

1 The year-round distribution and habitat preferences of Campbell albatross (*Thalassarche impavida*)

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25

26 Abstract

- 27 1. The use of miniaturised electronic tracking devices has illuminated our understanding of seabird
28 distributions and habitat use, and how anthropogenic threats interact with seabirds in both space and time.
29 In order to determine the year-round distribution of Campbell albatross (*Thalassarche impavida*), a single-
30 island endemic breeding only at Campbell Island in New Zealand's subantarctic, a total of 68 year-long
31 location data sets were acquired from light-based geolocation data-logging tags deployed on breeding birds
32 in 2009 and 2010.
- 33 2. During the incubation and chick-guard phases of the breeding season birds used cool (< 10°C) waters over
34 the Campbell Plateau, but also ranged over deeper, shelf-break and oceanic waters (4000-5500 m) beyond
35 the Plateau. Later in the breeding season, during chick-rearing, Campbell albatrosses exploited generally
36 deep waters (4000-5000 m) beyond the Campbell Plateau.
- 37 3. During the non-breeding period, birds tended to move northwards into warmer (approximately 15°C) waters
38 and occupied areas beyond western Australia in the west to offshore from Chile in the east. Overall, about
39 30% of birds spent some of their non-breeding period in the central and eastern Pacific Ocean, substantially
40 expanding the previously reported range for this species.
- 41 4. One bird, that failed in its breeding attempt in October 2009, departed Campbell Island and
42 circumnavigated the southern oceans before being recaptured back at Campbell Island in October 2010.
43 This is the first example of an annually-breeding albatross species completing a circumnavigation between
44 breeding attempts.
- 45 5. Overlap with fishing effort, using data from the Global Fishing Watch database, was assessed on a monthly
46 and seasonal basis. Generally, levels of overlap between Campbell albatross and fishing effort were
47 relatively low during the breeding season but were approximately 60% higher during the non-breeding
48 period, underlining the need for international initiatives to safeguard this species.

49

50 Keywords: fisheries overlap, geolocation, habitat use, New Zealand, seabird, subantarctic

51

52 1. Introduction

53 Our understanding of seabird distributions has been transformed in recent decades by the use of bird-borne
54 tracking devices. The acquisition of accurate distribution information across space and time has illuminated
55 diverse aspects of their foraging ecology (Clay et al., 2019a; Kroeger et al., 2019), habitat use (Wakefield et al.,

56 2011; Torres et al., 2015; Cleeland et al., 2019), exposure to pollutants (Leat et al., 2013; Watanuki et al., 2015)
57 and interactions with commercial fisheries (Torres et al. 2011; Clay et al. 2019b; Carneiro et al. 2020). The data
58 have also been used to identify key marine areas (Lascelles et al., 2016; Augé et al., 2018; Dias et al. 2018), and
59 to underpin other aspects of marine conservation management (Hays et al., 2019). Individual tracking data are
60 particularly useful for mapping distribution and habitat use of wide-ranging species that are difficult or
61 impossible to distinguish at sea from plumage, e.g. common diving petrel (*Pelecanoides urinatrix*) and South
62 Georgia diving petrel (*P. georgicus*) (Navarro et al., 2013), or black-legged kittiwake (*Rissa tridactyla*) and red-
63 legged kittiwake (*R. brevirostris*) (Orben et al., 2015).

