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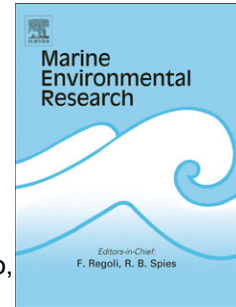
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4

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30 **Abstract**

31

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

44

45

46 **Keywords:** Argentina; Black-browed Albatross; Feather tissues; Trace metals; Ocean
47 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

72 several methodological advantages they bring over other tissues (e.g. feathers provide
73 easily obtainable and non-invasive matrices, they also provide retrospective time series
74 analyses, and endangered species can be resampled systematically and released without
75 substantial harm) (see Goede and De Bruin, 1986; Burger, 1993; Pilastro et al., 1993;
76 Monteiro et al., 1998; Burger and Gochfeld, 2004, 2009). This is particularly relevant
77 considering that all albatross species are globally threatened with extinction (ACAP,
78 2009; BirdLife International, 2010).

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

89 This article presents novel data on concentrations of cadmium, chromium,
90 copper, iron, lead, nickel and zinc in feathers of Black-browed Albatross *Thalassarche*
91 *melanophrys* (herein BBA), coming from individuals incidentally killed while attending
92 commercial longliners operating in the Patagonian Shelf off Argentina. Black-browed
93 albatrosses breed in several subantarctic islands and archipelagoes in the Southern
94 Ocean chiefly at the Malvinas/ Falkland Islands and other island groups off southern
95 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**

143 P10 and breast feathers were washed vigorously (at least three times) in
144 deionized water alternated with acetone to remove loosely adherent external
145 contamination (Burger et al., 1994), and then dried at 60° C. All materials associated
146 with trace metal extraction were thoroughly acid-cleaned and rinsed with deionized
147 water before use (Clesceri et al., 1998). Samples were digested in a mixture of
148 concentrated acids, according to methods described by Marcovecchio and Ferrer (2005).
149 About 250 mg were removed from the outermost (distal) segment of each feather and
150 mineralized with a 1:3 perchloric-nitric acid mixture in a thermostatic bath (at 120 ± 10
151 °C) up to minimum volume. Solutions were made up to 10 ml with 0.7 % nitric acid.
152 Each feather segment was sectioned, and each section digested separately to ensure the
153 reproducibility of the method.

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

166

167 2.3. Data analysis

168 Elements with mean concentrations below limits of detection (LOD), such as nickel
169 and chromium, were reported in the summary statistics but excluded from further
170 considerations or statistical analyses (see Anderson et al., 2010). Among the remaining
171 elements, concentrations in some samples were below the limits of detection (maximum
172 48% and 24% of samples for cadmium in P10 and breast feathers respectively, 36% and
173 42% of samples for lead in P10 and breast feathers respectively). In these cases, a value
174 equal to one-half the LOD limit for the type of feather sampled was assigned. Where
175 element concentrations were below the limits of detection in >40% of samples overall
176 for a particular type of feather those elements were also included in summary statistics
177 but excluded from subsequent statistical analyses.

178 To analyze the relationship of metal concentrations with type of feather and sex,
179 we employed general linear mixed models (GLMM) with normal error structure and
180 identity link function (Crawley, 2007). This analysis was performed using GLMM to
181 consider the non-independence of the type of feather within an individual bird. The
182 relationship between the metal concentrations and type of feather and sex was modeled
183 with individual identity as a random effect and type of feather and sex as fixed effect
184 (Crawley, 2007). We also examined the covariation among elements in type of feathers
185 of male and female birds using Pearson correlations. To run the GLMM and the
186 Pearson, data were transformed using $\log_{10}(x)$ when necessary to accomplish
187 assumptions of normality and variance homoscedasticity (Zar, 1999). Both arithmetic
188 and geometric means are given to facilitate comparisons with other studies in literature.
189 Statistical analysis of the data was performed using R software, Version 2.5.1. (R
190 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**

