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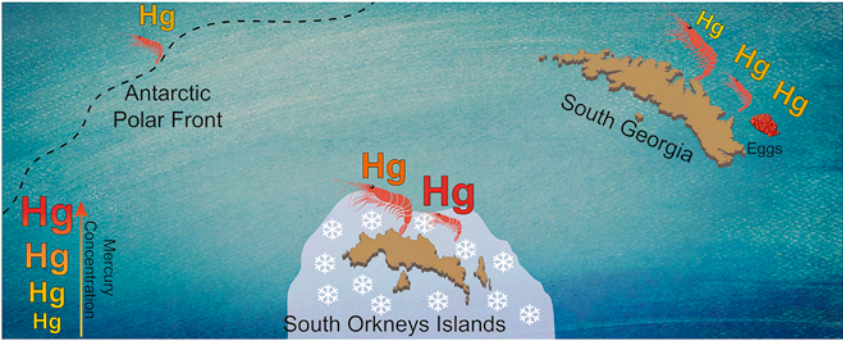
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1 Spatial variability in total and organic mercury levels in Antarctic 2 krill *Euphausia superba* across the Scotia Sea

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16 **Abstract:**

17 Total and organic mercury concentrations were determined for males, females and
18 juveniles of *Euphausia superba* collected at three discrete locations in the Scotia Sea
19 (the South Orkney Islands, South Georgia and the Antarctic Polar Front) to assess
20 spatial mercury variability in Antarctic krill. There was clear geographic differentiation
21 in mercury concentrations, with specimens from the South Orkneys having total
22 mercury concentrations 5 to 7 times higher than Antarctic krill from South Georgia
23 and the Antarctic Polar Front. Mercury did not appear to accumulate with life-stage
24 since juveniles had higher concentrations of total mercury (0.071 $\mu\text{g g}^{-1}$ from South
25 Orkney Islands; 0.015 $\mu\text{g g}^{-1}$ from South Georgia) than adults (0.054 $\mu\text{g g}^{-1}$ in females
26 and 0.048 $\mu\text{g g}^{-1}$ in males from South Orkney Islands; 0.006 $\mu\text{g g}^{-1}$ in females and
27 0.007 $\mu\text{g g}^{-1}$ in males from South Georgia). Results suggest that females use egg
28 laying as a mechanism to excrete mercury, with eggs having higher concentrations
29 than the corresponding somatic tissue. Organic mercury makes up a minor
30 percentage of total mercury (15 to 37%) with the percentage being greater in adults
31 than in juveniles. When compared to euphausiids from other parts of the world, the
32 concentration of mercury in Antarctic krill is within the same range, or higher,
33 highlighting the global distribution of this contaminant. Given the high potential for
34 biomagnification of mercury through food webs, concentrations in Antarctic krill may
35 have deleterious effects on long-lived Antarctic krill predators.
36

37 **Capsule:** Mercury concentrations in Antarctic krill decrease along life stage (females
38 use egg laying to excrete mercury) and vary along the Scotia Sea.

39 **Key words:** Food-web; Eggs; Organic Mercury; Southern Ocean, Antarctica

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41 **Introduction**

42 Mercury contamination in the environment has been acknowledged as a global
43 problem, and the production and use of this element is nowadays very strictly
44 regulated and limited (Selin, 2009; UNEP, 2013). Pathways of dispersion through
45 ecosystems, including in the Antarctic, of this long-range contaminant are complex
46 (Streets et al., 2009). Interplay between the distinctive Antarctic atmosphere and the
47 seasonal sea-ice cycle in the Southern Ocean generates a unique combination
48 environmental factors that can explain why the remote Southern Ocean has some of
49 the highest reported concentrations of organic mercury (i.e. compounds containing
50 covalent bonds between carbon and mercury) in open waters (Cossa et al., 2011).
51 Due to its high affinity for proteins (Bustamante et al., 2006), organic mercury is the
52 most toxic form of the element (Clarkson, 1992). It accumulates in aquatic organisms
53 and biomagnifies within food webs, being toxic for top predators (Ackerman et al.,
54 2014; Chouvelon et al., 2012; Coelho et al., 2010; Dehn et al., 2006) with
55 consequences at the population level (Goutte et al., 2014a; 2014b). Wandering
56 albatrosses are an example of this biomagnification effect in Antarctica, as it was
57 found that they had some of the highest concentration of total mercury (from now on
58 noted as mercury) in marine birds (up to $24.80 \pm 8.61 \mu\text{g g}^{-1}$ dry weight) (Cherel et
59 al., 2018; Tavares et al., 2013).

