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1 **Organic pollutants and their correlation with stable isotopes in**
2 **vegetation from King George Island, Antarctica**

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21 **Abstract:** Vegetation samples from King George Island, Antarctica (62°05'S, 058°23'W)
22 were collected in the austral summer of 2004-05. Lichens (*Usnea aurantiaco-atra* and *Usnea*
23 *antarctica*), mosses (*Sanionia uncinata*, *Syntrichia princeps* and *Brachytecium* sp.), and one
24 angiosperm (*Colobanthus quitensis*) species were analyzed for persistent organic pollutants as
25 well as $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotopes. The following contaminants were found above the
26 method detection limit (MDL): HCB (0.141 to 1.06 ng g⁻¹ dry weight), HCHs (< MDL to 1.20
27 ng g⁻¹ dw), DDTs (< MDL to 1.73 ng g⁻¹ dw), PCBs (7.76 to 18.6 ng g⁻¹ dw) and PBDEs
28 (0.146 to 0.811 ng g⁻¹ dw). In all cases, levels in mosses were higher than in lichens (one
29 order of magnitude higher for OCs), suggesting that specific biogeochemical processes were
30 involved in the transport, exposure and absorption for each group. Carbon stable isotope ratios
31 showed clearly different ranges for lichens ($\delta^{13}\text{C}$ from -21.13 up to -18.43‰) and mosses
32 (-25.99 to -21.64‰). The only angiosperm species investigated exhibited ¹³C signature within
33 the moss range. A large range of $\delta^{15}\text{N}$ was found (-7.67 to 20.75‰) and seemed to be related
34 to nitrogen uptake from different animal-derived sources. Pearson's correlation showed
35 significant results for some contaminants (e.g. HCHs/HCB and PCBs/DDTs) and suggested
36 the influence of the origin of both nitrogen and pollutants, notably taking secondary sources
37 (animal excrements/remains, for instance) into consideration.

38

39

40 **Keywords:** Antarctica; lichens; mosses; PBDEs; POPs; stable isotopes

41

42 **1. INTRODUCTION**

43 Antarctica still is one of the least polluted regions on Earth, what provides unique
44 opportunities for studying environmental pollution processes at both local and global scales
45 (Borghini et al., 2005). Even though Antarctica has had limited direct exposure to persistent
46 organic pollutants (POPs), the atmosphere represents a source of contaminants through long
47 range transport. According to a mechanism known as “global distillation”, semi-volatile
48 compounds evaporate in warmer regions and are atmospherically transported to colder
49 regions (i.e., high altitudes/latitudes) where they are deposited and enter the ecosystem
50 (ARQP, 2007; Cipro et al., 2010). Oceanic currents and animals also play a minor role in this
51 transport as described in (Roosens et al. (2007) and Choy et al. (2010).

52 Lichens and mosses have been extensively used in environmental pollution studies
53 throughout the world, since their collection is relatively easy and they can absorb
54 contaminants directly from the air. In the Antarctic environment, a variety of contaminants
55 has been reported in these organisms such as trace metals (Poblet et al., 1997) and
56 radioactive elements (Mietelski et al., 2000). Information on POPs, especially PBDEs, is
57 scarce in these matrices (see Borghini et al., 2005; Yogui & Sericano, 2008).

58 According to Liu et al. (2010), $\delta^{13}\text{C}$ has been extensively used to examine physiological,
59 ecological, and biogeochemical processes related to C cycling, providing insights to the
60 interactions between plants and environmental factors at a variety of temporal and spatial
61 scales (Farquhar et al., 1989; Israeli et al., 1996). $\delta^{15}\text{N}$, on the other hand, has been
62 recognized as an effective tool holding source-specific information for tracing the deposition
63 of N pollutants and N availability to plants (Robinson, 2001). Because of the close
64 correlation between C and N, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are recognized as a biologically important
65 stable isotope pair and are frequently used in combination to investigate N supply and C
66 fixation occurring from individual organism to ecosystem level (e.g. Hietz et al., 1999;

67 Robinson et al., 2000). Xiao et al. (2010) state that this isotope pair is used to understand
68 mixing processes, transport pathways, deposition, and history of atmospheric pollutants in
69 the environment (Xiao and Liu, 2002; Liu et al., 2009). The $\delta^{15}\text{N}$ values of atmospheric N
70 sources range from -15 to $+10\%$, with the oxidized N (NO_x) more positive and the reduced
71 N (NH_x) more negative (Heaton, 1990; Xiao and Liu, 2002).