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

233 There is very limited information in the literature on toxic elements apart from
234 mercury in feathers from seabirds attending the Patagonian Shelf (González-Solís et al.,
235 2002; Anderson et al., 2010). However, regional comparisons are possible given that
236 concentrations of some of the metals analyzed in this study are available for the same
237 species from Georgias del Sur/ South Georgia, and the southern Indian Ocean (see Kim

238 et al., 1998; Anderson et al., 2010). Since pollution by trace metals in the Patagonian
239 Shelf is presumably non-existent or negligible (Stewart et al., 1999; González-Solís et
240 al., 2002; Barbieri et al., 2007), we expected the concentrations of metals in feathers to
241 be relatively low. In fact, Table 3 draws a parallel between elemental concentrations in
242 feathers of BBA from the Southern Ocean region and related species – all
243 Procellariiformes – from other locations in the world.

244 Cadmium is a non-essential metal that comes from a variety of anthropogenic
245 sources (Burger, 1993; Furness, 1996). When compared with concentrations in the same
246 tissue, cadmium concentrations in feathers of BBA analyzed in this study were lower
247 than those reported in adult BBA and Grey-headed Albatross *T. chrysostoma* from
248 Georgias del Sur/ South Georgia (Anderson et al., 2010) but higher than those of the
249 same species from the southern Indian Ocean (Kim et al., 1998). In a broader
250 comparison, on average, cadmium fall within the known range of concentrations from
251 bird feathers of related Procellariiformes species from different biogeographic areas (see
252 Table 3). Like cadmium, lead is an element that plays no role in metabolic processes of
253 animal organisms. It is an extremely toxic element with a wide range of harmful effects
254 in birds (see review in De Francisco et al., 2003). Normal background concentrations of
255 lead in feather of adult seabirds are in the range of 0.51 to 1.68 $\mu\text{g g}^{-1}$ dry mass (Mendes
256 et al., 2008; Burger and Gochfeld, 2009). Unfortunately regional comparisons are not
257 possible since lead concentrations in BBA from neighboring waters were below the
258 limit of detection (Anderson et al., 2010). Still, lead concentrations in BBA analyzed in
259 this study were higher than those reported for birds obtained from fishing operations in
260 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

333 **5. References**

- 334 Acha, E.M., Mianzan, H.W., Guerrero, R.A., Favero, M., Bava, J. 2004. Marine fronts
335 at the continental shelves of austral South America: Physical and ecological
336 processes. *Journal of Marine Systems* 44, 83–105.
- 337 Agreement on the Conservation of Albatrosses and Petrels (ACAP). 2009. The ACAP
338 Species Assessments. Available from: <http://www.acap.aq/acap-species>.
- 339 Anderson, O.R.J., Phillips, R.A., Shore, R.F., McGill, R.A.R., McDonald, R.A.,
340 Bearhop, S. 2010. Element patterns in albatrosses and petrels: influence of
341 trophic position, foraging range, and prey type. *Environmental Pollution* 158,
342 98–107.
- 343 Barbieri, E., Garcia, C.A.B., Passos, E.A., Aragão, K.A.S. 2007. Heavy metal
344 concentration in tissues of *Puffinus gravis* sampled on the Brazilian coast.
345 *Ararajuba* 15, 69–72.
- 346 Becker, P.H., González-Solís, J., Behrends, B., Croxall, J.P. 2002. Feather mercury
347 levels in seabirds at South Georgia: influence of trophic position, sex and age.
348 *Marine Ecology Progress Series* 243, 261–269.
- 349 BirdLife International. Species factsheet: *Thalassarche melanophrys*. Available from:
350 <http://www.birdlife.org/datazone/speciesfactsheet.php?id=3959>.
- 351 Bond, A.L., Diamond, A.W. 2008. High within-individual variation in total mercury
352 concentration in seabird feathers. *Environmental Toxicology and Chemistry* 27,
353 2375–2377.
- 354 Bond, A.L., Diamond, A.W. 2009. Total and methyl mercury concentrations in seabird
355 feathers and eggs. *Archives of Environmental Contamination and Toxicology*
356 56, 286–291.