60 In the Southern Ocean, Antarctic krill, *Euphausia superba*, is a key species in
61 the marine food webs connecting primary producers and higher predators (Everson,
62 2000). It has an estimated biomass of around 379million tonnes (Atkinson et al.,
63 2009) and being the main food for many vertebrates (Murphy et al., 2007; Xavier and
64 Peck, 2015). For example, minke whales, *Balaenoptera acutorostrata* and Crabeater
65 seals, *Lobodon carcinophaga*, feed almost exclusively (>95 %) on Antarctic krill
66 (Adam, 2005; Armstrong and Siegfried, 1991; Croll and Tershy, 1998; Dimitrijević et

67 al., 2018; Perrin et al., 2008). Chinstrap penguins, *Pygoscelis antarctica*, Gentoo
68 penguins, *Pygoscelis papua*, and other species of penguins, in the Southern Ocean,
69 also feed mostly on Antarctic krill (Dimitrijević et al., 2018; Xavier et al., 2018) with
70 values around 1.2 kg d⁻¹ (Croll and Tershy, 1998). Finally, Antarctic krill is the most
71 harvested species in the Southern Ocean, with > 260 000 tonnes fished in 2016,
72 regulated under the Convention for the Conservation of Antarctic Living Resources
73 (Nicol et al. 2000; Tou et al. 2007; CCAMLR 2017).

74 In the context of environmental change (Constable et al., 2014; Cossa, 2013;
75 Gutt et al., 2015), it is important to evaluate the impact of contaminants like mercury,
76 particularly in a remote and presumably less impacted environments such as
77 Antarctica with the associated risk to Southern Ocean top predators. This approach
78 will contribute to a more in-depth knowledge of mercury bioaccumulation dynamics,
79 in an effort towards the preservation of Antarctica ecosystems into the future (Rintoul
80 et al., 2018; Seewagen, 2010). Despite the major role of Antarctic krill in the Southern
81 Ocean, there are only a few studies reporting mercury concentrations in this region
82 (Bargagli et al., 1998; Brasso et al., 2012b; Locarnini and Presley, 1995; Moren et al.,
83 2006). Indeed, to our knowledge, no studies have ever analysed organic mercury
84 content in Antarctic krill. Assessing the levels of organic mercury in such an important
85 prey as Antarctic krill is crucial to better understand the pathway of this contaminant
86 through Southern Ocean food webs. In this context, this study compares the total and
87 organic mercury of Antarctic krill from three different locations: the South Orkney
88 Islands, an Antarctic island group which experiences winter sea ice (Murphy et al.,
89 1995); South Georgia, a sub-Antarctic island free of sea ice (Rogers et al., 2015);
90 and the Antarctic Polar Front, a transition area from the Southern Ocean to the
91 Atlantic Ocean with warmer waters (Dong et al., 2006). Under this context,

92 differences among life stages (eggs, juveniles, adults) and sexes (males and
93 females), were assessed and interpreted in the scope of a possible biomagnification
94 of mercury in the Antarctic trophic web.

95

96 **Material and methods**

97 *Sampling*

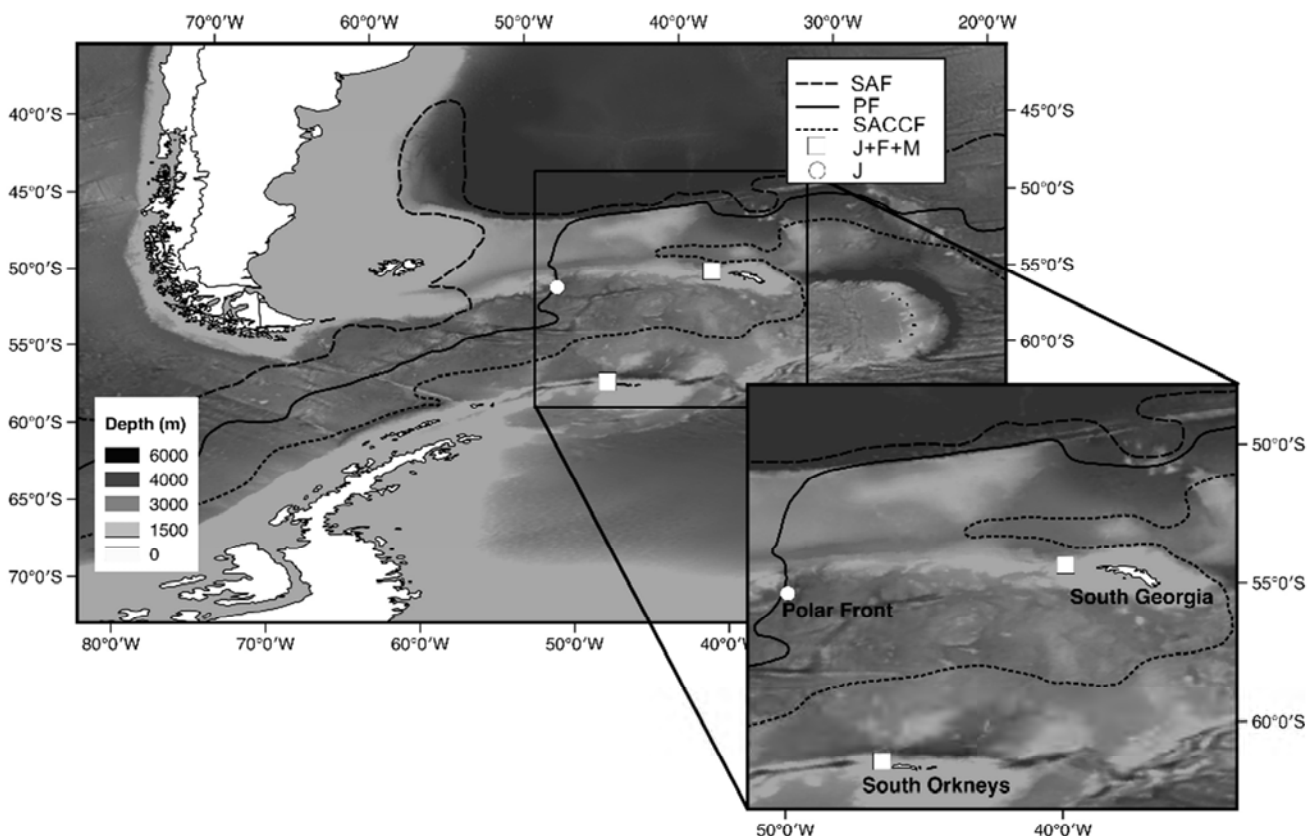
98 Antarctic krill *Euphausia superba* were collected from the British research
99 vessel RRS *James Clark Ross* during the austral summers of 2007/08, 2015/16 and
100 2016/17 (cruises JR177, JR15004 and JR16003 respectively). The three cruises
101 sampled three areas of the Scotia Sea (Figure 1) with different oceanic
102 characteristics. JR16003 had one sampling point at the Antarctic Polar Front. Both
103 JR16003 and JR177 sampled predominantly around South Georgia, and JR15004
104 sampled around the South Orkney Islands.

