

In stark contrast to widespread declines along the Scotia Arc, a survey of the South Sandwich Islands finds a robust seabird community

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1 In stark contrast to widespread declines along the Scotia Arc, a survey of the South Sandwich
2 Islands finds a robust seabird community

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17

18 **Abstract**

19 The South Sandwich Islands, in the south Atlantic Ocean, are a major biological hotspot for
20 penguins and other seabirds, but their remoteness and challenging coastlines preclude regular
21 biological censuses. Here we report on an extensive survey of the South Sandwich Islands, the first
22 since the late 1990s, which was completed through a combination of direct counting, GPS mapping,
23 and interpretation of high-resolution commercial satellite imagery. We find that the South Sandwich
24 Islands host nearly half of the world's Chinstrap Penguin (*Pygoscelis antarctica*) population (1.3
25 million breeding pairs), as well as c. 95,000 breeding pairs of Macaroni Penguins (*Eudyptes*
26 *chrysolophus*), and several thousand breeding pairs of Gentoo Penguins (*Pygoscelis papua*).
27 Despite being at the northern edge of their breeding range, we found an unexpectedly large
28 ($\geq 125,000$ breeding pairs) population of Adélie Penguins (*Pygoscelis adeliae*). Additionally, we
29 report that nearly 1,900 pairs of Southern Giant Petrels (*Macronectes giganteus*) breed in the South
30 Sandwich Islands, 4% of the global population, almost all of which are found on Candlemas Island.
31 We find that the South Sandwich Islands have not experienced the same changes in penguin
32 abundance and distribution as the rest of the Scotia Arc and associated portions of the western
33 Antarctic Peninsula. This discovery adds important context to the larger conversation regarding
34 changes to penguin populations in the Southern Ocean.

35

36 **Introduction**

37 Changes in the distribution and abundance of penguin populations on the Antarctic Peninsula and
38 associated islands of the Scotia Arc have been widely reported. On the western Antarctic Peninsula,
39 Adélie Penguins (*Pygoscelis adeliae*) and Chinstrap Penguins (*Pygoscelis antarctica*) are declining
40 north of Marguerite Bay whereas Gentoo Penguins (*Pygoscelis papua*) are increasing in abundance
41 and expanding their breeding range to the south (Trivelpiece et al. 2011; Lynch et al. 2012b;
42 Casanovas et al. 2015). Macaroni Penguins (*Eudyptes chrysolophus*) are declining sharply at South
43 Georgia (Trathan et al. 2012) while King Penguin (*Aptenodytes patagonicus*) populations have
44 increased (Trathan et al. 2007). While these trends appear quite robust, the drivers responsible for
45 these changes are far less clear; hypotheses include the direct influence of sea ice on habitat
46 suitability for ice-intolerant species, the indirect effects of sea ice on krill availability, krill
47 harvesting, tourism and human disturbance, and cetacean recovery (Ducklow et al. 2007; Murphy et
48 al. 2007; Trathan et al. 2007; Ainley et al. 2010; Lynch et al. 2010; Trivelpiece et al. 2011).

49 The South Sandwich Islands (Figure 1), a long isolated chain of volcanic islands along the
50 Scotia Arc connecting South Georgia with the Antarctic Peninsula, have long been identified as a
51 major ecological hotspot for penguins, but their remote location and challenging coastline have
52 made it difficult to gain accurate estimates of seabird breeding abundance and distribution. Several
53 factors make the South Sandwich Islands unique and potentially important for disentangling the
54 drivers of changes seen elsewhere along the Scotia Arc. The extent of mid-winter sea ice (as
55 defined by the boundary of 15% sea ice concentration) cuts right through the South Sandwich
56 Islands in most years; as a result, the northernmost islands of Zavodovski and Visokoi are often ice-
57 free all year, whereas the southernmost islands are rarely, if ever, ice-free all year round (Murphy et
58 al. 2007). The waters surrounding the South Sandwich Islands have some of the highest Antarctic
59 krill (*Euphausia superba*) and chlorophyll-a densities in the Southern Ocean (Atkinson et al. 2008),
60 yet some of the lowest rates of krill harvest (CCAMLR 2015). While tourism activity has increased
61 ten-fold over the last 20 years on the Antarctic Peninsula (Bender et al. 2016), commercial cruise

62 trips to the South Sandwich Islands are rare. For all of these reasons, the South Sandwich Islands
63 represent a key element of our regional understanding of how environmental or human influences
64 affect seabird abundance and distribution.