- 357 Bond, A.L., Lavers, J.L. 2011. Trace element concentrations in feathers of Flesh-footed
358 Shearwaters (*Puffinus carneipes*) from across their breeding range. Archives of
359 Environmental Contamination and Toxicology. DOI: 10.1007/s00244-010-9605-
360 3.
- 361 Borga, K., Campbell, L., Gabrielsen, G.W., Norstrom, R.J., Muir, D.C.G., Fisk, A.T.
362 2006. Regional and species specific bioaccumulation of major and trace
363 elements in arctic seabirds. Environmental Toxicology 25, 2927–2936.
- 364 Bugoni, L., McGill, R.A.R., Furness, R.W. 2010. The importance of pelagic longline
365 fishery discards for a seabird community determined through stable isotope
366 analysis. Journal of Experimental Marine Biology and Ecology 391, 190–200.
- 367 Burger, J. 1993. Metals in avian feathers: bioindicators of environmental pollution.
368 Reviews in Environmental Toxicology 5, 203–311.
- 369 Burger, J., Gochfeld, M. 1990. Tissue levels of lead in experimentally exposed Herring
370 Gull (*Larus argentatus*) chicks. Journal of Toxicology and Environmental
371 Health 29, 219–233.
- 372 Burger, J., Gochfeld, M. 1991. Lead, mercury and cadmium in feathers of tropical terns
373 in Puerto Rico and Australia. Archives of Environmental Contamination and
374 Toxicology 21, 311–315.
- 375 Burger, J., Gochfeld, M. 1992. Heavy metal and selenium concentrations in Black
376 skimmers *Rynchops niger*: gender differences. Archives of Environmental
377 Contamination and Toxicology 23, 431–434.
- 378 Burger, J., Gochfeld, M. 2000a. Effects of chemicals and pollution on seabirds, in:
379 Schreiber, E.A., Burger, J. (Eds.), Biology of marine birds. CRC Press, Boca
380 Raton, Florida, pp. 485–525.

- 381 Burger, J., Gochfeld, M. 2000b. Metals in albatross feathers from Midway Atoll:
382 influence of species, age and nest location. Environmental Research Section A
383 82, 207–221.
- 384 Burger, J., Gochfeld, M. 2000c. Metals in Laysan Albatrosses from Midway Atoll.
385 Archives of Environmental Contamination and Toxicology 38, 254–259.
- 386 Burger, J., Gochfeld, M. 2000d. Metals levels in feathers of 12 species of seabirds from
387 Midway Atoll in the northern Pacific Ocean. Science of the Total Environment
388 257, 37–52.
- 389 Burger, J., Gochfeld, M. 2004. Marine birds as sentinels of environmental pollution.
390 EcoHealth 1, 263–274.
- 391 Burger, J., Gochfeld, M. 2009. Mercury and other metals in feathers of Common Eider
392 *Somateria mollissima* and Tufted Puffin *Fratercula cirrhata* from the Aleutian
393 Chain of Alaska. Archives of Environmental Contamination and Toxicology 56,
394 596–606.
- 395 Burger, J., Nisbet, I.C.T., Gochfeld, M. 1994. Heavy metal and selenium levels in
396 feathers of known-aged Common terns *Sterna hirundo*. Archives of
397 Environmental Contamination and Toxicology 26, 351–355.
- 398 Burger, J., Schreiber, E.A., Gochfeld, M. 1992. Lead, cadmium, selenium and mercury
399 in seabird feathers from the tropical mid-Pacific. Environmental Toxicology and
400 Chemistry 11, 815-822.
- 401 Clesceri, L.S., Greenberg, A.E., Eaton, A.D. 1998. Standard methods for the
402 examination of water and wastewater. 20th ed. American Public Health
403 Association, Washington.
- 404 Crawley, M.J. 2007. The R book. Wiley, Chichester, U.K.