64
65 Among seabirds, albatrosses (Family Diomedidae) have been the focus of numerous tracking studies because
66 their relatively large size enabled heavier versions of satellite transmitters and GPS loggers to be deployed in the
67 1990s and early 2000s (Jouventin and Weimerskirch, 1990; Fukuda et al., 2004). By comparison, the first
68 tracking data from many smaller species only became available subsequently with the development of small
69 geolocators, also termed Global Location Sensors or GLS loggers (Rayner et al., 2011; Grecian et al., 2016).
70 Additionally, albatrosses are conspicuous surface-nesters, aiding capture and recapture for deployment and
71 retrieval of devices. Albatrosses also represent the most threatened of all seabird families (Dias et al., 2019): of
72 the 22 species recognised by the International Union for Conservation of Nature (IUCN), 15 (68%) are
73 classified as threatened, and only one species, black-browed albatross (*Thalassarche melanophris*) as ‘Least
74 Concern’ (see <https://www.iucnredlist.org/>, accessed October 2020). Bycatch in commercial fisheries causes
75 increased mortality and is the greatest threat to albatrosses at sea (Phillips et al., 2016; Dias et al., 2019). In New
76 Zealand, seabird distribution information is an important component of the Spatially Explicit Fisheries Risk
77 Assessment (SEFRA), which quantifies the risk to all seabird species from commercial fishing operations within
78 the Exclusive Economic Zone (EEZ) (Richard et al., 2020). This risk assessment informs and prioritises seabird
79 conservation management decisions made and implemented by the regulatory authorities, the Department of
80 Conservation (DOC) and Ministry for Primary Industries (MPI). Furthermore, because New Zealand supports
81 the most diverse seabird assemblage on Earth, the risk assessment process, including the requirement for reliable
82 data on distribution, is used to direct limited resources towards the seabird species most at risk.

83
84 The Campbell albatross (*Thalassarche impavida*) is endemic to Campbell Island and the adjacent islet, Isle de
85 Jeanette Marie, off its northwest coast, and breeds in mixed colonies with grey-headed albatross (*T.*

86 *chrysostoma*) and a relatively small number of black-browed albatross, with which Campbell albatross
87 hybridises (Moore et al., 2001). Campbell albatross is classified as ‘Vulnerable’ by IUCN (see
88 <https://www.iucnredlist.org/>, accessed October 2020) and as ‘Threatened – Nationally Vulnerable’ in the New
89 Zealand threat classification system (Robertson et al., 2017). The Campbell albatross population declined during
90 the 1970s and into the 1980s, coinciding with the development of a longline fishery for tunas (*Thunnus* spp.) in
91 Australasian waters (Waugh et al., 1999a). The most recent estimate of 21,649 breeding pairs suggests the
92 population stabilised or showed a moderate increase between the mid-1990s and the period 2006 to 2012 (Sagar,
93 2014).

94
95 Detailed information on the at-sea distribution of Campbell albatrosses is restricted to the breeding season. Birds
96 tracked during chick-rearing in the 1990 travelled to two main areas of contrasting oceanography: 1) the
97 Campbell Plateau, a region of relatively shallow water to the east of the Auckland Islands and Stewart Island,
98 and 2) a broad area to the south of Campbell Island between 60° and 65° S in association with the Antarctic
99 Polar Front and northern Antarctic waters (Waugh et al., 1999b). Based on tracking data collected from 2011 to
100 2013, birds in incubation exploit waters over the Campbell Plateau and also regions southeast of Australia, east
101 of mainland New Zealand, or around the Antarctic Polar Front far to the southeast, whereas distribution during
102 the brood-guard stage is restricted to waters from the south of the South Island of New Zealand to the Antarctic
103 Polar Front (Sztukowski et al., 2017; 2018; Kroeger et al., 2019). Due to the challenges of distinguishing
104 Campbell albatrosses from black-browed albatrosses at sea, our knowledge of distribution during the non-
105 breeding period (approximately May to August) is much more limited, and based largely upon recoveries of
106 banded birds away from Campbell Island, which suggest that birds disperse to the waters of southern and
107 southeastern Australia, northern New Zealand and eastwards into the southwestern Pacific region (Waugh et al.,
108 1999c).