105 Samples were collected from the water column using an 8 m² mouth-opening
106 Rectangular Midwater Trawl (RMT8; mesh size reducing from 4.5 mm to 2.5 mm in
107 the cod end) (Roe and Shale, 1979). The net was rigged with two nets that could be
108 remotely opened and closed at different depths. The RMT8 was used to target
109 particularly Antarctic krill swarms and other layers of interest (e.g. fish layers)
110 identified by the vessel scientific echosounder system (i.e. Simrad EK60/EK80
111 operating between 38 and 200 kHz).

112 Antarctic krill in the catches were identified and total length (TL) of each
113 individual was measured, from the anterior edge of the eye to the tip of the telson
114 and rounded down (Morris et al., 1992). Sex and maturity stage were determined with
115 reference to the presence of a petasma (males), thelycum (females) or absent
116 (juveniles; individuals without visible external sexual characteristics) (Ross and

117 Quetin, 2000). Samples were either preserved in sample bags at -20°C (JR15004
 118 and JR16003) or on vials in ethanol (for JR177) (Fort et al., 2016).
 119

Figure 1 – Sampling sites of Antarctic krill (white square – samples of juveniles, females and males; white dot – samples of juveniles) and general positions of the Subantarctic Front (SAF), Polar Front (PF) and the Southern boundary of the Antarctic Circumpolar Current Front (SACCF) (Sallé et al., 2008).



120 *Laboratory procedures*

121 Prior to the mercury analysis, all samples were freeze-dried for at least 24
 122 hours. The eggs of females (Maturity stage III) (Ross and Quetin, 2000) from JR177
 123 (South Georgia) were removed under the microscope before freeze-drying.

124 Dried individuals and tissues were homogenized and analysed for total
125 mercury by thermal decomposition atomic absorption spectrometry with gold
126 amalgamation, using a LECO AMA-254 (Advanced mercury analyser) following
127 (Coelho et al., 2008). Organic mercury was determined through digestion with a
128 mixture of 18 % potassium bromide (KBr) in 5 % sulfuric acid (H₂SO₄), followed by
129 extraction of organic mercury into toluene as described in (Válega et al., 2006).
130 Analytical quality control was performed using certified reference material (CRM; in
131 this case TORT-2 and TORT-3 [lobster hepatopancreas, National Research Council,
132 Canada]). The obtained values (mean ± SD) for the whole of the CRM analyses
133 ranged from 81 to 102 % (TORT-2: 87 ± 3 %, n = 41; TORT-3: 90 ± 8 %, n = 27),
134 results were corrected using the daily recovery efficiency of CRMs. The mass of
135 CRM used for quality control analyses was adjusted to be within the range of total
136 mercury (in ng) present in the samples. Analyses were performed in duplicate, blanks
137 were analysed at the beginning of each set of samples and the coefficient of variation
138 between replicates never exceeded 10%. CRMs were also used to validate organic
139 mercury analyses, with an extraction efficiency of 80 ± 2 % and 98 ± 5 %,
140 respectively. The limit of detection for this analytical method is 0.00001 µg g⁻¹ of
141 absolute mercury and 0.004 µg g⁻¹ for organic mercury. All concentration data are
142 expressed subsequently in µg g⁻¹ dry weight.

143

144 *Statistical analysis*

145 Wilcoxon test were used to investigate whether there were any differences in
146 mercury concentrations between females and males, between eggs and females, or
147 between sampling sites. Kruskal-Wallis were performed to examine if there were
148 statistical differences between sex/maturity and location. Linear regressions were

149 calculated to examine possible relationships between Antarctic krill length and
150 individual mercury concentration. All analyses were performed using the R software
151 version 3.4.2 (R Core Team, 2013). All values are presented as mean \pm SD.