- 405 Croxall, J.P., Gales, R. 1998. An assessment of the conservation status of albatross, in:
406 Robertson, G., Gales, R. (Eds.), *Albatross Biology and Conservation*. Surrey
407 Beatty and Sons Ltd, Australia, pp. 46–65.
- 408 Croxall, J.P., Wood, A.G. 2002. The importance of the Patagonian Shelf for top
409 predator species breeding at South Georgia. *Aquatic Conservation: Marine and*
410 *Freshwater Ecosystems* 12, 101–118.
- 411 Dauwe, T., Bervoets, L., Pinxten, R., Blust, R., Eens, M. 2003. Variation of heavy
412 metals within and among feathers of birds of prey: effects of molt and external
413 contamination. *Environmental Pollution* 124, 429–436.
- 414 De Francisco, N., Ruiz Troya, J.D., Aguera, E.I. 2003. Lead and lead toxicity in
415 domestic and free living birds. *Avian Pathology* 32, 3–13.
- 416 Edwards, A.R., Rohwer, S. 2005. Large-scale patterns of molt activation in the flight
417 feathers of two albatross species. *Condor* 107, 835–848.
- 418 Elliot, J.E., Scheuhammer, A.M., Leighton, F.A., Pearce, P.A. 1992. Heavy metal and
419 metallothionein concentrations in Atlantic Canadian seabirds. *Archives of*
420 *Environmental Contamination and Toxicology* 22, 63–73.
- 421 Favero, M., Khatchikian, C., Arias, A., Silva Rodríguez, M.P., Cañete, G., Mariano-
422 Jelich R. 2003. Estimates of seabird by-catch along the Patagonian Shelf by
423 Argentine longline fishing vessels, 1999 - 2001. *Bird Conservation International*
424 13, 273–281.
- 425 Favero, M., Silva Rodríguez, M.P. 2005. Estado actual y conservación de aves pelágicas
426 que utilizan la plataforma continental Argentina como área de forrajeo. *El*
427 *Hornero* 20, 95–110.

- 428 Favero, M. 2008. South American perspective: fisheries mortality, in: De Roy, T.,
429 Jones, M., Fitter, J. (Eds.), Albatross: their world, their ways. David Bateman
430 Ltd, Auckland, pp. 176–177.
- 431 Furness, R.W. 1996. Cadmium in birds, in: Beyer, W.N., Heinz, S.H., Redmon-
432 Norwood, A.W. (Eds.), Environmental contaminants in wildlife. Lewis
433 Publishers, Boca Raton, Florida, pp. 389-404.
- 434 Furness, R.W., Camphuysen, Kees (C.J.). 1997. Seabirds and monitors of the marine
435 environment. ICES Journal of Marine Science 54, 726–737.
- 436 Furness, R.W., Muirhead, S.J., Woodburn, M. 1986. Using bird feathers to measure
437 mercury in the environment: relationship between mercury content and moult.
438 Marine Pollution Bulletin 17, 27–37.
- 439 Gandini, P., Frere, E., García, M.F., Seco Pon, J.P. 2009. Sexual differences in external
440 measurements of Black-browed albatross *Diomedea melanophrys* incidentally
441 killed during longline operations. El Hornero 23, 43–46.
- 442 Gandini, P., Seco Pon, J.P. 2007. Seabird assemblages attending longline vessels in the
443 Argentinean Economic Exclusive Zone. Ornitología Neotropical 18, 553–561.
- 444 Gandini, P.A., Frere, E. 2006. Spatial and temporal patterns in the bycatch of seabirds in
445 the Argentinean longline fishery. Fisheries Bulletin 104, 482–485.
- 446 Gard, N.W., Hooper, M.J. 1995. An assessment of potential hazards of pesticides and
447 environmental contaminants, in: Martin, T.E., Finch, D.M. (Eds.), Ecology and
448 management of neotropical migratory birds: A synthesis and review of critical
449 issues. Oxford University Press, New York, pp. 295–310.
- 450 Goede, A.A., De Bruin, M. 1986. The use of bird feathers for indicating heavy metal
451 pollution. Environmental Monitoring and Assessment 7, 249–256.