109
110 During the brood-guard stage, Campbell albatrosses spent approximately half of their time outside the New
111 Zealand EEZ (Sztukowski et al., 2017). When within the EEZ, they exhibited limited overlap with commercial
112 fisheries, with approximately 8% of foraging trips within 30 km of fishing vessels >28 m in length (Sztukowski
113 et al., 2017). This relatively low level of overlap is reflected in the few reports - eight in total for the last five
114 years for which data are available (2014-2019) – of Campbell albatrosses killed and returned by New Zealand
115 fishing vessels (Bell and Mischler, 2015; Bell and Bell, 2017a; 2017b; 2018; 2019). While the impact of

116 commercial fishing on Campbell albatross appears to be relatively minor within New Zealand waters, and the
117 overall risk in the SEFRA is categorised as relatively low (Richard et al., 2020), there are no reliable data on
118 exposure to fishing activity elsewhere during the non-breeding period. Here we present year-round distribution
119 data for Campbell albatross from deployments of light-based GLS loggers. The aims were to map distribution
120 and determine habitat use throughout the annual cycle for a comparison with the closely related black-browed
121 albatross. We also provide the first robust year-round assessment of overlap of Campbell albatrosses with
122 commercial fishing effort and potential bycatch risk for this globally Vulnerable species.

123

124 2. Methods

125 2.1 Study site and device deployment

126 Campbell Island (52°32' S 169°8' E), the southern-most of the sub-Antarctic islands in the New Zealand sector,
127 is ~700 km south of the South Island of New Zealand. Campbell albatross breeds in discontinuous colonies
128 around the northern coastline of Campbell Island. Although birds begin returning to the colony in August, here
129 we define the breeding season as September to April, and the non-breeding period as May to August (Marchant
130 and Higgins 1990). In October 2009, 30 GLS loggers (MK7 and MK17; British Antarctic Survey, Cambridge,
131 England), were deployed on breeding Campbell albatrosses during incubation at the Bull Rock colony, at the
132 extreme northeast of the island. In November and December 2010, a further 56 GLS loggers (some retrieved
133 from the previous deployments), were deployed on breeding birds, which were either incubating (45 birds) or
134 guarding a chick (11 birds). The GLS loggers were attached to a plastic leg band using two plastic cable ties,
135 each fitted with a stainless-steel pawl. Individuals were only equipped in one season. In all cases, total mass of
136 the tag, leg band and cable tie was < 5 g (~0.15% of bird mass). All fieldwork at Campbell Island was carried
137 out under permits from the New Zealand Department of Conservation and approved by the National Institute of
138 Water and Atmospheric Research's animal ethics committee.

139

140 2.2 Geolocation data

141 Geolocation data were processed in R (R Core Team, 2017) using the 'twilight-free' method developed by
142 Bindoff et al. (2018) which is capable of estimating locations from noisy data. Briefly, we used the TwilightFree
143 function within the 'twilight-free' package in R (available from <https://github.com/ABindoff/TwilightFree>) to
144 estimate the most likely track for each bird. We used a zenith value of 96, removed light errors that were
145 present in otherwise dark periods (three tracks), and in some instances, removed days where locations could not

146 be estimated (two days from one track). Movement parameters (alpha and beta) ranged from 0.10-0.20 and 0.25-
147 0.60, respectively, depending on the properties of the track.

148

149 Because pre- and post-deployment calibration data from the island were not available for most loggers, a tag-
150 specific threshold value could not be obtained. Instead, a threshold value of ten for luminescence at twilight was
151 used except in instances when light appeared within a period of darkness. In such cases, the ‘max_light_delta’
152 function’ within the ‘TwilightFree’ package was used to find the maximum light level in each five-minute
153 period and smoothed over every six observations. The threshold was recalculated based on the smoothed light
154 values and the model was rerun. This process was repeated until all erroneous light data were removed. The
155 deployment and retrieval location was also included in the model. Daily locations were estimated on a 0.50
156 degree grid and the ‘fit_smm’ function in the R package ‘bsam’ (Jonsen et al., 2005; Jonsen, 2016) was used to
157 smooth the track and estimate locations every 12 hours.