65 Prior surveys of the South Sandwich Islands include Baker et al. (1964), Cordier et al.
66 (1981), and Convey et al. (1999), though of these, only Convey et al. (1999) provides estimates of
67 breeding abundance against which to assess changes in the abundance and distribution of seabirds
68 and seals. The recent development of high-resolution commercial satellite imagery as a tool for
69 surveying penguin populations (e.g., Lynch et al. 2012a) provides a promising alternative to direct
70 survey for areas as remote as the South Sandwich Islands. Here we report on a coordinated ground
71 and satellite imagery survey of the South Sandwich Islands which updates Convey et al. (1999),
72 provides some estimates of population change among seabirds, and lays the groundwork for future
73 surveys through improved distribution maps, geo-referenced photographs, and suggested guidelines
74 for future ground surveys.

75

76 **Methods**

77 *Ground survey*

78 We (RW and AB) surveyed the South Sandwich Islands from January 1-February 5, 2011 using the
79 *MS Golden Fleece*, skippered by Jérôme Poncet, as a platform for survey and access to the islands.

80 We worked from north to south through the archipelago making Zodiac landings to conduct
81 biological surveys on all the main islands in the group, with the exception of Leskov, which (by all
82 available accounts) presents an extraordinarily difficult landing (Table 1). Our methods for
83 surveying breeding seabirds varied depending on the species involved, the stage of the breeding
84 cycle, the size of the colony, and the time available onshore. In general, we counted smaller
85 colonies (<10,000 individuals) in full by direct counting of occupied nests and/or chicks using
86 hand-held tally-counters. In larger colonies or areas with limited time ashore we mapped colony
87 boundaries with GPS to facilitate the interpretation of high-resolution satellite imagery (e.g., Lynch

88 et al. 2012a). Tables 1 and 2 provide further details on the field survey. Our survey was biased
89 towards identifying the locations of penguin colonies and no attempt was made to record the exact
90 locations of cliff nesting petrels (Antarctic Fulmar, Cape Petrel, Snow Petrel). It is important to note
91 that we do not yet understand the breeding phenology of seabirds on the South Sandwich Islands
92 well enough to deduce the date of peak nesting and thus correct abundance estimates for nest
93 failures; however, we do make note of the approximate phase of breeding for each site where it
94 provides context for our reported counts.

95

96 *Satellite imagery survey*

97 Table 3 contains a summary of satellite imagery used for this analysis. We used the same basic
98 technique for manual interpretation of satellite imagery described in Lynch et al. (2012a) and
99 LaRue et al. (2014). We manually delineated penguin sub-colonies using the guano stain associated
100 with the nesting area of the colony. Our identification of guano was based on prior experience with
101 ground validated imagery interpretation at other locations (e.g., Chinstrap Penguins on Deception
102 Island, Naveen et al. [2012]; Adélie Penguins on the western Antarctic Peninsula, Casanovas et al.
103 [2015]), GPS data obtained during the ground survey, and photodocumentation. Guano stains are
104 distinguished from background substrates (usually volcanic sand, mineral soils, or bare rock) by
105 their spectral reflectance (their ‘color’ as seen in false color images), texture, size, and distance to
106 the shoreline. In many cases, interpretation of satellite imagery was aided by GPS data collected on
107 the ground (e.g., tracklogs encircling sub-colonies) and photodocumentation, the latter of which was
108 particularly important for distinguishing different species where they were nesting in adjacent or
109 even fully mixed colonies. For Chinstrap Penguins, we were able to use field counts of sub-colonies
110 paired with satellite imagery of those same sub-colonies to estimate the ‘apparent’ density of
111 nesting penguins at Zavodovski Island; this number was used for all of the South Sandwich Islands.
112 Note that this is not necessarily the true density as would be measured in the field, but the number
113 of occupied nests in the guano-stained area identified in the satellite imagery as belonging to that

114 sub-colony (see LaRue et al. [2014]). For the other species, we used nesting density estimates from
115 the literature. It is important to note that while it is not possible to differentiate nesting penguins and
116 non-nesting penguins from satellite imagery, the guano stain is created by penguins incubating nests
117 over an extended period of time and reflects long-term occupation of an area rather than transient
118 occupation by non-nesting penguins that may wander through the colony.