152

153 **Results**

154 *Total mercury concentrations in Antarctic krill according to geographic areas*

155 Total mercury concentrations varied between $0.054 \pm 0.018 \mu\text{g g}^{-1}$ in females,
156 $0.048 \pm 0.011 \mu\text{g g}^{-1}$ in males and $0.071 \pm 0.023 \mu\text{g g}^{-1}$ in juveniles from the South
157 Orkney Islands to $0.006 \pm 0.002 \mu\text{g g}^{-1}$ in females, $0.007 \pm 0.002 \mu\text{g g}^{-1}$ in males and
158 $0.014 \pm 0.005 \mu\text{g g}^{-1}$ in juveniles from the South Georgia and $0.017 \pm 0.006 \mu\text{g g}^{-1}$ in
159 juveniles from the Antarctic Polar Front.

160 There was a clear differentiation in mercury concentrations between the three
161 locations (Figure 2): Adult Antarctic krill from the South Orkney Islands had
162 concentrations of mercury about 7 times higher in females (Wilcoxon rank sum test,
163 $W = 120$, $p < 0.001$) and males (Wilcoxon rank sum test, $W = 120$, $p < 0.001$) than adult
164 Antarctic krill from South Georgia, and juveniles showed concentrations around 5
165 times higher in the South Orkney Islands (Kruskall-Wallis, $H_3 = 41.03$, $p < 0.001$) than
166 those collected at South Georgia and the Antarctic Polar Front. Juveniles from the
167 northern locations (South Georgia and Antarctic Polar front) had similar mercury
168 concentrations (Wilcoxon rank sum test, $W = 192$, $p = 0.093$).

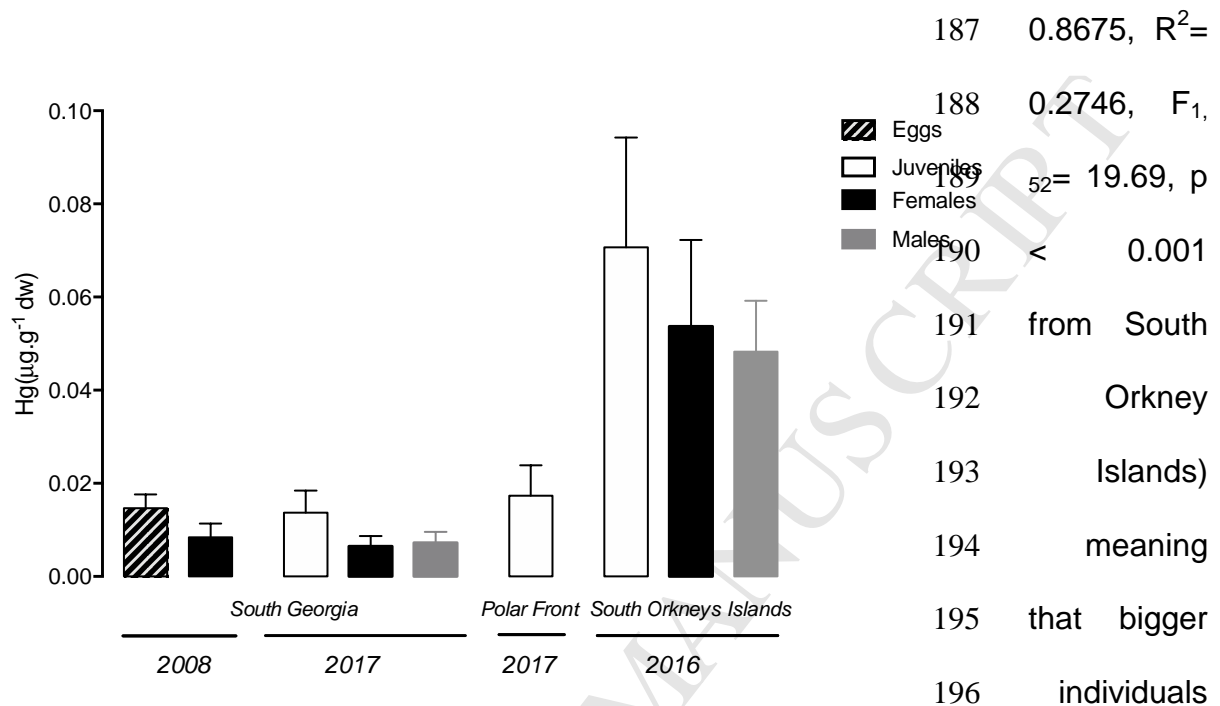
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170 *Total mercury concentrations in Antarctic krill according to life stage*

171 There were significant differences (Wilcoxon signed rank test, $Z = -3.351$, $p =$
172 0.001) between the mercury concentrations in the eggs ($0.015 \pm 0.002 \mu\text{g g}^{-1}$) and
173 the corresponding female somatic tissue ($0.008 \pm 0.003 \mu\text{g g}^{-1}$) from South Georgia