72 The aim of this work is to determine concentration of several POPs in Antarctic vegetation as
73 well as their carbon and nitrogen stable isotope signatures. Correlation between these
74 variables is also investigated in order to better understand pollution processes in Antarctica.

75

76 **2. MATERIAL AND METHODS**

77 **2.1. Area of study and sample collection**

78 King George Island ($62^{\circ}05'S$ $58^{\circ}23'W$), the largest one of the South Shetlands Islands, is
79 separated from the northern portion of the Antarctic Peninsula by the Bransfield Strait. The
80 island is mostly ice-covered and even during summer an ice cap remains over at least 90% of
81 its surface area (SCAR, 2010). Ice-free areas are abundantly vegetated by lower plants such
82 as lichens and mosses (Lee et al. 2009). In the present study, plants were collected at eleven
83 sites along the coast of Admiralty Bay, the largest fjord-like embayment on King George
84 Island encompassing a surface area of 122 km^2 (Rakusa-Suszczewski et al., 1993). The coast
85 of Admiralty Bay is fairly irregular alternating between gravel/sandy beaches, rocky shores
86 and glaciers along its ca. 84 km long shoreline (Rakusa-Suszczewski, 1995). Its climate is
87 predominantly cold oceanic, characteristic of maritime Antarctica. It can be considered
88 relatively warm and humid, supporting a substantial bryophyte flora including mosses and
89 liverworts, lichens, and some freshwater algae. Bryophytes predominate in moister and more
90 sheltered habitats, while lichens in more arid and exposed rocky habitats (Kim et al., 2007).

91 Samples were collected in the austral summer, from early December 2004 to early January

92 2005. Plants were collected by hand, and carefully shaken to remove animal-related debris
93 and/or soil particles. They were then stored in clean containers (previously combusted at
94 450°C for 4 hours), frozen at -20°C upon return to the Brazilian Research Station (Estação
95 Antártica Comandante Ferraz), and kept frozen until analysis.

96

97 **2.2. Chemical analyses**

98 Organochlorine (OC) analyses were performed at University of São Paulo (Brazil).
99 Laboratory protocol was based on MacLeod et al. (1986) and quality assurance/quality
100 control (QA/QC) followed guidelines described by Wade & Cantillo (1994). Briefly, 10 g of
101 wet sample were ground with anhydrous Na₂SO₄ and surrogate (PCB103) was added before
102 extraction in a Soxhlet apparatus for 8 h with 80 mL of n-hexane and methylene chloride
103 (1:1, v/v). The extract was concentrated to 1 mL and cleaned up in a column filled (from top
104 to bottom) with 16 g alumina and 8 g silica gel (both 5% deactivated with water). The extract
105 was eluted with 100 mL of methylene chloride and subsequently concentrated to 900 µL.
106 Finally, internal standard (TCMX, used to estimate surrogate recovery) was added to the
107 purified extract prior to injection in the gas chromatograph.