- 452 Gómez-Laich, A., Favero, M., Mariano-Jelicich, R., Blanco, G., Cañete, G., Arias, A.,
453 Silva Rodríguez, M.P., Brachetta, H. 2006. Environmental and operational
454 variability affecting the mortality of Black-Browed Albatrosses associated to
455 longliners in Argentina. *Emu* 106, 21–28.
- 456 González-Solís, J., Sampera, C., Ruiz, X. 2002. Metals and selenium as bioindicators of
457 geographic and trophic segregation in Giant petrels *Macronectes* spp. *Marine*
458 *Ecology Progress Series* 244, 257–264.
- 459 Grémillet, D., Wilson, R.P., Wanless, S., Chater, T. 2000. Black-browed albatrosses,
460 international fisheries and the Patagonian Shelf. *Marine Ecology Progress Series*
461 195, 269–280.
- 462 Hindell, M.A., Brothers, N., Gales, R. 1999. Mercury and cadmium concentrations in
463 the tissues of three species of southern albatrosses. *Polar Biology* 22, 102–108.
- 464 Honda, K., Marcovecchio, J.E., Kan, S., Tatsukawa, R., Ogi, H. 1990. Metal
465 concentrations in pelagic seabirds from the North Pacific Ocean. *Archives of*
466 *Environmental Contamination and Toxicology* 19, 704–711.
- 467 Honda, K., Nasu, T., Tatsukawa, R. 1986. Seasonal changes in mercury accumulation in
468 the Black-eared Kite, *Milvus migrans lineatus*. *Environmental Pollution* 42,
469 325–334.
- 470 Huin, N. 2002. Foraging distribution of the Black-browed Albatross, *Thalassarche*
471 *melanophrys*, breeding in the Falkland Islands. *Aquatic Conservation: Marine*
472 *and Freshwater Ecosystems* 12, 89–99.
- 473 Hutton, M. 1991. Accumulation of heavy metals and selenium in three seabird species
474 from the United Kingdom. *Environmental Pollution* 26, 129–145.

- 475 Kim, E.Y., Goto, R., Tanabe, S., Tanaka, H., Tatsukawa, R. 1998. Distribution of 14
476 elements in tissues and organs of oceanic seabirds. Archives of Environmental
477 Contamination and Toxicology 35, 638–645.
- 478 Kojadinovic, J., Le Corre, M., Cosson, R.P., Bustamante, P. 2007. Trace elements in
479 three marine birds breeding on Reunion Island (Western Indian Ocean): Part 1-
480 Factors influencing their bioaccumulation. Archives of Environmental
481 Contamination and Toxicology 52, 418–430.
- 482 Lacoue-Labarthe, T., Warnau, M., Oberhänsli, F., Teyssié, J.L., Jeffree, R., Bustamante,
483 P. 2008. First experiments on the maternal transfer of metals in the cuttlefish
484 *Sepia officinalis*. Marine Pollution Bulletin 57, 826–831.
- 485 Lewis, S.A., Furness, R.W. 1991. Mercury accumulation and excretion in laboratory
486 reared black-headed gull *Larus ridibundus* chicks. Archives of Environmental
487 Contamination and Toxicology 21, 316–320.
- 488 Mallory, M.L., Robinson, S.A., Hebert, C.E., Forbes, M.R. 2010. Seabirds as indicators
489 of aquatic ecosystem conditions: A case for gathering multiple proxies of seabird
490 health. Marine Pollution Bulletin 60, 7–12.
- 491 Marcovecchio, J., Ferrer, L. 2005. Distribution and geochemical partitioning of heavy
492 metals in sediments of the Bahía Blanca Estuary, Argentina. Journal of Coastal
493 Research 21, 826–834.
- 494 Mendes, P., Eira, C., Torres, J., Soares, A.M.V.M., Melo, P., Vingada, J. 2008. Toxic
495 element concentration in the Atlantic Gannet *Morus bassanus* (Pelecaniformes,
496 Sulidae) in Portugal. Archives of Environmental Contamination and Toxicology
497 55, 503–209.