158

159 2.3 Environmental data

160 In order to identify habitat characteristics associated with core distributions of Campbell albatrosses, and how
161 these varied temporally, we compiled data on depth, distance to land, sea surface temperature and chlorophyll-*a*
162 from various sources. To examine ocean depth, we used ETOPO-1, a one arc-minute global relief model of the
163 earth’s surface (Amante and Eakins, 2009). In addition, we obtained a high-resolution coastline, Global Self-
164 consistent Hierarchical High-resolution Shorelines (Wessel and Smith, 1996) and subsequently created a
165 distance from land raster using the ‘Euclidian distance’ tool in ArcGIS Pro. Pathfinder global monthly sea
166 surface temperature climatologies using data from 1985 to 2005 were downloaded from BloomWatch360 in
167 netcdf format, with a spatial resolution of 0.05 degree (~4.4 km). Modis-Aqua Level-3 binned chlorophyll-*a*
168 monthly climatologies were downloaded in netcdf format from the Ocean Color website (NASA Goddard Space
169 Flight Center, 2018); these were compilations of monthly chlorophyll from 2002 to 2020 and had a spatial
170 resolution of 0.05 degrees (~4.4 km). All files were converted into 5 km raster layers with a Mercator projection
171 centred on 170° E. Environmental data for each geolocation position were extracted in R. For sea surface
172 temperature and chlorophyll-*a*, points were sampled for each month (for example, geolocation data collected in
173 January were matched to the sea surface temperate raster from that month).

174

175 2.4 Spatial analysis

176 We used the ‘adehabitatHR’ package (Calenge, 2006) in R to generate utilization distribution kernels with a 5
177 km grid size and a 185 km smoothing parameter (or bandwidth) to account for the mean error associated with
178 geolocation data (Phillips et al., 2004). The same package was used to generate the 50% data contour, which we
179 considered to be the core habitat (following Hyrenbach et al., 2002; Ramirez et al., 2013; Torres et al. 2015),
180 and the 95% data contour, which we defined as the home range. Geolocation data within the 50% kernel density
181 contour for each month were extracted and environmental data were summarized to examine habitat preference.
182 Unless indicated otherwise, means are given \pm SD.

183

184 2.5 Overlap with fishing effort

185 We examined overlap between the distribution of Campbell albatross and fishing effort by month and season
186 (breeding vs. non-breeding). Daily global fishing effort data based on vessels fitted with automatic identification
187 system (AIS) transceivers (Kroodsma et al., 2018), were available for five years (2012-2016) at 0.01° resolution
188 from Global Fishing Watch (GFW: Global Fishing Watch, 2020). We did not restrict fishing effort data by
189 fishing vessel or gear type. The number of fishing hours that were within the core and home range of Campbell
190 albatross was summed for each month and season. These data were then averaged across replicate months and
191 seasons, respectively, to assess overlap between mean monthly and seasonal fishing effort, and Campbell
192 albatross distribution.

193

194 3. Results

195 Twenty-seven of the 30 GLS tags deployed in 2009 were retrieved in 2010 (hereafter referred to as 2009 data),
196 and 40 of the 56 tags deployed in 2010 were retrieved in 2011 (hereafter referred to as 2010 data) with a single
197 tag from the 2009 deployment (overall recovery rate of 79%). From the retrieved tags, 28 and 40 usable data
198 sets were obtained for the 2009 and 2010 deployments, respectively. The mean length of deployment in 2009
199 was 371 ± 20 days, excluding the single tag retrieved after two years, and in 2010 was 344 ± 27 days.

200

201 3.1 Campbell albatross distribution

202 There was extensive overlap in home ranges (95% density contour) of birds tracked in the two years, which
203 extended from approximately 30° to 70° S and 90° E to 80° W, but with an easterly extension to waters off the
204 coast of Chile in the 2010 dataset. In both years, the core range (50% density contour) included areas around
205 Campbell Island and in the Great Australian Bight. Additional core areas were east of Tasmania and east of the

206 North Island of New Zealand in the 2009 dataset, and west of the South and North islands in the 2010 dataset
207 (Figure 1). In 2009, one bird that failed early in its breeding attempt departed eastwards from Campbell Island
208 and circumnavigated the southern oceans before returning to the colony for the start of the 2010 breeding season
209 (Figure 1).

