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Authors: Juan Pablo Seco Pon, Ornella Beltrame, Jorge Marcovecchio, Marco Favero, Patricia Gandini

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Title:

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

Name of authors:

Juan Pablo Seco Pon^{a,b*}, Ornela Beltrame^{c,d}, Jorge Marcovecchio^d, Marco Favero^{a,b},
Patricia Gandini^{a,e,f}

Affiliations of the authors:

^aConsejo Nacional de Investigaciones Científicas y Técnicas (CONICET). Av.
Rivadavia 1917 (C1033AAJ) Buenos Aires, Argentina.

^bVertebrados, Departamento de Biología, Facultad de Ciencias Exactas y Naturales,
Universidad Nacional de Mar del Plata. Funes 3250 (B7602AYJ) Mar del Plata,
Provincia de Buenos Aires, Argentina. Tel. +54 223 4752426 int. 466.

^cDepartamento de Biología, Facultad de Ciencias Exactas y Naturales, Universidad
Nacional de Mar del Plata. Funes 3250 (B7602AYJ) Mar del Plata, Provincia de Buenos
Aires, Argentina.

^dLaboratorio de Química Marina, Instituto Argentino de Oceanografía (IADO). Florida
4000, Edificio E1, Casilla de Correo 804 (8000) Bahía Blanca, Provincia de Buenos
Aires, Argentina.

^eUniversidad Nacional de la Patagonia Austral. CIPD Av. Prefectura s/n (9050) Puerto
Deseado, Provincia de Santa Cruz, Argentina.

^fWildlife Conservation Society. Wildlife Conservation Society, 2300 Southern
Boulevard, 18 Bronx, New York 10460.

***Corresponding author:**

Juan Pablo Seco Pon (double family name)
Tel. +54 223 4752426 int. 466.
E-mail: secoPON@mdp.edu.ar

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.

Keywords: Argentina; Black-browed Albatross; Feather tissues; Trace metals; Ocean space; Patagonian Shelf, Pollution monitoring; Seabirds.

48 **1. Introduction**

49 Seabirds, and in particular albatrosses, have been widely used for monitoring the
50 concentrations of contaminants in diverse marine regions as they feed far away from
51 land and occupy high trophic levels in marine food webs, thus making them susceptible
52 to the bioaccumulation of pollutants (Burger et al., 1994; Wolfe et al., 1998).
53 Accordingly, monitoring of seabird species has proved to be an important method for
54 assessing concentrations and effects of chemical contaminants in the aquatic
55 environment (Gard and Hooper, 1995; Burger and Gochfeld, 2004; Mallory et al.,
56 2010), and a growing number of studies is currently available for monitoring pollution
57 (Honda et al., 1990; Elliott et al., 1992; Hindell et al., 1999; Burger and Gochfeld,
58 2000a; Savinov et al., 2003; Borga et al., 2006). Nevertheless, it has to be stressed that
59 trace metal concentrations in seabirds depend on a variety of features such as their life
60 history traits, breeding cycle, behavior and physiology, diet composition and the
61 intensity and timing of exposure in foraging areas (Honda et al., 1986; Elliot et al.,
62 1992; Nygård et al., 2001).

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

96 67% of the global population (estimated at ca. 602,000 breeding pairs) breeds in
97 Malvinas/Falkland Islands (ACAP 2009), just 400 km of the Argentine mainland. The
98 majority of the Malvinas/ Falkland Islands BBAs are resident on the Patagonian Shelf
99 throughout the year, remaining largely within the core area of incubating birds (ca.
100 within 3500 km), and in shelf and shelf-break waters (see Grémillet et al., 2000; Huin,
101 2002). Birds from adjacent colonies (e.g. Georgias del Sur/ South Georgia Islands)
102 migrate primarily to the east, reaching the Benguela Current area, with small numbers
103 wintering on the Patagonian Shelf or around Australia (Prince et al., 1998; Phillips et
104 al., 2005).

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

116

117

118 **2. Materials and methods**

119 **2.1. Sample collection**

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

141

142 **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 91-101% 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 ($\mu\text{g g}^{-1}$) 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

191 where P was ≤ 0.05 . Due to the small number of juvenile birds analyzed in this study (n
 192 = 6), statistical analyses were conducted in adult birds only. Metal concentrations ($\mu\text{g g}^{-1}$
 193 dry mass) are presented as means $\pm$ one SD.