108 OC analyses were run in a gas chromatograph equipped with an electron capture detector
109 (GC-ECD, Agilent Technologies, model 6890N). Hydrogen was used as carrier gas at
110 constant pressure (13.2 psi, i.e. 91.01 kPa). The injector was operated in splitless mode and
111 kept at 300 °C. The capillary column used was a DB-5 (30 m length × 250 µm internal
112 diameter × 0.25 µm film thickness). The detector operated at 320 °C using N₂ as makeup gas
113 at a flow rate of 58 mL min⁻¹. The oven was programmed as follows: 70°C for 1 min, 5°C.min⁻¹
114 to 140°C (1min), 1.5°C.min⁻¹ to 250°C (1 min) and 10°C to 300°C (5 min). The investigated
115 compounds were PCBs (IUPAC Nos. 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 77, 87,
116 95, 97, 99, 101, 105, 110, 114, 118, 123, 126, 128, 132, 138, 141, 149, 151, 153, 156, 157,

117 158, 167, 169, 170, 174, 177, 180, 183, 187, 189, 194, 195, 199, 201, 203, 206 and 209),
118 DDTs (*o,p'*-DDE, *p,p'*-DDE, *o,p'*-DDD, *p,p'*-DDD, *o,p'*-DDT, and *p,p'*-DDT), HCB, HCHs
119 (α , β , γ and δ isomers), chlordanes (α - and γ -chlordane, heptachlor, and heptachlor epoxide),
120 mirex and drins (aldrin, dieldrin, and endrin). Surrogate recovery ranged from 98% to 111%.
121 Detection limits were set as three times the standard deviation (σ) of seven method blank
122 replicates. Spiked matrices were recovered within the acceptance ranges (i.e., 40-130% for at
123 least 80% of the spiked analytes) suggested by Wade & Cantillo (1994). Method validation
124 was performed using NIST SRM 1945. Blanks were included in every analytical batch
125 (usually 10–12 samples) and all data were blank-subtracted.

126 PBDE analyses were performed at Texas A&M University (USA) following procedures
127 described in Yogui & Sericano (2008). Briefly, approximately 10 g of wet plant tissue was
128 mixed with 40 g of anhydrous Na₂SO₄ and extracted with 300 mL of methylene chloride
129 using a tissumizer (PRO Scientific Inc., model PRO250). Plant extracts were extensively
130 cleaned up with sulfuric acid, silica/alumina chromatography and gel permeation
131 chromatography/high performance liquid chromatography (GPC/HPLC). A suite of 36 di-
132 through hepta-BDEs was measured including the following congeners: 7, 8, 10, 11, 12, 13,
133 15, 17, 25, 28, 30, 32, 33, 35, 37, 47, 49, 66, 71, 75, 77, 85, 99, 100, 116, 118, 119, 126, 138,
134 153, 154, 155, 166, 181, 183 and 190 (numeration according to the same IUPAC system used
135 for PCBs. Dry and lipid weights were gravimetrically determined using an analytical
136 balance following standard procedures used at the Geochemical and Environmental Research
137 Group (GERG) facilities.

138 Stable isotope analyses were performed at University of La Rochelle (Plateau Analyses
139 Élémentaires et Isotopiques). Samples were ground and lyophilized. Clean up was performed
140 in a test tube containing 100 mg of sample and 4 mL of cyclohexane. The mixture was
141 shaken for an hour, then centrifuged for separation (as many times as needed, until the liquid

142 phase, which is discarded, comes out clear) and dried at 50°C for 48h. Purified samples were
143 analyzed using a Thermo Scientific Delta V Advantage, ConFlo IV interface (NoBlank and
144 SmartEA) and Thermo Scientific Flash EA1112 Elemental Analyzer. Each injection
145 corresponded to 1 mg of sample encapsulated in tin cups, and there were no replicates. Pee
146 Dee Belemnite and atmospheric nitrogen were used as standards for calculation of $\delta^{13}\text{C}$ and
147 $\delta^{15}\text{N}$, respectively. Based on replicate measurements of internal laboratory standards,
148 experimental precision is of ± 0.15 and ± 0.20 ‰ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively.