210

211 Monthly kernel density plots (Figure 2) showed that during the breeding season (September to April), the
212 distribution of Campbell albatrosses was centred on the Campbell Plateau during incubation (late September-
213 October to early December). During post-guard chick-rearing (hereafter “chick-rearing”; late December to
214 April) the 50% density contour included areas to the west of Tasmania, to the east of mainland New Zealand
215 and a relatively large area around Campbell Island to approximately 65° S (Figure 2). During the non-breeding
216 period (May to August), the distribution was much larger, extending from the west of Australia, across the
217 Pacific Ocean to the coast of Chile (Figure 2). This broad non-breeding area was bounded to the north at 25° S,
218 and, for the core non-breeding months of May to July, to as far as 45° S (Figure 2). Combining data from both
219 years, 34% (n = 23), 9% (n = 6) and 28% (n = 19) of birds tracked during the non-breeding period utilised
220 waters around Australia, New Zealand or both regions, respectively. The remaining 30% (n = 20) of birds spent
221 the non-breeding period in the central and eastern Pacific Ocean (east of ~135° W), but only 3% (n = 2) of birds
222 did so exclusively. Overall, 27% (n = 18) of birds spent some of the non-breeding period in the central and
223 eastern Pacific Ocean and in Australian and New Zealand waters.

224

225 3.2 Habitat characteristics

226 Based on values for environmental parameters at each location of a tracked birds within the monthly 50%
227 density contours, median sea surface temperature (SST) of core areas used by Campbell albatrosses during the
228 breeding season (September to April) were generally 5-10°C. During the non-breeding period (May to August),
229 median SST values exceeded 10°C, and for May to July were close to 15°C (Figure 3). There was relatively little
230 variation in chlorophyll-*a* values across months, with medians of around 0.15-0.30 mg m⁻³ and peak values of
231 0.70-0.80 mg m⁻³ except in September and July (Figure 3). During the incubation and brood-guard stages
232 (September to December), the core areas of tracked birds were mainly waters either of around 500-1500 m or
233 4000-5500 m depth (Figure 3). During chick-rearing (January to April), core locations tended to be restricted to
234 waters around 4000-5000 m deep (Figure 3). During the non-breeding period (May to August), median values
235 were ~5000 m, but birds also used much shallower waters (~1000 m deep), as they had in first half of the

236 breeding season (Figure 3). Distance to land of locations in core areas were around 500 km for most of the year
237 but increased to ~1000 km during chick-rearing in January to April (Figure 3).

238

239 3.3 Overlap with fisheries

240 Monthly overlaps between the distributions of Campbell albatrosses and fishing effort (based on vessel AIS
241 data) were lower in the breeding than non-breeding seasons, both in terms of the 50% and 95% contour areas
242 (Figure 4). Within core areas during breeding (September to April), mean fishing effort was always less than
243 5000 hours per month, and was close to nil in December to March. During the non-breeding period (May to
244 August), mean fishing effort generally exceeded 5000 hours per month for core areas, and 20000 hours per
245 month within the 95% contour (Figure 4). Across the south Pacific Ocean and in waters to the west of Australia,
246 areas of relatively high fishing effort tended to be to the north of the distribution of Campbell albatross in both
247 breeding and non-breeding seasons (Figure 5). Considering the 95% contour areas, overlap of the tracked birds
248 with fishing effort was low, and mainly occurred around New Zealand and off the coast of Chile during the
249 breeding season, whereas fisheries overlap was higher in the non-breeding period, with hotspots to the
250 southwest of Australia, and in the Tasman Sea (Figure 5).

251

252 4. Discussion

253 Before this study, the distribution of Campbell albatross was considered to be restricted to the Australasian
254 region from roughly 25° S to 65° S, and 100° E to 150° W (BirdLife International, 2020; Figure 6). This appears
255 to have been based on an analysis of the locations of recoveries of banded birds (Waugh et al., 1999c) and on a
256 brief description of the distribution as possibly being confined to waters off southern Australia, the Bass Strait
257 and western Pacific Ocean (Croxall and Gales, 1998). Ours is the first study of distribution of this species during
258 the non-breeding season, extending the known, year-round distribution into the central Indian Ocean, and central
259 and eastern Pacific Ocean, as far as waters off Chile.