194

195 3. Results

196 The mean concentration of cadmium, copper, iron, lead and zinc in the last
 197 grown primary and breast feathers of BBA are given in Table 1. Using GLMM, we
 198 found no significant interaction between feather type and sex for any of the metals
 199 analyzed (GLMM, all $P > 0.49$). However, the cadmium (GLMM: $F_{1,43} = 35.08$, $P <$
 200 0.001), copper (GLMM: $F_{1,43} = 72.43$, $P < 0.001$), iron (GLMM: $F_{1,43} = 39.80$, $P <$
 201 0.001), lead (GLMM: $F_{1,43} = 19.48$, $P < 0.001$), and zinc (GLMM: $F_{1,43} = 122.73$, $P <$
 202 0.001) concentrations differed significantly among the type of feather within individual
 203 BBA. Breast feathers had significantly higher concentrations of cadmium, copper and
 204 lead than primary feathers, whilst primary feathers had significantly higher
 205 concentrations of iron and zinc than breast feathers.

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

212

213 4. Discussion

Overall, variation in the concentration of some metals (e.g. cadmium, copper, 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 flight 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 Rowher (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 *T. 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 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 to 1.68 $\mu\text{g g}^{-1}$ 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

261 examined in the present study tended to be higher than those in any of the seabird
 262 species compared (see Table 3).

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

275 There are few studies concerning studies of sex differences in elemental
 276 concentrations in birds. Burger (1993) summarized studies of sex-related differences in
 277 metal concentrations in feathers of birds and reported differences in three out of eight
 278 species studied. For example, there were no significant differences between sexes for
 279 the same array of metals in feathers of adult Laysan Albatrosses *Phoebastria*
 280 *immutabilis* from northern Pacific (Burger and Gochfeld, 2000c). In this study, no
 281 different metal concentration with sex was observed for cadmium, copper, iron, lead,
 282 and zinc in feathers. Considering that biometric measurements revealed significant
 283 body-size differences between sexes in BBA (in line with that reported by Phillips et al.,
 284 2004 and Gandini et al., 2009), this finding was unexpected considering that metal

285 concentrations were reported to vary in those species with body-size differences
286 between sexes or differential diets, and also that females can eliminate trace metals by
287 sequestering them in the eggshell or transferred via vitellus or the albumen (Burger,
288 1993; Furness, 1996; Lacoue-Labarthe et al., 2008; Bond and Diamond, 2009; Burger
289 and Gochfeld, 2009). Other relevant variables (e.g. age, sex-specific foraging strategies,
290 relative proportion of sex and time that birds spend behind fishing vessels, etc.) could
291 play a role in determining metal concentrations. BBA frequently follow fishing vessels,
292 being benefited from discards along the Patagonian Shelf (Croxall and Gales, 1998).
293 Accordingly, BBA is the most abundant Procellariiform species attending national
294 longline vessels, roughly representing 40% of individuals recorded in recent years
295 (Gandini and Seco Pon, 2007). Additional research is needed to address the relative
296 contribution of discards and offal from national longliners in BBA diet and the
297 influence diet has upon metal concentrations in sexes of the species.

298

299

300 **5. Conclusion**

301 The results of this study indicate that the bulk of the toxic elements analyzed in
302 feathers were below the medians of those reported for seabirds worldwide, but lead
303 concentrations were higher than BBA from the Indian Ocean and any of the related
304 Procellariiformes species selected for comparison. Thus, our results may be indicating
305 that level of pollution in Patagonia may not be as negligible as previously thought at
306 least for some trace metals. However, one disadvantage when using pelagic seabirds
307 such as albatrosses to characterize marine environments is the wide feeding range of
308 albatrosses also greatly varying between and within the year (Grémillet et al., 2000;