119

120 *Survey uncertainties*

121 Irrespective of the source for our estimates of abundance (direct ground count or satellite-based),
122 we have adopted the ordinal scheme for denoting census precision used by previous authors (e.g.,
123 Croxall and Kirkwood 1979; Woehler 1993): Accuracy = 1: accurate to better than $\pm 5\%$; Accuracy
124 = 2: accurate to 5-10%; Accuracy = 3: accurate to 10-15% (in practice, we extend this upper limit to
125 25% to ensure continuity); Accuracy = 4: accurate to 25-50%; Accuracy = 5: accurate to nearest
126 order of magnitude. Accuracy was assessed based on the observer's prior experience counting
127 seabirds and the methodology used. Counts with high precision (N1 or C1) represent direct counts
128 of occupied nests and/or chicks by an observer standing just outside the colony (~5 m from the
129 edge). In other cases, binoculars would have been used to estimate the sizes of populations, and in
130 these cases the precision of the counts would be downgraded accordingly. Where counts of
131 individual groups of penguins within the site were counted with different accuracies, the site-wide
132 accuracy is calculated by propagating errors accumulated in each colony count assuming
133 independence among the colony counts.

134 While nest and chick counts have been reported separately, archipelago-wide total
135 abundance estimates for each penguin species assume each penguin chick is associated with one
136 nest when combining nest and chick counts. This conversion assumes ~50% egg or chick loss prior
137 to the survey, which may or may not be appropriate for each island. Therefore, archipelago-wide
138 abundance estimates are less precise than each of the island-wide abundance estimates.

139

140 **Results**

141 Detailed island-specific accounts for each species, along with maps and photographs for each
142 island, have been included as an Online Resource for use by other researchers (Online Resource 1).
143 High-resolution satellite imagery, merged where necessary with existing coastline information, was
144 used to create a GIS shapefile for the coastlines of the South Sandwich Islands (Online Resource 2).

145

146 Penguins

147 While large uncertainties preclude a quantitative assessment of population trends, our findings
148 strongly suggest that Adélie, Chinstrap, and Macaroni Penguin populations are at least stable and
149 are likely to have increased in abundance since the survey of Convey et al. (1999) (Table 4).

150 Chinstrap Penguins are the most abundant bird species in the South Sandwich Islands and
151 the massive scale of the Chinstrap colonies made direct census challenging at most locations.
152 Nevertheless, we estimate a minimum population of 1.3 million breeding pairs (Table 4). Most pairs
153 were still brooding chicks during the survey, so we used active nests as our unit of counting for
154 Chinstrap Penguins, though an increased number of birds moving towards the crèche stage was
155 observed at Thule Island at the end of the survey period. We estimate a minimum breeding
156 population of 125,000 pairs of Adélie Penguins in the South Sandwich Islands (Table 4). Adélie
157 Penguins were absent from the northern islands, with the northernmost record coming from
158 Candlemas Island. Moving further south, Adélies became a more prominent part of the seabird
159 community. Breeding was well advanced in all colonies with chicks in the crèche stage and some
160 birds already fledged; for this reason, we counted chicks rather than adults. Gentoo Penguins were
161 present in low numbers within the surveyed area, typically in loose colonies at very low densities
162 just above the beach. We estimate a minimum population of 1,902 breeding pairs of Gentoo
163 Penguins for the South Sandwich Islands. Most Gentoo Penguin pairs had large chicks that had
164 reached the crèche stage at the time of census, so chick counts were used to derive population
165 estimates. Where appropriate, an additional estimate was made of active nests with birds incubating

166 eggs or small chicks. King Penguins were present in small numbers at all islands, typically less than
167 50 individuals, with most onshore to moult. The exception to this was at Zavodovski Island where,
168 within the large Chinstrap Penguin colony on the south-east coast, two birds were seen in a posture
169 that strongly suggested they were incubating eggs or brooding small chicks.