260

261 Somewhat unexpectedly, a single adult from the 2009 deployments completed a full circumnavigation of the
262 southern oceans and was recaptured at Campbell Island in the early 2010/11 breeding season (Figure 1). This
263 bird departed Campbell Island at the end of October 2009, presumably because its breeding attempt had failed,
264 flew east across the Pacific Ocean, spending all of December at approximately 60° S and 90° W, before
265 continuing east across the Atlantic and Indian oceans, before eventually returning to Campbell Island. To the

266 best of our knowledge, this is the first record of an annually-breeding species of albatross completing a
267 circumnavigation between breeding attempts. Circumnavigations are typically observed in biennial species that
268 take off the following season if their chick fledges. Even among those, complete circumnavigations have been
269 confirmed in only four species: wandering albatross (*Diomedea exulans*: Mackley et al., 2010; Weimerskirch et
270 al., 2015; Cleeland et al., 2019), northern royal albatross (*D. sanfordi*: Robertson and Nicholls, 2000), grey-
271 headed albatross (Croxall et al., 2005; Clay et al., 2016) and light-mantled albatross (*Phoebastria palpebrata*:
272 Mackley et al., 2010; Cleeland et al., 2019). Speed estimates indicated that a complete circumnavigation of the
273 Southern Ocean by an albatross could be completed in 30 days and one grey-headed albatross completed the
274 journey in 46 days (Croxall et al., 2005). For an annually-breeding species such as Campbell albatross that
275 departs the breeding site following a successful breeding attempt in April and returns to the colony in
276 September, completing a circumnavigation while at the same time regaining body condition and undergoing at
277 least some moult ahead of a new breeding attempt would be energetically challenging. Our study suggests
278 complete circumnavigation during the non-breeding period represents an uncommon behaviour in Campbell
279 albatross (the single circumnavigation was carried out by just one adult (4%) out of the 23 birds in our study
280 which appeared to fail in their breeding attempt, based on track characteristics), and perhaps is only adopted by
281 birds that fail early. This hypothesis that migration strategy can be dependent on the time available is
282 corroborated by tracking data from grey-headed albatrosses at South Georgia, in which circumpolar journeys
283 were much less common (5% vs 52%) in birds that failed during incubation compared with those that bred
284 successfully (Clay et al., 2016). This is probably because most failed birds choose to return to breed in the
285 following season, whereas successful birds take 16 months between attempts.

286

287 4.1 Non-breeding period distribution and comparison with black-browed albatross

288 Campbell albatrosses appeared to adopt one of four strategies during the non-breeding period: 1. remain entirely
289 in Australian waters, particularly, but not exclusively, in the Great Australian Bight; 2. remain entirely in New
290 Zealand waters; 3. partition time in both Australian and New Zealand waters, and; 4. partition time between the
291 central and eastern Pacific Ocean, and usually, but not always, Australian and New Zealand waters. Of these
292 four strategies, remaining exclusively in New Zealand waters was adopted by approximately 10% of birds, and
293 the other three strategies in approximately equal proportions (30% of birds). In contrast, black-browed
294 albatrosses, which are very closely related to Campbell albatross (Berg and Croxall, 2001; Burg et al., 2017),
295 typically adopt one predominant non-breeding period strategy. For example, black-browed albatrosses breeding

296 at the Falkland Islands are predominantly resident, remaining on the Patagonian Shelf year-round (Grémillet et
297 al., 2000; Ponchon et al., 2019). Nearly all (94%) tracked black-browed albatrosses breeding at South Georgia
298 spent the non-breeding period in the Benguela upwelling region off southwest Africa, while single birds (each
299 representing 3% of those tracked) remained in the southwest Atlantic Ocean or travelled to southeast Australia
300 (Phillips et al., 2005). Black-browed albatrosses breeding at the Kerguelen Islands spent the non-breeding period
301 in southeast Australia, particularly to the west and southwest of Tasmania (Desprez et al., 2018). Cleeland et al.
302 (2019) noted more diverse destinations among non-breeding black-browed albatrosses tracked from Macquarie
303 Island, ~700 km to the southwest of Campbell Island, including a bird that migrated eastwards to the Benguela
304 region but then returned westwards, although the number of tracked birds was relatively small ($n = 4$).