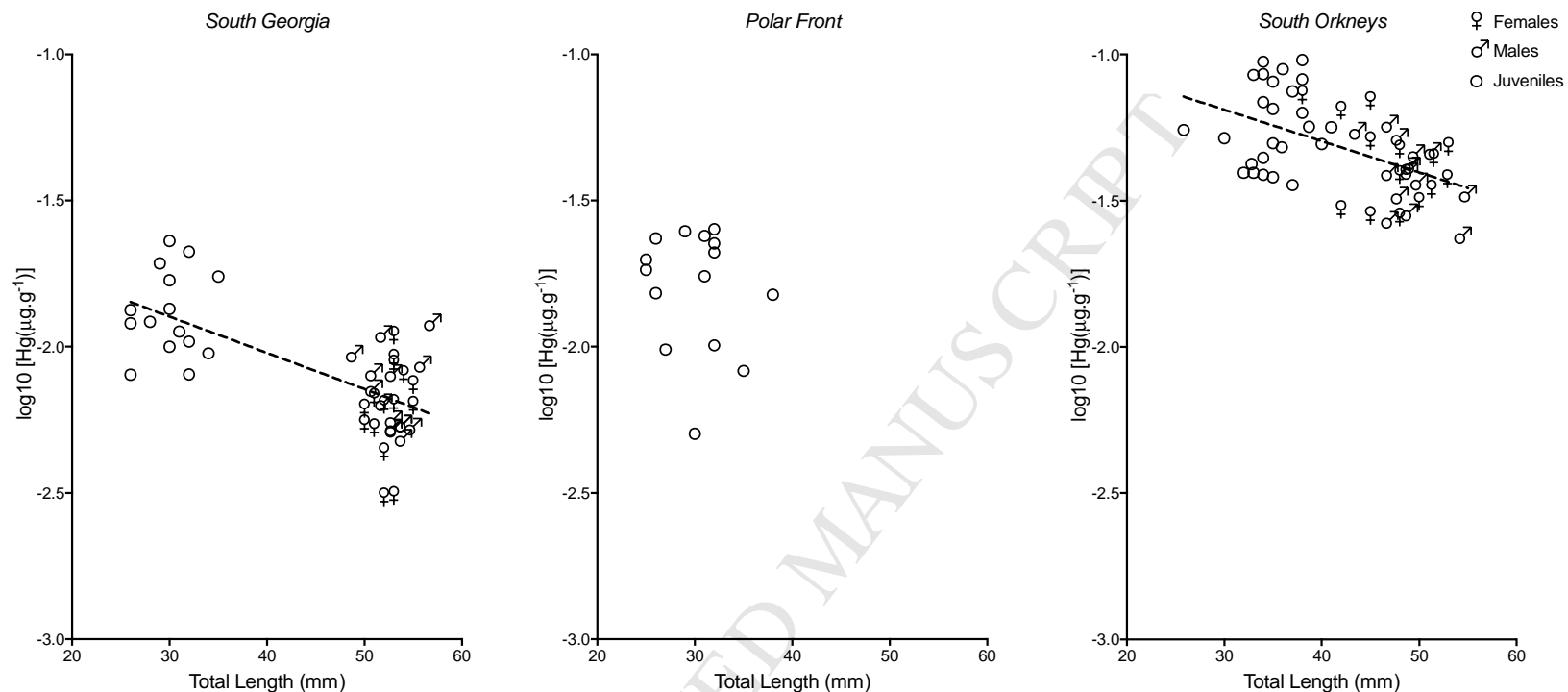
174 (Figure 2). There were no significant differences (Wilcoxon rank sum test, $W = 189$, p
175 $= 0.071$) between the females sampled in 2007/08 and 2016/17 at South Georgia
176 ($0.007 \pm 0.002 \mu\text{g g}^{-1}$). Juveniles caught around South Georgia ($0.014 \pm 0.005 \mu\text{g g}^{-1}$)
177 had significantly higher mean concentration of mercury than adults ($0.007 \pm 0.002 \mu\text{g}$
178 g^{-1} ; Kruskal-Wallis $H = 41.031$, $p < 0.01$) from the same region. Juveniles and eggs
179 from South Georgia also had similar concentrations (Wilcoxon rank sum test, $W =$
180 205 , $p = 0.254$). Like in juveniles from South Georgia, juveniles caught at the South
181 Orkney Islands ($0.071 \pm 0.024 \mu\text{g g}^{-1}$) also had significantly higher mercury
182 concentrations than adults ($0.051 \pm 0.015 \mu\text{g g}^{-1}$; Kruskal-Wallis $H = 10.048$, p
183 $= 0.07$).

184 Significant negative correlations of mercury concentration with body size was
 185 common to both the South Orkney Islands and South Georgia ($Y = -0.0124 * X -$
 186 1.525 , $R^2 = 0.46$, $F_{1, 43} = 36.41$, $p < 0.001$ from South Georgia; $Y = -0.01072 * X -$



197 had lower mercury concentrations (Figure 3). It was not possible to discern if such a
 198 relationship also existed at the Antarctic Polar Front, since only juveniles were found
 199 at this location.

Figure 2- Total mercury concentrations ($\mu\text{g g}^{-1} \text{ dw}$) in Antarctic Krill (*Euphausia superba*) collected around South Georgia and at the Antarctic Polar Front in the austral summer of 2016/17, and around the South Orkney Islands during the austral summer of 2015/16. Bars show the mean. Error bar is 1 standard deviation.