149

150 **3. RESULTS AND DISCUSSION**

151 **3.1. Organic pollutants**

152 Average concentrations of POPs are shown in Table 1. PCBs presented the highest
153 concentration among POPs in all plant species, exhibiting values at least an order of
154 magnitude higher than all other contaminants. Similar distribution of POPs was observed by
155 Borghini et al. (2005) for several moss species (*Bryum argenteum*, *Pottia heimii* and
156 *Ceratodon purpureus*) collected in Antarctica at latitudes ranging from 72° to 77° S, sites
157 possibly subject to distinct contaminant trapping effects due to colder temperatures. Total
158 PCBs found by Borghini et al. (2005) ranged from 23 to 34 ng g⁻¹ dry weight. DDTs were an
159 order of magnitude lower, while HCB and HCHs were 1-2 orders of magnitude lower than
160 PCBs. Similar trends in organochlorine pattern between both studies may be an indication of
161 the long range transport and exposure characteristics. Bacci et al. (1986), whose work
162 investigated the genus *Usnea* and *Sanionia uncinata* (there described as *Drepanocladus*
163 *uncinatus*, a synonym), had observed similar patterns two decades ago. This may be
164 associated to the long lifespan of such organisms, whose age estimation may reach over 500
165 years (Tatur et al., 1997) as well as very low productivity rates (Glime, 2007). The
166 combination of such factors may account for a large difference in PCBs and PBDEs

167 concentrations due to the more recent environmental inputs of the latter. Levels of POPs in
168 eggs of gentoo penguin collected at King George Island also revealed large differences
169 between PCBs and PBDEs (Yogui and Sericano, 2009a; Cipro et al., 2010). Roosens et al.
170 (2007) also show this difference in soil from Adélie penguin colonies and reference sites at
171 Hop Island, Antarctica: PCBs totals reach up to 328 pg g⁻¹ dw and PBDEs totals were in
172 none of the cases superior to the limit of quantification of 200 pg g⁻¹ dw.

173 Distribution of PCBs and PBDEs as a function of their respective chlorination
174 and bromination numbers (i.e., molecular weight) in plant species is shown in
175 Figure 3. In the case of PCBs, there is a prevalence of tetra-, followed by penta- and tri- CBs,
176 except for *Sanionia uncinata* which exhibited a balanced distribution (~20%) from tri-
177 through hexa-CBs. Although concentration levels are on the same order of magnitude, the
178 pattern of PCBs in lichens in this study is slightly different from the one found by Park et al.
179 (2010) that had a different congener composition aimed. Negoita et al. (2003) presents results
180 within this same quantitative range for lichens from East Antarctica coast, however an even
181 different distribution: hexa, penta and tri-CBs, in this order. Nevertheless, both of these
182 previous studies strongly suggested the influence of PCBs resulting from anthropogenic
183 activity and/or local biotic origin rather than sole atmospheric transport as a significant
184 pathway of contamination. Indeed, it has been demonstrated that seabird colonies represent a
185 secondary source of contamination with persistent organic pollutants (Roosens et al., 2007)
186 or heavy metals (Choy et al. 2010). In this respect, large colonies of penguins at King George
187 Island would likely constitute an input of POPs contamination to terrestrial organisms such
188 as lower plants. Since Montone et al. (2001) found no evidence of local sources after
189 analyzing the marine macroalgae *Desmarestia* sp., it is hereby hypothesized that terrestrial
190 plants are more likely to be affected by these secondary sources (such as the local transport
191 of pollutants in runoff water or physiological factors, for instance).

192 With regard to PBDEs, tetra and penta homologues represented over 90% of the total
193 composition (Figure 1). Such a distribution is similar to commercial mixtures of Penta-BDE,
194 which has over 70% of its formulation comprised of BDE-47 (tetrabrominated) and BDE-99
195 (pentabrominated) which also dominated the composition of plants. These are congeners of
196 great environmental concern since they are known to best bioaccumulate among PBDEs (de
197 Wit, 2002; Alcock et al., 2003; Darnerud, 2003; Hale et al., 2003; Yogui and Sericano,
198 2009b). Homologue pattern correspondence between Penta-BDE technical mixtures and
199 Antarctic vegetation suggests that PBDEs do not undergo major fractionation during
200 transport to Antarctica. The composition of brominated homologues in the samples resembles
201 patterns observed in penguin eggs (with deviation of samples in regard to Penta-BDE not
202 superior to 5% for skuas and chinstrap penguins) and other vegetation samples collected at
203 King George Island (Yogui and Sericano, 2008; 2009a). BDEs 47 and 99 were also prevalent
204 congeners in the composition of mosses from Norway (Mariussen et al., 2008), probably due
205 to the use of Penta-BDE mixtures in Europe.