305

306 The key destinations for black-browed albatrosses during the non-breeding season (Patagonian Shelf, Benguela
307 region, and west and southwest Tasmania) are all very productive areas, characterised by near-shore upwelling
308 regimes in the case of the Benguela and off Tasmania. For example, chlorophyll-*a* concentrations on the
309 Patagonian Shelf and shelf-break generally exceed 2.0 and 1.5 mg m^{-3} in austral summer and autumn,
310 respectively (Romero et al., 2006), can reach 10 mg m^{-3} close to the southwest African coast (Lamont et al.,
311 2019) and peak at approximately 3 mg m^{-3} , with winter values of approximately 1.5 mg m^{-3} , on the western
312 Tasmanian shelf (Kämpf, 2015). In contrast, during the non-breeding period, Campbell albatrosses appear to
313 favour relatively deep waters (approximately 5000 m), with higher median SST values (typically around 15°C)
314 and with much lower chlorophyll-*a* concentrations (median values around 0.20-0.30 mg m^{-3} , see Results). For
315 example, it would appear that even in waters to the south of Australia, including to the west of Tasmania, where
316 both species overlap during the non-breeding period, Campbell albatrosses tend to occupy the relatively deep
317 waters of the Great Australian Bight (see May to August, Figure 2) rather than the shelf and shelf-break to the
318 west of Tasmania utilised both by black-browed albatrosses from the Kerguelen Islands (Desprez et al., 2018),
319 and the single bird tracked to that area from South Georgia (Phillips et al., 2005).

320

321 4.2 Breeding season distribution

322 Our data on the distribution of Campbell albatross during the breeding season were in general agreement with
323 those of earlier studies, except that some birds tracked previously in the incubation phase (late September to
324 early December) also utilised waters around Tasmania and to the east of mainland New Zealand (Sztukowski et
325 al., 2017; 2018; Kroeger et al., 2019). Instead, we found that during incubation, Campbell albatrosses remained

326 primarily over the Campbell Plateau, including the shelf slopes around the Auckland Islands, the Snares Islands
327 and Stewart Island to the north, and the subantarctic slope to the southeast, but additionally made use of
328 relatively deep waters to the west of Campbell Plateau and beyond the subantarctic slope (Figure 2). During
329 chick-rearing (late December to April), Campbell albatrosses utilised deep oceanic waters to the south of
330 Campbell Island, to the west of Tasmania and to the east of mainland New Zealand. Wakefield et al. (2011)
331 compared the habitat preferences of black-browed and Campbell albatrosses during the breeding season, using
332 satellite tracking data from nine colonies including those reported by Waugh et al. (1999b) from Campbell
333 albatross during chick-rearing. Wakefield et al. (2011) concluded that black-browed albatrosses preferred neritic
334 habitats (0-500 m water depth), followed by shelf-break and upper-slope habitats (500-1000 m water depth) and
335 then deeper, oceanic habitats (> 1000 m water depth). Further, that Campbell albatrosses showed similar
336 bathymetric preferences to black-browed albatrosses but noted that there was relatively little neritic habitat
337 available to Campbell albatrosses, and that deeper oceanic waters and frontal systems were also exploited. Our
338 results provide support for the utilisation of relatively deep oceanic waters and shelf-breaks, although around the
339 New Zealand subantarctic islands, shelf-breaks drop steeply into waters over 500 m deep, and shelf-breaks
340 around the Campbell Plateau drop into waters more than 5000 m deep. During the incubation phase, we found
341 that Campbell albatrosses exploited a relatively wide range of water depths, particularly waters around 1000 m
342 deep or 4000-5500 m deep, whereas during chick-rearing, preferred water depths were mostly 4000-5000 m
343 (Figure 3). There was evidence that across the breeding season, Campbell albatrosses exploited the subantarctic
344 and Antarctic Polar fronts to the south of Campbell Island, and not the Subtropical Front to the north of
345 Campbell Island, which flows eastwards around the southern end of South Island and then northwards along the
346 east coast before turning towards the Chatham Rise (Chiswell et al., 2015). Overall, while there appear to be
347 some similarities in the habitats exploited by Campbell and black-browed albatrosses (for example, shelf-breaks
348 during the breeding season), Campbell albatross appears to favour much deeper waters of relatively low
349 productivity throughout the year.

