodes* fishery. Fisheries Research 85, 101–105.

Prince, P.A., Rodwell, S., Jones, M., Rother, Y.P., 1993. Moult in Black-browed and Grey-headed Albatrosses *Diomedea melanophrys* and *D. chrysostoma*. Ibis 135, 121–131.

Prince, P.A., Croxall, J.P., Trathan, P.N., Wood, A.G., 1998. The pelagic distribution of South Georgia albatrosses and their relationship with fisheries. In: Robertson, G., Gales, R. (Eds.), Albatross Biology and Conservation. Surrey Beatty and Sons Ltd, Australia, pp. 137–167.

R Development Core Team., 2004. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing Vienna, Austria. Available from http://www.R-project.org.

Randell, M.G., Patnaik, A.K., Gould, W.J., 1981. Hepatopathy associated with excessive iron storage in mynah birds. Journal of the American Veterinary Medical Association 179, 1214–1217.

Savinov, V.M., Gabrielsen, G.W., Savinova, T.N., 2003. Cadmium, zinc, copper, arsenic, selenium and mercury in seabirds from the Barents Sea: levels, inter-specific and geographical differences. Science of the Total Environment 306, 133–158.

Stewart, F.M., Phillips, R.A., Bartle, J.A., Craig, J., Shooter, D., 1999. Influence of phylogeny, diet, moult schedule and sex on heavy metal concentrations in New Zealand Procellariiformes. Marine Ecology Progress Series 178, 295–305.

Sunde, M.L., 1972. Zinc requirement for normal feathering of commercial Leghorn-type pullets. Poultry Science 51, 1316–1322.

Thompson, D.R., Furness, R.W., 1989a. Comparison of the levels of total and organic mercury in seabird feathers. Marine Pollution Bulletin 20, 577–579.

Thompson, D.R., Furness, R.W., 1989b. The chemical form of mercury stores in South Atlantic seabirds. Environmental Pollution 60, 305–317.

Tickell, W.L.N., 2000. Albatrosses. Pica Press, East Sussex, U.K.

Wolfe, M.F., Schwarzbach, S., Sulaiman, R.A., 1998. Effects of mercury on widlife: a comprehensive review. Environmental Toxicology and Chemistry 17 (2), 146–160.

Zar, I., 1999. Biostatistical Analysis. Forth Edition. Prentice-Hall Press, Englewood Cliffs, New Jersey.