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Figure 3 – Total mercury concentration ($\mu\text{g g}^{-1}$ dw) on a log₁₀ scale versus total length (mm) for individual Antarctic krill (*Euphausia superba*) by maturity stage and sex respectively. Data are shown separately for krill collected around South Georgia ($Y = -0.0124 \cdot X - 1.525$, $R^2 = 0.46$, $F_{1, 43} = 36.41$, $p < 0.001$), the Antarctic Polar Front (both in the austral summer of 2016/17) and the South Orkney Islands ($Y = -0.01072 \cdot X - 0.8675$, $R^2 = 0.2746$, $F_{1, 52} = 19.69$, $p < 0.001$; summer of 2015/16).

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Total mercury concentrations in Antarctic krill according to sex

Concentrations of mercury in adult females ($0.054 \pm 0.018 \mu\text{g g}^{-1}$) and males ($0.048 \pm 0.011 \mu\text{g g}^{-1}$) from South Georgia were similar ($t_{28} = 0.9323$, $p = 0.4$; Figure 2). There were also no differences in mercury concentration between sexes in the samples collected from the South Orkney Islands ($t_{27} = 0.917$, $p = 0.4$; Figure 2).

Organic mercury in Antarctic krill

Adult Antarctic krill from the South Orkney Islands had higher concentrations of organic mercury than adults from South Georgia (Table 1) (for both males and females), but concentrations in juveniles were similar between the two locations. While no significant differences between juveniles, males and females were observed in the South Orkney Islands, juveniles in South Georgia had higher organic mercury concentrations than adults.

Organic mercury percentages in Antarctic krill were lower in the South Orkney Islands (15% in juveniles, 16% in females and 21% in males) than at South Georgia (29% in juveniles, 37% in females and 36% in males) and the Antarctic Polar Front (35% in juveniles; Table 1). Adults had slightly higher organic mercury percentages than juveniles (Table 1).

223 Table 1 – Organic mercury (OHg) and total mercury (THg) concentrations in samples
 224 of Antarctic krill (*Euphausia superba*) collected from different locations in the Scotia
 Sea during the austral summers of 2015/16 and 2016/17. Average \pm Standard
 Deviation

Location	Year	Sex / Maturity	Number	OHg ($\mu\text{g g}^{-1}$ dw)	THg ($\mu\text{g g}^{-1}$ dw)	%C
South Orkney Islands	2016	Juvenile	20	0.008 ± 0.003	0.051 ± 0.016	1
South Orkney Islands	2016	Female	20	0.008 ± 0.002	0.052 ± 0.022	1
South Orkney Islands	2016	Male	20	0.008 ± 0.003	0.040 ± 0.014	2
South Georgia	2017	Juvenile	20	0.008 ± 0.002	0.024 ± 0.006	2
South Georgia	2017	Female	20	0.002 ± 0.0002	0.006 ± 0.0003	3
South Georgia	2017	Male	20	0.003 ± 0.0001	0.007 ± 0.0004	3
Antarctic Polar Front	2017	Juvenile	20	0.005 ± 0.001	0.014 ± 0.005	3

225

226 Discussion

227 Despite some studies reporting mercury levels in Antarctic krill (Bargagli et al.,
 228 1998; Brasso et al., 2012b; Locarnini and Presley, 1995; Moren et al., 2006), there
 229 has remained a gap in knowledge regarding variability in mercury concentration by
 230 size, gender and location. Furthermore, to our knowledge this is the first study to
 231 determine organic mercury concentrations in Antarctic krill.

232

233 *Total mercury concentrations according to geographic areas*

234 We found Antarctic krill from South Orkney Islands had mercury body burdens
 235 5 to 7 times higher than those from South Georgia and from the Antarctic Polar Front.
 236 Habitat differences may explain the differences in contamination levels between

237 these three areas in the Southern Ocean. The average sea surface temperature
238 around the South Orkney Islands is lower than in South Georgia (Barnes et al., 2005;
239 Clarke and Leakey, 1996) and at the Antarctic Polar Front. This temperature gradient
240 leads to an important ecosystem difference, promoting the presence of more winter
241 ice in the South Orkney Islands (Atkinson et al., 2001). Ice formation can act as a
242 buffer for mercury and other elements (Lindberg et al., 2002). Furthermore, the ice
243 may act as a trap for contaminants precipitating from the atmosphere (Beyer and
244 Matthies, 2001; Cossa et al., 2011), which are released into the water column upon
245 ice melting (Brierley and Thomas, 2002; Geisz et al., 2008; Mastromonaco et al.,
246 2017). In the Arctic, for instance, higher concentrations of mercury were measured in
247 seawater under sea-ice, when compared with ice-free regions (Hintelmann et al.,
248 2007) and higher concentrations of mercury were found under ice during spring
249 (Mastromonaco et al., 2017). Additionally, depletion events promote higher
250 precipitation rates of atmospheric mercury in colder areas, mainly during springtime,
251 when halogen radicals oxidize the mercury (Ebinghaus et al., 2002; Lindberg et al.,
252 2002). Indeed, these depletion events have been reported along and between
253 regions of Antarctic sea-ice (Dommergue et al., 2010). Thus, higher depletion rates,
254 sea ice formation and its melting may explain why there were more contaminants
255 available to Antarctic krill around the South Orkney Islands than around South
256 Georgia. Comparing our data with previous records of mercury in Antarctic krill, we
257 see that samples from the Ross Sea, an area with winter sea ice (Bargagli et al.,
258 1998), had higher concentrations than South Georgia and the Antarctic Peninsula
259 (Brasso et al., 2012a; Cipro et al., 2016; Locarnini and Presley, 1995), but similar to
260 those at the South Orkney Islands (Table 2).