206

207 **3.2. Stable isotopes**

208 Stable isotope ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are plotted in Figure 2. Carbon stable isotope analysis
209 showed a clearly different range for lichens ($\delta^{13}\text{C}$ from -21.13 up to -18.43‰) and mosses
210 ($\delta^{13}\text{C}$ from -25.99 up to -21.64‰). The sole angiosperm sample (*Colobanthus quitensis*) was
211 within the mosses range. A previous study (Lee et al., 2009), also in King George Island,
212 showed similar trends, however with some overlapping between moss and lichen ranges,
213 attributing the differences probably to plant physiology and biochemistry. Overall, the $\delta^{13}\text{C}$
214 values of the mosses are more consistent with that of C3 photosynthesis (Smith and Epstein,
215 1971).

216 Regarding nitrogen isotopes, Heaton (1986) suggests that once deposited, urea and uric acid

217 hydrolyze, producing a temporary rise in pH, favoring the formation of ammonia, which
218 easily volatilizes to the atmosphere. The kinetic fractionations accompanying these steps
219 result in strongly ^{15}N -depleted ammonia, while the remaining ammonium is ^{15}N -enriched.
220 These fractionations result in plants around the excrement zone assimilating ^{15}N enriched in
221 inorganic nitrogen while the species at the upland sites have $\delta^{15}\text{N}$ signatures that reflect the
222 $\delta^{15}\text{N}$ of the isotopically depleted ammonia source. That is the reason why animal-derived
223 nitrogen uptake is associated with large $\delta^{15}\text{N}$ ranges (e.g. Erskine et al., 1998). Typical values
224 of $\delta^{15}\text{N}$ of seabird excrement and soil under influence of the colonies range between 6 and
225 26‰ (Wada et al., 1981; Mizutani and Wada, 1988; Cocks et al., 1998; Wainright et al.,
226 1998), which comes in agreement to the values hereby presented, ranging from -7.67 up to
227 4.30‰ for lichens and from -0.53 up to 20.75‰ for mosses.

228 Mosses are characterized by higher sensitivities to atmospheric N supply due to the lack of a
229 true root system to acquire N from substratum (Liu et al. 2010). Unlike some lichens and
230 algae, mosses can barely utilize atmospheric N_2 due to the lack of azotobacteria, but the
231 deposited N, which accounts for higher variability as well. Overall, moister habitats and
232 marine influence were related to lower $\delta^{13}\text{C}$ and higher $\delta^{15}\text{N}$ (Lee et al. 2009), which comes
233 in agreement with our results, since mosses are more water dependant than lichens.
234 Interestingly, the only plant species with true root system, *Colobanthus quitensis*, exhibited
235 one of the highest ^{15}N enrichments. This may be explained by water uptake via roots since
236 dissolved ammonium (and its byproducts) is ^{15}N -enriched.

237

238 **3.3. Correlation between variables**

239 Pearson's product-moment correlation analysis was performed between paired variables (see
240 Table 2). Since a large range of $\delta^{15}\text{N}$ was found (from -7.67 up to 20.75‰, i.e. a range of
241 28.42‰), which is related to animal-derived nitrogen uptake, this variable was also included

242 in order to investigate if these nitrogen sources would act as a secondary organic pollutants
243 sources as well.