- 498 Metcheva, R., Yurukova, L., Tedorova, S., Nikolova, E. 2006. The penguin feathers as
499 bioindicator of Antarctica environmental state. *Science of the Total Environment*
500 362, 259–265.
- 501 Monteiro, L.R., Furness, R.W. 2001. Kinetics, dose-response, and excretion of
502 methylmercury in free-living adult Cory's Shearwaters. *Environmental Science*
503 and Technology 35, 739–746.
- 504 Monteiro, L.R., Granadeiro, J.P., Furness, R.W. 1998. Relationship between mercury
505 levels and diet in Azores seabirds. *Marine Ecology Progress Series* 166, 259–
506 265.
- 507 Muirhead, S.J., Furness, R.W. 1988. Heavy metals concentrations in the tissues of
508 seabirds from Gough Island, South Atlantic Ocean. *Marine Pollution Bulletin*
509 19, 278–283.
- 510 Nygård, T., Lie, E., Rørv, N., Steinnes, E. 2001. Metal dynamics in an Antarctic food
511 chain. *Marine Pollution Bulletin* 7, 598–602.
- 512 Onley, D., Scofield, P. 2007. *Albatrosses, petrels and shearwaters of the world*.
513 Princeton University Press.
- 514 Phillips, R.A., Silk, J.R.D., Croxall, J.P., Afanasyev, V., and Bennett, V.J. 2005.
515 Summer distribution and migration of non-breeding albatrosses: Individual
516 consistencies and implications for conservation. *Ecology* 86, 2386–2396.
- 517 Phillips, R.A., Silk, J.R.D., Phalan, B., Catry, P., and Croxall, J.P. 2004. Seasonal
518 sexual segregation in two *Thalassarche* albatross species: competitive exclusion,
519 reproductive role specialization or foraging niche divergence? *Proceedings of*
520 *the Royal Society of London Series B Biological Sciences* 271, 1283–1291.

- 521 Pilastro, A., Congiu, L., Tallandini, L., Turchetto, M. 1993. The use of bird feathers for
522 the monitoring of cadmium pollution. *Archives of Environmental Contamination*
523 and *Toxicology* 24, 355–358.
- 524 Prince, P.A., Croxall, J.P., Trathan, P.N., and Wood, A.G., 1998. The pelagic
525 distribution of South Georgia albatrosses and their relationship with fisheries, in:
526 Robertson, G., Gales, R. (Eds.), *Albatross Biology and Conservation*. Surrey
527 Beatty and Sons Ltd, Australia, pp. 137–167.
- 528 Prince, P.A., Rodwell, S., Jones, M., Rother, Y.P. 1993. Moulting in Black-browed and
529 Grey-headed Albatrosses *Diomedea melanophrys* and *D. chrysostoma*. *Ibis* 135,
530 121–131.
- 531 R Development Core Team. 2004. R: a language and environment for statistical
532 computing. R Foundation for Statistical Computing, Vienna, Austria. Available
533 from: <http://www.R-project.org>.
- 534 Randell, M.G., Patnaik, A.K., Gould, W.J. 1981. Hepatopathy associated with excessive
535 iron storage in mynah birds. *Journal of the American Veterinary Medical*
536 *Association* 179, 1214–1217.
- 537 Savinov, V.M., Gabrielsen, G.W., Savinova, T.N. 2003. Cadmium, zinc, copper,
538 arsenic, selenium and mercury in seabirds from the Barents Sea: levels, inter-
539 specific and geographical differences. *Science of the Total Environment* 306,
540 133–158.
- 541 Seco Pon, J.P., Gandini, P., Favero, M. 2007. Effect of longline configuration on the
542 seabird mortality in the Argentine semi-pelagic Kingclip *Genypterus blacodes*
543 fishery. *Fisheries Research* 85, 101–105.