309 Huin, 2002). Yet, other disadvantage when using feathers to evaluate concentrations of
310 lead, cadmium, and many other elements is that total concentration may be the result of
311 two combined processes: deposition (from the atmosphere onto the surface of feather)
312 or incorporation (from the blood) (Furness and Camphuysen, 1997). For feathers to be
313 maximally useful as tools to assess current body burden or concentrations of metals in
314 internal avian tissues there should be a solid relationship between the concentrations in
315 feathers and other tissues (Burger, 1993). Given that relatively high lead concentrations
316 have been reported in several tissues (e.g. blood, bones, feathers) and vital organs (e.g.
317 liver, kidneys, salt gland) of pelagic seabird species (see Kim et al., 1998; Burger and
318 Gochfeld, 2000c; González-Solís et al., 2002; Metcheva et al., 2006; Anderson et al.,
319 2010), further investigations are needed to study features of lead bioaccumulation in
320 different tissues of Black-browed albatrosses feeding in the Patagonian Shelf,
321 particularly in bone as this is the principal site for long-term storage (De Francisco et
322 al., 2003).

323

324

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332

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- 566

567 **Table 1** – Mean trace metal concentrations (in $\mu\text{g g}^{-1}$, dry mass) $\pm$ SD in the last grown
568 primary (P10) and breast feathers of adult Black-browed Albatross *Thalassarche*
569 *melanophrys* killed as by-catch in longline fisheries off Argentina in 2005. Geometric
570 means are given in parentheses.
571

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

575

576

577

578 **Table 3** - Average (arithmetic mean) trace metal concentrations in feathers ($\mu\text{g g}^{-1}$, dry
579 mass) of Black-browed Albatross and other seabirds from the literature and from this
580 study.
581

582 **Appendix A** - Biometric data (mean $\pm$ SD) of adult Black-browed Albatross
583 *Thalassarche melanophrys* incidentally killed in longliners off Argentina. Kruskal-
584 Wallis one-way ANOVA (H) and probabilities (P) are also given.
585

> Information on the concentrations of trace metals in southern ocean seabirds is scarce.
> We examine concentrations of seven trace metals in feathers of Black-browed Albatross off Argentina. > Concentrations of cadmium, copper, iron, lead and zinc in feathers were not affected by sex. > The mean concentrations of copper, iron, and zinc in feathers of birds were lower than those reported for the species from relative nearby oceanic areas. > While cadmium concentrations fall within the known range 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.

- > Concentrations of trace metals in feathers of Black-browed Albatross were examined.
- > Concentrations of cadmium, copper, iron, lead and zinc were not affected by sex. >
- Concentrations of essential elements were lower than those reported for the species. >
- As cadmium concentrations fall within the known range for feathers lead were not. >
- Level of pollution in Patagonia may not be negligible at least for lead.

	Male (<i>n</i> = 27)		Female (<i>n</i> = 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 1

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	*****

²First 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

TABLE 2

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*	0.070	10.4	Na	0.426	71.7	Kim et al. (1998)
		Patagonian Shelf**	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***	0.188	14.005	Na	0.493	50416	Bond and Lavers (2010)
		Kauwahaia and Lady Alice Islands, New Zealand***	0.065	14.063	Na	0.419	96115	Bond and Lavers (2010)
Other Procellariiformes globally								
Black-footed Albatross	Phoebastria nigripes	Midway Atoll, North Pacific	0.152	Na	Na	0.973	Na	Burger and Gochfeld (2000b)
Laysan Albatross	Phoebastria immutabilis	Midway Atoll, North Pacific	0.364	Na	Na	0.799	Na	Burger and Gochfeld (2000b)
Bonin Petrel	Pterodroma hypoleuca	Midway Atoll, North Pacific	0.129	Na	Na	1.35	Na	Burger and Gochfeld (2000d)
Wedge-tailed Shearwater	Puffinus pacificus	Midway Atoll, North Pacific	0.071	Na	Na	0.478	Na	Burger and Gochfeld (2000d)
Christmas Shearwater	Puffinus nativitatis	Midway Atoll, North Pacific	0.950	Na	Na	2.38	Na	Burger and Gochfeld (2000d)

^a < LOD below the limit of detection; Na not analyzed.

* Black-browed Albatross, Grey-headed Albatross and White-chinned Petrel combined.

** Breast feather of males and females combined.

*** Values reported in fresh mass.

TABLE 3