170 Macaroni Penguins were present at most locations, and we estimate a minimum abundance
171 of 95,000 breeding pairs in the South Sandwich Islands (Table 4). Because Macaroni Penguins were
172 usually present in small numbers within much larger Chinstrap Penguin colonies, locating birds in
173 the field was not straightforward, and it was difficult to guarantee that all birds within a colony had
174 been counted. However, it quickly became apparent that the Macaroni Penguin colonies could be
175 located by their darker appearance (Figure S11a). This was thought to be a combination of the
176 stance of the birds (more hunched for Macaroni Penguins brooding small chicks, more upright in
177 Chinstrap Penguins brooding larger chicks) and the density of birds (higher in Macaroni than in
178 Chinstrap). We do not know whether Macaroni and Chinstrap Penguins are always differentiable in
179 this manner or whether we captured them at a fortuitous time in the breeding cycle. Nevertheless, as
180 described in Lynch et al. (2012a), these differences were also apparent in high resolution satellite
181 imagery, allowing us to differentiate between Macaroni Penguins and Chinstrap Penguins (Figure
182 S11b) and estimate populations from satellite imagery where field counts were highly uncertain or
183 unavailable. Many birds were present on territories without apparently breeding. Those that were
184 breeding were mainly brooding a small chick, and so active nests were counted.

185

186 Flying birds

187 Both Southern and Northern Giant Petrels (*Macronectes giganteus* and *Macronectes halli*,
188 respectively) were a prominent feature of the penguin colonies visited, where they were
189 scavenging/predating penguins both onshore and in coastal waters. Southern Giant Petrels were
190 present throughout the islands, and were the only species found breeding in the South Sandwich
191 Islands. We found nearly 1,900 pairs of Southern Giant Petrels breeding in the South Sandwich

192 Islands, almost all of which were found on Candlemas Island (Table 4). White morph birds were
193 noted at several sites. Northern Giant Petrels were recorded inshore and in coastal waters of all the
194 islands and this species was frequently observed scavenging/predating penguins. The largest
195 number recorded of this species was 25 birds at Irving Point on Visokoi Island.

196 South Georgia Shags (*Phalacrocorax [atriceps] georgianus*) were present throughout the
197 islands in small numbers, with rarely more than ten birds at any location. No effort was made to
198 visit specific locations where this species has been recorded breeding in the past so updated
199 population estimates are not available. Wilson's Storm-petrels (*Oceanites oceanicus*) were
200 frequently seen flying over land at probable breeding locations during the day, but no nests were
201 located. Black-bellied Storm-petrels (*Fregata tropica*) were confirmed breeding on Candlemas and
202 Montagu Islands. On the former, several dead chicks were found; on the latter, a dead chick and an
203 occupied nest were found. Antarctic Terns (*Sterna paradisaea*) were present at Zavodovski Island
204 where breeding was confirmed when chicks were seen on several offshore stacks at the northern
205 end of the island. Adults were also seen carrying food flying north-west past Fume Point. An adult
206 was also seen carrying food at Beach Point, Thule Island, in what seemed to be courtship display.
207 Kelp Gulls (*Larus dominicanus*) were present in small numbers (<100 fully-grown birds) at all sites
208 surveyed, but we recorded little evidence of breeding. Confirmed breeding was recorded for
209 Zavodovski Island (three nest sites with chicks located on the north coast), Candlemas Island (on at
210 least five sites on Breakbones Plateau, no chick count), Thule Island (minimum eight chicks at
211 Hewison Point), and Bellingshausen Island (minimum 11 chicks).

212 Antarctic Skuas (*Stercorarius antarctica*) were present at all islands associating with
213 penguin colonies and often seen in skua clubs, including up to 50 birds at Zavodovski Island.
214 However, breeding activity was not widespread. The unusually large concentration of birds at
215 Candlemas Island reported by Convey et al. (1999) was again noted, but a count of nests was
216 abandoned due to time limitations. The next largest breeding population appeared to be on
217 Bellingshausen Island where at least 20 nests were found. Otherwise, breeding activity was either

218 limited to single nests or absent altogether. Individual South Polar Skuas (*Stercorarius*
219 *maccormickii*) were seen on shore at several islands, including at Allen Point on Montagu Island
220 and at Hewison Point on Thule Island. While there was no evidence of breeding, a South Polar Skua
221 paired with an Antarctic Skua was found at Allen Point on Montagu Island.