244 Significant positive correlations were found between HCB and HCHs when all plants are
245 taken into account. This is probably a consequence of similar long range atmospheric
246 transport processes since these chemicals have high volatility. DDTs showed significant
247 correlation with both PCBs and PBDEs. These POPs have intermediate to low volatility. The
248 moderate association between DDTs and PCBs is hypothesized to be related to the plants
249 long lifespan that would contribute to proportional contaminant burdens being deposited after
250 several depositional cycles in spite of the discrepancy between the restrictions for these
251 groups. This observation is also plausible when mosses are taken separately. In regard to
252 mosses only, HCHs correlation with both DDTs and PCBs could be related to the interaction
253 of HCHs with the water phase (resulting from recent snowpack melting, or even water from
254 glacier melting that percolates a bird or seal colony, for instance), as they are more water
255 soluble, and not directly atmosphere-moss, since mosses have tremendous ability to sequester
256 water (Glime, 2007). The absence of correlation between PCBs and PBDEs is probably due
257 to the temporal shifts in production, utilization and restriction/banning policies throughout
258 the world. The differences in volatility might also play a role, since a PCB is more volatile
259 than its PBDE equivalent.

260 $\delta^{15}\text{N}$ correlations should be examined carefully. Two significant correlations were observed
261 when all plants are taken into consideration: a negative correlation between $\delta^{15}\text{N}$ and HCHs,
262 and a positive correlation between $\delta^{15}\text{N}$ and PBDEs. As described above, uptake of
263 volatilized ammonia from animal-derived nitrogen sources leads to depletion in $\delta^{15}\text{N}$, while
264 uptake of dissolved ammonium leads to enrichment in $\delta^{15}\text{N}$. Therefore, it is suggested that
265 plant species relying on the latter would have positive correlation between low volatility
266 contaminants and $\delta^{15}\text{N}$. Conversely, plants relying on volatilized ammonia would have

267 negative correlation. This may explain the significant negative correlation between $\delta^{15}\text{N}$ and
268 HCHs (high volatility chemicals) and the positive correlation between $\delta^{15}\text{N}$ and PBDEs (low
269 volatility compounds). When lichens and mosses are taken separately, no significant
270 correlation is found probably due to the relatively small sampling number and occasional
271 cross interference of nitrogen sources in a smaller sample set; however it is noticeable that
272 lichens results are generally more negative than the ones for mosses, which indicates a higher
273 dependency on volatilized ammonia. The absence of correlation with PCBs could be due to
274 temporal issues already considered in this work, but also to the comparatively higher
275 volatility of PCBs when compared to PBDEs.

276

277 **4. CONCLUSIONS**

278 Lichens and mosses present similar contamination patterns. Overall, there is a predominance
279 of PCBs, being one order of magnitude higher than the other organochlorines (DDTs, HCB
280 and HCHs) and one to two orders of magnitude higher than PBDEs. Considering the
281 contamination levels, our results for lower plants from King George Island are consistent
282 with findings of previous studies. Nonetheless, the use of carbon and nitrogen stable isotopes
283 provides a deeper insight on the origin of POPs in these terrestrial plants.

284 Lichens and mosses exhibited clearly distinct fractionation of carbon as observed in $\delta^{13}\text{C}$
285 ratios. Nitrogen stable isotope signatures are less specific, but they apparently indicate a
286 sensitivity to the influence of animal-derived nitrogen and therefore, to its source.

287 Correlation analyses showed significant results in some historically linked contaminant
288 groups and suggested the influence of the origin of both nitrogen and pollutants, notably
289 taking secondary sources into consideration.

290

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301

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- 423 Yogui, G.T., Sericano, J.L., 2009b. Polybrominated diphenyl ether flame retardants in the US
424 marine environment: a review. *Environment International* 35, 655-666.
- 425

426 Table 1. Average concentration of POPs (ng g⁻¹ dry weight) and standard deviations (when
 427 possible) in plants collected at King George Island, Antarctica during the austral summer
 428 2004-05.
 429