261 Other possible explanations for the higher mercury contamination in Antarctic
262 krill from the South Orkney Islands could be the proximity to active volcanoes, which
263 are well-known sources of mercury (Varekamp and Buseck, 1981; Zambardi et al.,
264 2009). Several volcanoes have recently been reported in the Antarctic Peninsula
265 (van Wyk de Vries et al., 2018), which is closer to the South Orkney Islands than to
266 the other two sampling sites in the present study. Nevertheless, the uptake of
267 mercury from such sources is likely to be variable given that previous studies
268 measuring mercury concentrations in Antarctic krill from the Antarctic Peninsula
269 measured levels that were lower than those specifically in the South Orkney Islands
270 Antarctic krill population reported here (Brasso et al., 2012a; Locarnini and Presley,
271 1995; Moren et al., 2006) (Table 2). Mercury body burdens in Antarctic krill may also
272 be related to food availability (Chen and Folt, 2005). Phytoplankton blooms, which
273 are a main source of mercury to krill, are spatially and temporally variable in the
274 Southern Ocean and have a large influence on Antarctic krill growth (Atkinson et al.,
275 2006; Cuzin-Roudy, 2000). Accordingly, the dynamics and availability of food
276 between locations will probably have a significant effect on the mercury
277 bioavailability, intake and bioaccumulation in Antarctic krill.

278 In comparison with other krill species around the world (Table 2), there are
279 examples where the concentration of mercury is lower, for instance, species from the
280 Order Euphausiacea in the Hudson bay (Canada) (Foster et al., 2012) and
281 *Euphausia pacifica* in the Californian Current (Sydeman and Jarman, 1998) than in
282 some of our samples. Mercury concentrations in euphausiids from more
283 industrialized European regions (Chouvelon et al., 2012; Leatherland et al., 1973;
284 Minganti et al., 1996) and the Arctic (Ritterhoff and Zauke, 1997) are nevertheless
285 considerably higher than in Antarctic krill (Table 2). Higher concentrations are also

286 evident in euphausiid populations in the sub-Antarctic Kerguelen Islands (Cipro et al.,
287 2018) which, like the Southern Ocean, is likely to result from remote atmospheric
288 sources (Cossa et al., 2011).

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Table 2 – Total mercury concentrations ($\mu\text{g g}^{-1}$ dw) in different species of Antarctic krill around the world from published data and this study (mean \pm standard deviation).

Species	Hg ($\mu\text{g g}^{-1}$)	Location	Reference
<i>Euphausia frigida</i>	0.023 \pm 0.002	Kerguelen Islands	Cipro et al. (2017)
<i>Euphausia pacifica</i> , <i>Thysanoessa spinifera</i>	0.030	Californian Current	Sydeman et al (1998)
<i>Euphausia superba</i>	0.008 \pm 0.002	Antarctic Peninsula	Brasso 2012
<i>Euphausia superba</i>	0.008	Krill food	Moren 2006
<i>Euphausia superba</i>	0.018 \pm 0.005	King George Island	Cipro et al. (2016)
<i>Euphausia superba</i>	0.013 to 0.049	Antarctic Peninsula	Locarnini (1995)
<i>Euphausia superba</i>	0.077 \pm 0.026	Ross Sea	Bargali 1998
<i>Euphausia superba</i> (Adult)	0.007 \pm 0.002	South Georgia	This study
<i>Euphausia superba</i> (Adult)	0.051 \pm 0.015	South Orkneys	This study
<i>Euphausia superba</i> (Female)	0.008 \pm 0.003	South Georgia	This study
<i>Euphausia superba</i> (Juvenile)	0.014 \pm 0.004	South Georgia	This study
<i>Euphausia superba</i> (Juvenile)	0.017 \pm 0.006	Polar Front	This study
<i>Euphausia superba</i> (Juvenile)	0.071 \pm 0.023	South Orkneys	This study
<i>Euphausia triacantha</i>	0.036 \pm 0.006	Kerguelen Islands	Cipro et al. (2017)
<i>Euphausia vallentini</i> (Large 25-30mm)	0.017 \pm 0.001	Kerguelen Islands	Cipro et al. (2017)
<i>Euphausia vallentini</i> (Small 16-24mm)	0.042 \pm 0.003	Kerguelen Islands	Cipro et al. (2017)
Euphausiacea	0.023 \pm 0.004	Hudson Bay (Canada)	Foster et al. (2012)
<i>Meganyctiphanes norvegica</i>	0.130 \pm 0.004	Arctic	Ritterhoff et al. (1997)
<i>Meganyctiphanes norvegica</i>	0.172 \pm 0.014	Bay of Biscay	Chouvelon et al (2012)