222 Antarctic Fulmars (*Fulmarus glacialoides*) were observed breeding on steep slopes and cliff
223 ledges on all islands except Zavodovski and Bellingshausen Islands. Although no direct counts of
224 nests were attempted, breeding sites were photodocumented when encountered. In terms of
225 distribution and relative abundance, the observations made during this survey are consistent with
226 findings by Convey et al. (1999). Breeding Cape Petrels (*Daption capense*) were sighted on all the
227 islands visited, although generally in low numbers. The largest breeding aggregation of this species
228 was observed on the west coast of Thule Island, where several thousand nests were observed and
229 photographed. Snow Petrel (*Pagodroma nivea*) nests were seen on all the islands visited except
230 Zavodovski Island. Like the Cape Petrel, the largest breeding aggregation of Snow Petrels was
231 observed on the west coast of Thule Island. No attempt was made to census the island-wide
232 population of Snow Petrels. We observed two Light-mantled Sooty Albatrosses (*Phoebetria*
233 *palpebrata*) flying over Candlemas Island on 17 January 2011. These birds were behaving as a pair
234 flying in tandem high over the island. They were not seen to settle at any point and departed after 15
235 minutes of observation after an encounter with some Antarctic Skuas. Finally, it is important to note
236 that despite deliberate effort to search for Snowy Sheathbills (*Chionis alba*), no individuals were
237 recorded at any of the South Sandwich Islands.

238

239 **Discussion**

240 *Summary of observations and apparent trends*

241 Our observations regarding the species composition of the South Sandwich Islands accord with
242 those of previous surveys (Cordier et al. 1981; Convey et al. 1999). No new species were recorded
243 breeding in the islands; however, we did identify six new locality records. The following species

244 were confirmed breeding on islands where they had not previously been recorded: Gentoo Penguins
245 were confirmed breeding on Zavodovski and Bristol Islands; Adélie Penguins were confirmed
246 breeding on Cook Island; Macaroni Penguins were confirmed breeding on Vindication and Thule
247 Islands; and Black-bellied Storm-petrels were confirmed breeding on Montagu Island.

248 While the census of breeding penguins was by no means complete, several observations can
249 be made about penguin populations in the region. Gentoo Penguin numbers are stable or increasing
250 overall. Locally, a decline may have been observed at Irving Point, Visokoi Island, although it is
251 possible that part of the colony was not located. A marked increase in the Gentoo Penguin
252 population was noted at Saunders Island where 300 pairs recorded in 1997 is now a colony
253 producing over 800 chicks. At other sites, numbers are comparable with Convey et al. (1999),
254 including Hewison Point which, having increased from 20 pairs in 1955 (Wilkinson 1956) to 600
255 pairs in 1997 (Convey et al. 1999), now appears to have stabilized.

256 On the evidence of those populations counted, the abundance of Macaroni Penguins in the
257 islands is at least stable, or perhaps increasing. While the largest population in the archipelago (on
258 Zavodovski Island) was not directly counted, we estimate that the colony includes more than the
259 52,000 pairs reported by Convey et al. (1999). The total population on Visokoi Island is probably
260 between 4,000 and 5,000 pairs, higher than the 2,000 pairs reported by Convey et al. (1999). The
261 number of nests on Candlemas Island was similar to the total in 1997. A new site with about 200
262 nests was recorded on Vindication Island, where the species had been recorded previously
263 (Holdgate and Baker 1979) but not proven to breed.

264 The Adélie Penguin population on Candlemas Island has changed little in size since 1997.
265 However, Adélie Penguin colonies on Montagu, Bellingshausen, and Thule Islands were far larger
266 than had been previously reported by Convey et al. (1999). For example, the chick count on
267 Bellingshausen Island was about two-thirds complete with a total of 30,000 chicks; an estimate of
268 the remainder of the colony suggests a total number of chicks in the range of 45,000 (C3). On Thule
269 Island, where Convey et al. (1999) report only 10,000 Adélie pairs, we encountered 26,000-27,000

270 (C4) chicks even without a survey at Beach Point. No count was possible at Scarlett Point on
271 Montagu Island but the population clearly numbers in the thousands compared with 200 reported
272 for the whole of Montagu Island by Convey et al. (1999). Initial impressions on Saunders Island
273 were of a colony in excess of 50,000 pairs of Adélie Penguins at Cordelia Bay-Nattriss Point but
274 this is unconfirmed. As a result, the Adélie Penguin population estimate for the South Sandwich
275 Islands could be doubled to at least 125,000 pairs. Finally, we note that the absence of Adélie
276 Penguins at the two most northerly islands (Zavodovski and Visokoi), which lie north of the 15%
277 mid-winter sea ice contour, is consistent with other studies suggesting 15% as a lower limit of
278 acceptability for Adélie Penguins (Ainley 2002).