- 544 Stewart, F.M., Phillips, R.A., Bartle, J.A., Craig, J., Shooter, D. 1999. Influence of
545 phylogeny, diet, moult schedule and sex on heavy metal concentrations in New
546 Zealand Procellariiformes. *Marine Ecology Progress Series* 178, 295–305.
- 547 Stewart, F.M., Thompson D.R., Furness R.W., Harrison N. 1994. Seasonal variation in
548 heavy metals levels in tissues of Common guillemots *Uria aalga* from
549 Northwest Scotland. *Archives of Environmental Contamination and Toxicology*
550 27, 168-175.
- 551 Sunde, M.L. 1972. Zinc requirement for normal feathering of commercial Leghorn-type
552 pullets. *Poultry Science* 51, 1316–1322.
- 553 Thompson, D.R., Furness, R.W. 1989a. Comparison of the levels of total and organic
554 mercury in seabird feathers. *Marine Pollution Bulletin* 20, 577–579.
- 555 Thompson, D.R., Furness, R.W. 1989b. The chemical form of mercury stores in South
556 Atlantic seabirds. *Environmental Pollution* 60, 305–317.
- 557 Tickell, W.L.N. 2000. Albatrosses. Pica Press, East Sussex, U.K.
- 558 Wenzel, C., Gabrielsen, G.W. 1995. Trace accumulation in three seabird species from
559 Hornøya, Norway. *Archives of Environmental Contamination and Toxicology*
560 29, 198–206.
- 561 Wolfe, M.F., Schwarzbach, S., Sulaiman, R.A. 1998. Effects of mercury on wildlife: A
562 comprehensive review. *Environmental Toxicology and Chemistry* 17(2), 146–
563 160.
- 564 Zar, I. 1999. *Biostatistical analysis*. Forth Edition. Prentice-Hall Press, Englewood
565 Cliffs, New Jersey.
- 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

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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

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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

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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

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> 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.

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| | 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 | <i>Thalassarche melanophrys</i> | 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 Shell** | 0.200 | 1.01 | 1.46 | 4.31 | 1.84 | This study |
| Grey-headed Albatross | <i>Thalassarche chrysostoma</i> | Bird Island, Georgias del Sur/ South Georgia | 0.196 | 5.661 | 229.219 | < LOD ^a | 50.115 | Anderson et al. (2010) |
| Wandering Albatross | <i>Diomedea exulans</i> | Bird Island, Georgias del Sur/ South Georgia | 0.317 | 6.032 | 166.858 | < LOD ^a | 58.16 | Anderson et al. (2010) |
| Northern Giant Petrel | <i>Macronectes halli</i> | Bird Island, Georgias del Sur/ South Georgia | 0.083 | 6.211 | 103.719 | < LOD ^a | 67.557 | Anderson et al. (2010) |
| Southern Giant Petrel | <i>Macronectes giganteus</i> | Bird Island, Georgias del Sur/ South Georgia | 0.289 | 6.877 | 95.208 | < LOD ^a | 90.208 | Anderson et al. (2010) |
| White-chinned Petrel | <i>Procellaria aequinoctialis</i> | Bird Island, Georgias del Sur/ South Georgia | 0.138 | 13.11 | 262.076 | < LOD ^a | 77.646 | Anderson et al. (2010) |
| Antarctic Prion | <i>Pachyptila desolata</i> | Bird Island, Georgias del Sur/ South Georgia | 0.059 | 20.176 | 1,010.868 | < LOD ^a | 113.658 | Anderson et al. (2010) |
| Blue Petrel | <i>Halobaena caerulea</i> | Bird Island, Georgias del Sur/ South Georgia | 0.074 | 8.745 | 986.705 | < LOD ^a | 6.953 | Anderson et al. (2010) |
| Flesh-footed Shearwater | <i>Puffinus carneipes</i> | 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 | <i>Phoebastria nigripes</i> | Midway Atoll, North Pacific | 0.152 | Na | Na | 0.973 | Na | Burger and Gochfeld (2000b) |
| Laysan Albatross | <i>Phoebastria immutabilis</i> | Midway Atoll, North Pacific | 0.364 | Na | Na | 0.799 | Na | Burger and Gochfeld (2000b) |
| Bonin Petrel | <i>Pterodroma hypoleuca</i> | Midway Atoll, North Pacific | 0.129 | Na | Na | 1.35 | Na | Burger and Gochfeld (2000d) |
| Wedge-tailed Shearwater | <i>Puffinus pacificus</i> | Midway Atoll, North Pacific | 0.071 | Na | Na | 0.478 | Na | Burger and Gochfeld (2000d) |
| Christmas Shearwater | <i>Puffinus nativitatis</i> | 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