	Angiosperm	Mosses			Lichen
	<i>Colobanthus quitensis</i> n=1	<i>Brachitecyum</i> sp. n=1	<i>Syntrichia princeps</i> n=2	<i>Sanionia uncinata</i> n=7	<i>Usnea</i> spp. n=6
HCB	1.01	0.779	1.06	0.811 ± 0.18	0.141 ± 0.10
ΣHCHs	1.05	< 0.18	< 0.18	1.20 ± 0.81	0.205 ± 0.08
ΣDDTs	< 0.11	1.22	1.73	1.62 ± 0.58	0.353 ± 0.04
ΣPCBs	14.5	15.7	16.8	18.6 ± 2.5	7.76 ± 2.3
ΣPBDEs	0.328	0.276	0.718	0.893 ± 0.28	0.236 ± 0.05

430

431 Table 2. Pearson's product-moment correlation matrix between all paired variables
 432 investigated in plants collected at King George Island, Antarctica during the austral summer
 433 2004-05. Significant results at $\alpha=0.05$ are marked with an asterisk.

434

	<i>HCB</i>	Σ HCHs	Σ DDTs	Σ PCBs	<i>PBDEs</i>	$\delta^{15}N$	
All Samples	<i>HCB</i>	1.00					
	Σ HCHs	0.48*	1.00				
	Σ DDTs	-0.33	0.17	1.00			
	Σ PCBs	-0.17	0.18	0.49*	1.00		
	<i>PBDEs</i>	-0.35	-0.21	0.51*	0.33	1.00	
	$\delta^{15}N$	-0.19	-0.60*	-0.01	0.17	0.55*	1.00
	Mosses	<i>HCB</i>	1.00				
Σ HCHs		0.14	1.00				
Σ DDTs		0.49	0.91*	1.00			
Σ PCBs		0.41	0.75*	0.64*	1.00		
<i>PBDEs</i>		-0.21	0.52	0.30	0.13	1.00	
$\delta^{15}N$		0.39	-0.28	-0.42	-0.03	0.23	1.00
Lichens		<i>HCB</i>	1.00				
	Σ HCHs	0.37	1.00				
	Σ DDTs	-0.50	0.01	1.00			
	Σ PCBs	-0.13	0.40	-0.44	1.00		
	<i>PBDEs</i>	0.15	0.72	-0.32	0.36	1.00	
	$\delta^{15}N$	0.24	-0.28	-0.54	-0.28	0.38	1.00

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436

437 **Caption to figures**

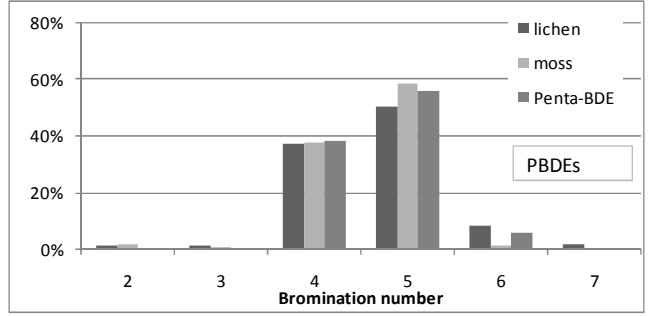
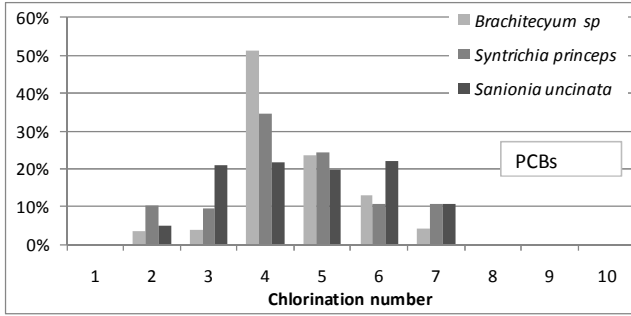
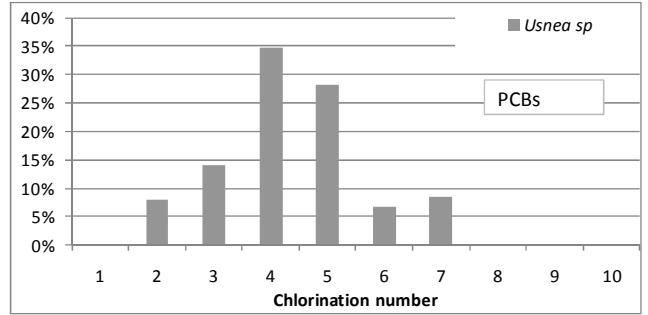
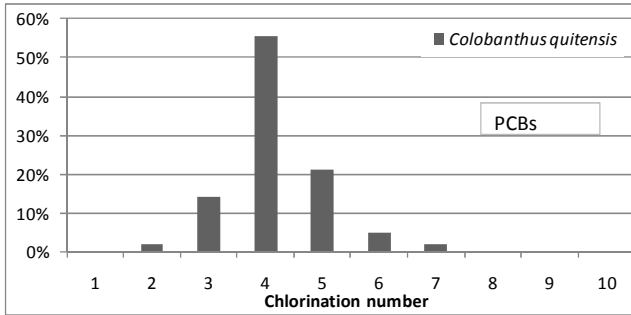
438