279 Chinstrap Penguin colonies encountered were generally too large to permit direct counts.
280 However, in all areas where direct counts or reasonable estimates could be made, colonies were at
281 least as large, if not larger, than those reported by Convey et al. (1999). In some cases, this appeared
282 to be a result of survey methodology, particularly in cases where we landed at colony sites rather
283 than conduct boat surveys that involved obscured views of the colony.

284 For Adélie, Chinstrap, and Macaroni Penguins, it seems clear that the massive declines
285 reported on South Georgia, in the South Orkney Islands, and along the western Antarctic Peninsula
286 (e.g., Trivelpiece et al. 2011; Lynch et al. 2012b; Trathan et al. 2012) are not reflected in the trends
287 seen in the South Sandwich Islands. The South Sandwich Islands have received considerably less
288 attention than either South Georgia or the western Antarctic Peninsula and little is known about
289 changes in prey availability, foraging effort, diet, phenology, or demography. Casual examination
290 of the guano suggests that penguins are eating both krill and fish in the South Sandwich Islands,
291 though more careful analysis is clearly required to compare penguin diet in this region to
292 populations elsewhere in the region. Advection in the vicinity of the South Sandwich Islands is
293 complex, and it is not clear what fraction of krill in the South Sandwich Islands are coming from the
294 area of the South Orkney Islands or further to the east from a clockwise gyre in the Weddell Sea
295 (Murphy et al. 2004; Thorpe et al. 2007). As such, it is difficult to know whether the diverging

296 trends between the South Sandwich Islands and the South Orkneys/western Antarctic Peninsula
297 region reflects differences in krill production and subsequent availability or differences in fishing
298 pressure. A more detailed understanding of krill transport to this region will be needed to explain
299 why penguin populations in the South Sandwich Islands have escaped the significant declines seen
300 elsewhere in the region. It was notable that many penguin colonies were located on ‘recent’
301 volcanic ash overlying ice that, while temporarily stabilized by penguin guano, was thin enough that
302 we would occasionally break through the ‘crust’ to the underlying ice. In some areas, penguin
303 breeding habitat was being eroded as the underlying ice melted. While volcanic activity can create
304 habitat for penguins to colonize, warming of the region may lead to melting and erosion of available
305 nesting habitat.

306 Compared to Convey et al. (1999), we observed a notable increase in the numbers of
307 Northern Giant Petrels. Only two individuals were recorded during the earlier survey, while we
308 regularly encountered groups of at least 10 individuals onshore with a peak count of 25 birds at
309 Irving Point on Visokoi Island. However, we cannot confirm whether this species is breeding. We
310 found evidence consistent with continued population growth for Southern Giant Petrel populations
311 in the South Sandwich Islands (at Candlemas Island: 520 pairs in 1979 [Cordier et al. 1981]; 1,516
312 pairs in 1997 [Convey et al. 1999]; 1,818 in 2011 [present survey]), though recognize the caveats
313 appropriate to comparing surveys using different methodologies (Creuwels et al. 2005). In contrast,
314 Shags appear to be declining throughout much of the archipelago. While we did not specifically
315 target surveys for previously known locations of this species, Bristol Island was the only location
316 where we found Shags nesting in numbers comparable to those given in Convey et al. (1999).

317 Several questions arise from the comparison of our survey with previous surveys (Cordier et
318 al. 1981; Convey et al. 1999). For example, how are we to interpret the apparently large increase in
319 the Adélie Penguin population in the southern islands? Cordier et al. (1981) report approximately
320 1,000 pairs of Adélie Penguins at Herd Point. Convey et al. (1999) indicate Adélie Penguins as
321 present at Herd Point (Figure 12 in Convey et al. [1999]), but list the Thule Island population as

322 approximately the same as the total for Hewison Point (10,000 pairs; cf. Convey et al. [1999] Table
323 3 with text on page 121); from this we infer that at the very least, the Herd Point population was far
324 smaller than the 10,000 pairs found at Hewison Point. So, we are faced with evidence suggesting
325 that in 13 years the Adélie Penguin population at Herd Point has gone from c. 1,000 pairs to
326 producing c. 20,000 chicks, while the Hewison Point population has remained stable over a thirty
327 year period (Cordier 1981). Furthermore, Convey et al. (1999) report “<10,000” pairs of Adélie
328 Penguins at Bellingshausen Island, while we estimate the current population to have produced
329 40,000-50,000 chicks. Another Adélie Penguin site with a recorded landing in Convey et al. (1999)
330 is Scarlett Point on Montagu Island where a 1.5 hour landing was made on 29 January 1997. This
331 would appear to be the source of the total of 200 pairs given for Montagu Island in Convey et al.
332 (1999) Table 3, while evidence of thousands of Adélie Penguins were observed at this site during
333 this survey (though we were unable to make a landing for a more precise count). It is difficult to
334 know to what extent these differences stem from survey effort as opposed to genuine population
335 growth, but the consistency between Cordier et al. (1981) and Convey et al. (1999), as well as the
336 fact that three different islands appear to have growing Adélie populations, suggest the latter.