<i>Meganyctiphanes norvegica</i>	0.250	South of Portugal	Leatherland et al. (1973) ²⁸⁹
<i>Meganyctiphanes norvegica</i>	0.490	Mediterranean	Minganti et al (1996) ²⁹⁰
<i>Thysanoessa inermis</i>	0.120 ± 0.004	Arctic	Ritterhoff et al. (1997) ²⁹¹
<i>Thysanoessa sp.</i>	0.067 ± 0.031	Kerguelen Islands	Cipro et al. (2017) ²⁹² ²⁹³

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294 *Total mercury concentration according to life stage and sex*

295 Mercury concentration in Antarctic krill unexpectedly decreased with age (see
296 results). Since juveniles have a faster rate of growth compared to adults, one would
297 otherwise expect burdens to be lower in juveniles through a growth dilution effect, as
298 reported for *Daphnia pulex* (Karimi et al., 2007). Furthermore, juveniles have more
299 frequent molting cycles compared to adults (Buchholz, 1991), and excretion ratios will
300 probably be more efficient at these early stages. Somatic growth of Antarctic krill is
301 pre-programmed to slow once a certain age or maturity has been reached (Tarling et
302 al., 2006), in order to divert considerable resources to reproductive tissue when
303 reaching adulthood (Atkinson et al., 2006; Cuzin-Roudy, 2000). Adults also prey on
304 higher trophic levels compared to juveniles (Atkinson et al., 2002) which should mean
305 higher bio-magnification potential, and therefore contrary to what was observed. The
306 higher contaminant load of juveniles when compared with adults has, however, been
307 reported in previous studies on Antarctic krill (Locarnini and Presley, 1995) as well as
308 the subantarctic krill *Euphausia vallentini* (Cipro et al., 2018). One mechanism that
309 may explain this phenomenon is through egg laying, which has been reported as an
310 important elimination route for mercury in several organisms such as birds (Brasso et
311 al., 2012a; Pedro et al., 2015) and fish (Johnston et al., 2001; Schofield et al., 1994),
312 and also previously hypothesized for crustaceans species (Coelho et al., 2008). In
313 the present study, the higher mercury concentrations were found in Antarctic krill
314 eggs when compared to corresponding somatic tissue, suggesting that egg laying
315 maybe an elimination mechanism. However, males also have lower mercury burdens
316 compared to juveniles which either rules out this hypothesis or indicates that males
317 also eliminate mercury through their own gonadic tissue. Spermatophores are

318 regularly produced and passed out of the body throughout the lifespan of males,
319 although concentrations of mercury in these structures has yet to be measured.

320

321 *Organic mercury*

322 We found concentrations of the highly toxic, organic form of mercury of
323 between 0.002 and 0.008 $\mu\text{g g}^{-1}$ dw, with the higher concentrations being found in
324 both the South Orkneys and South Georgia, particularly in juveniles. Antarctic krill is
325 the main prey for several Southern Ocean predators and it is estimated that more
326 than half of its total biomass of 379 Mt is eaten by whales, seals, seabirds, squid and
327 fish (Atkinson et al., 2009). Assuming the lowest individual mercury concentrations
328 measured by the present study, this would mean 1.33 t of mercury will be passed on
329 from the consumption of Antarctic krill, of which 0.57 t will be in the organic form.
330 However the 1.33t of mercury potentially transferred in the trophic web is a
331 conservative number, as it was calculated from the lowest concentration levels found
332 in the present study, that is, at the same time the lowest concentration ever
333 measured in the literature. So it can be considered an underestimation. This organic
334 mercury will be potentially bioaccumulated in the tissues of Antarctic krill predators
335 and transferred towards upper food web predators leading to its biomagnification.
336 Thus, it may reach concentrations that can affect the behaviour, reproductive
337 success and even to reduce the survival of the top predators (Tan et al. 2009;
338 Eagles-Smith et al. 2018). Such bioaccumulation of organic mercury from Antarctic
339 krill consumption can explain how some Antarctic seabirds have particularly high
340 concentrations of mercury (Tavares et al., 2013).

341

342 **Conclusions**

343 The accumulation of mercury in Antarctic krill decreases with increasing body
344 size and maturity. Juveniles have higher concentrations than adults which may be the
345 result of a growth dilution effect and also elimination through gonadic tissue (eggs
346 and spermatophores).

347 The observed spatial differences suggest that Antarctic krill reflects differential
348 contaminant bioavailability in the Southern Ocean, while further studies are needed
349 to discern the most significant variables governing site-specific mercury
350 bioaccumulation.

351 The range of mercury concentrations reported in Antarctic krill are within the
352 same range, or even higher, than other euphausiids from areas closer to the
353 industrialized part of the world, highlighting mercury as a global pollutant.

354 Overall, our results stress the need to put into action pollutant monitoring
355 programs to evaluate the sources, pathways and effects of contaminants in remote
356 ecosystems.

357

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Highlights:

- Mercury concentration in Antarctic Krill decreases with size and maturity;
- Adults have higher ratio of organic mercury than juveniles;
- Females may use egg laying as an mercury excretion mechanism;
- Mercury concentration in Krill vary along the Scotia Sea;
- Some euphausiids from other locations have lower concentration than Krill.