439 Figure 1. Percent distribution of PCB and PBDE homologues in plants collected at King
440 George Island, Antarctica during the austral summer 2004-05.

441

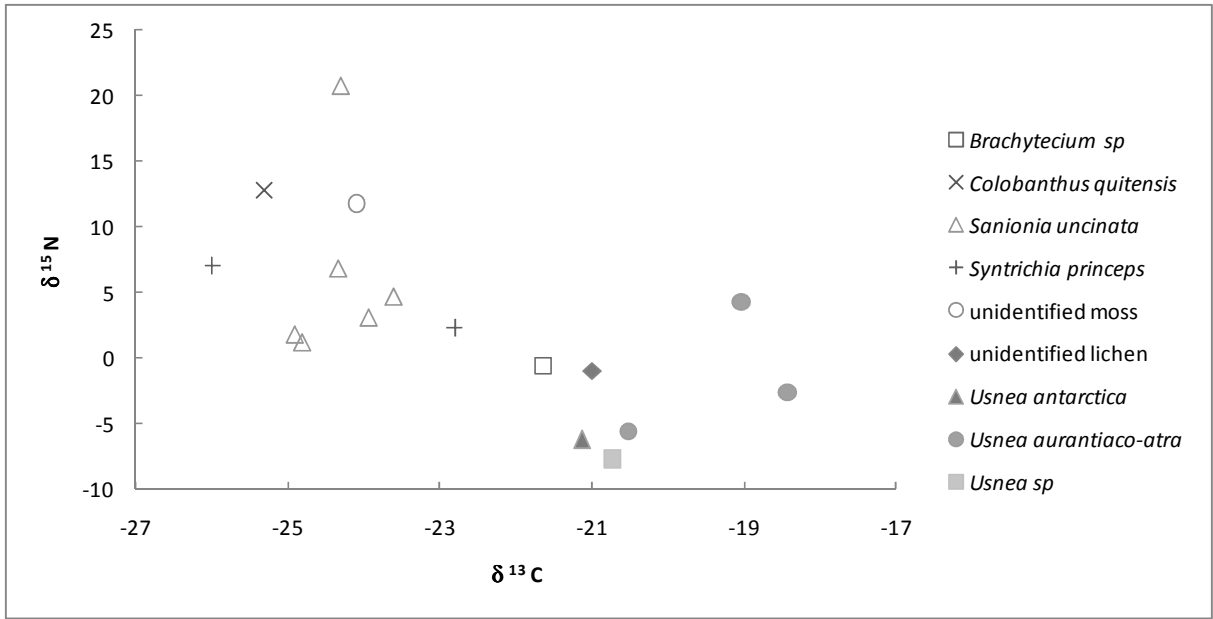
442 Figure 2 – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (‰) of lower plants (lichens are represented in closed, full
443 markers) collected at King George Island, Antarctica during the 2004-05 austral summer.

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445
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Figure 3



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 450
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Figure 2