337

338 *Missing elements of the South Sandwich Islands community*

339 Cordier et al. (1981) noted four species believed to be missing from the South Sandwich Islands
340 breeding bird community: Antarctic Terns, Antarctic Prions, Black-bellied Storm-petrels, and
341 Sheathbills. We confirm Convey et al.’s findings that Antarctic Terns and Black-bellied Storm-
342 petrels nest on the South Sandwich Islands, leaving Antarctic Prions and Sheathbills as the two
343 remaining species that might be considered missing from the South Sandwich Islands’ avian
344 community. Despite what appears to be an abundance of food and suitable habitat, no Sheathbills
345 have ever been reported on the South Sandwich Islands. Cordier et al. (1981) note that the South
346 Sandwich Islands lie in between the ranges of the Snowy Sheathbill (*Chionis albus*), which breeds
347 to the west (closest known breeding colony is South Georgia, 540 km away), and the Black-faced

348 Sheathbill (*C. minor*), which breeds to the east (closest known colony is Prince Edward Islands,
349 4345 km away), and suggest that insufficient prospecting of the islands rather than environmental
350 conditions explains their absence. However, Sheathbills are believed to migrate from the Antarctic
351 Peninsula to Argentina (BirdLife International 2015a), placing the South Sandwich Islands well
352 within their physical flight range (see also Cordier et al. 1981). The apparently unfilled niche for a
353 terrestrial scavenger specialist like the Sheathbill at the South Sandwich Islands remains a curious
354 mystery.

355

356 *South Sandwich Islands in a global context*

357 While the South Sandwich Islands contain <2% of the global population of Gentoo Penguins,
358 Adélie Penguins, and Macaroni Penguins, it contains more significant populations of several other
359 species. Our results suggest that the South Sandwich Islands host a minimum population of 1.3
360 million breeding pairs of Chinstrap Penguins, which is nearly half of the world's Chinstrap Penguin
361 population (assuming a total population of 2.67 million breeding pairs; Harris et al. 2015), and
362 approximately 4% of the global population of Southern Giant Petrels (BirdLife International 2015b;
363 see also Patterson et al. [2008]). In addition, roughly 13-31% of the global population of Antarctic
364 Fulmars breed in the South Sandwich Islands (Creuwels et al. 2007).

365

366 *Future survey work*

367 To facilitate future survey efforts, we have included in the Online Resources additional survey notes
368 and advice for future expeditions. We have also provided ArcGIS shapefiles representing the
369 location of penguin colonies, flying birds, and marine mammals. The photographs in Online
370 Resource 1 are only a small subset of images available from the ground survey, and future survey
371 teams are invited to contact us for additional imagery as needed.

372 While satellite imagery may permit some regular monitoring of highly visible species, it is
373 impractical to conduct regular direct censuses of all islands within the archipelago. Therefore, it will

374 be necessary to select a representative sample of accessible sites that could be monitored regularly
375 as access to the region permits. We suggest regular monitoring of Southern Giant Petrels and Adélie
376 Penguins on Candlemas Island and Chinstrap, Adélie and Gentoo Penguins at Hewison Point on
377 Thule Island. We suggest, as a second tier of priority surveys, Adélie Penguins on Montagu Island;
378 Adélie Penguins and Gentoo Penguins at Cordelia Bay, Saunders Island; and Southern Giant Petrels
379 and Chinstrap Penguins on Zavodovski Island. We hope that future visits to these remote and
380 inhospitable islands will permit more rigorous analyses of biological trends in this area, and more
381 comparative work with the Antarctic Peninsula to its south.

382

383

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476

477 **Figure captions:**

478 **Figure 1:** South Sandwich Islands relative to Antarctica (inset)

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