350

351 4.3 Overlap with commercial fishing effort

352 The new, much more comprehensive data now available in this study on the distribution of Campbell albatross
353 can be used to assess a range of spatially dynamic anthropogenic threats. Here we have considered the risk from
354 commercial fishing activity separately for the breeding and non-breeding periods using the GFW dataset. An
355 important caveat with GFW data is that AIS transceivers are only fitted to 50-75% of active vessels that are

356 >24m in length (McCauley et al., 2016; Kroodsmas et al., 2018; Shepperson et al., 2018). Nevertheless, these data
357 support the conclusion from the SEFRA that Campbell albatross is at relatively low risk from commercial
358 fishing operations within the New Zealand EEZ (Richard et al., 2020). Moreover, there was very little evidence
359 for interactions between this species and fishing vessels using high-resolution tracking data from breeding birds;
360 indeed, only 8.4% of 299 foraging trips by 81 adults during incubation and brood-guard were within 30 km of
361 fishing vessels (Sztukowski et al., 2017). Our results using an independent dataset on distribution confirm that
362 Campbell albatrosses are not currently exposed to high levels of interaction with commercial fishing vessels
363 during the breeding season, with the region of greatest overlap, and probably risk, at the northern extent of the
364 core range to the south of the South Island (see Figure 5) Even when considering the 95% polygon, overlap
365 between birds and fishing effort from GFW was relatively low except off the coast of Chile, probably involving
366 failed breeders that had already departed on migration.

367

368 The higher levels of overlap with fishing effort during the non-breeding season (~60% greater than during the
369 breeding period for both 50% and 95% polygons; see Figure 4) suggest strongly that the risk posed to this
370 species by fisheries is much greater during the winter months (May to August). Campbell albatrosses are
371 recorded as bycatch in tuna fisheries in the Western and Central Pacific Fisheries Commission (WCPFC)
372 Convention Area (WCPFC, 2020). Total mortality is unknown, and bycatch rates are spatially and temporally
373 heterogeneous, but even a crude extrapolation from the 52 birds killed in the WCPFC area in 2019 according to
374 a fisheries-wide observer coverage of 4.6% in that year would equate to >1000 birds. As far as we are aware,
375 there are no published records of bycatch of Campbell albatrosses in Chilean fisheries (Suazo et al., 2014).
376 However, black-browed albatrosses are caught frequently in those fisheries, and Campbell albatrosses may have
377 been overlooked given the close morphological similarity. Although overlap as assessed in this study does not
378 necessarily equate to increased bycatch and mortality, the higher levels of overlap between Campbell albatross
379 and fishing vessels found during the non-breeding period, particularly in the WCPFC Convention Area warrant
380 improved monitoring of the relevant fleets in terms of seabird bycatch rates and compliance with mandatory
381 bycatch mitigation. In addition, continued monitoring of population trends and, ideally, demographic parameters
382 of the Campbell albatross population are required. Finally, studies show that certain life-history stages may be
383 more susceptible to bycatch in some regions or fishery types (Gianuca et al., 2017). As such, further tracking
384 studies could focus on juveniles and immatures, which are major data gaps not just for Campbell albatross but

385 many other albatross species, and filling these gaps can help direct management and conservation efforts
386 (Carneiro et al., 2020).

387

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393

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398

399 Data Availability Statement

400 The data underlying this article are available in the Seabird Tracking Database (www.seabirdtracking.org)
401 administered by BirdLife International.

402

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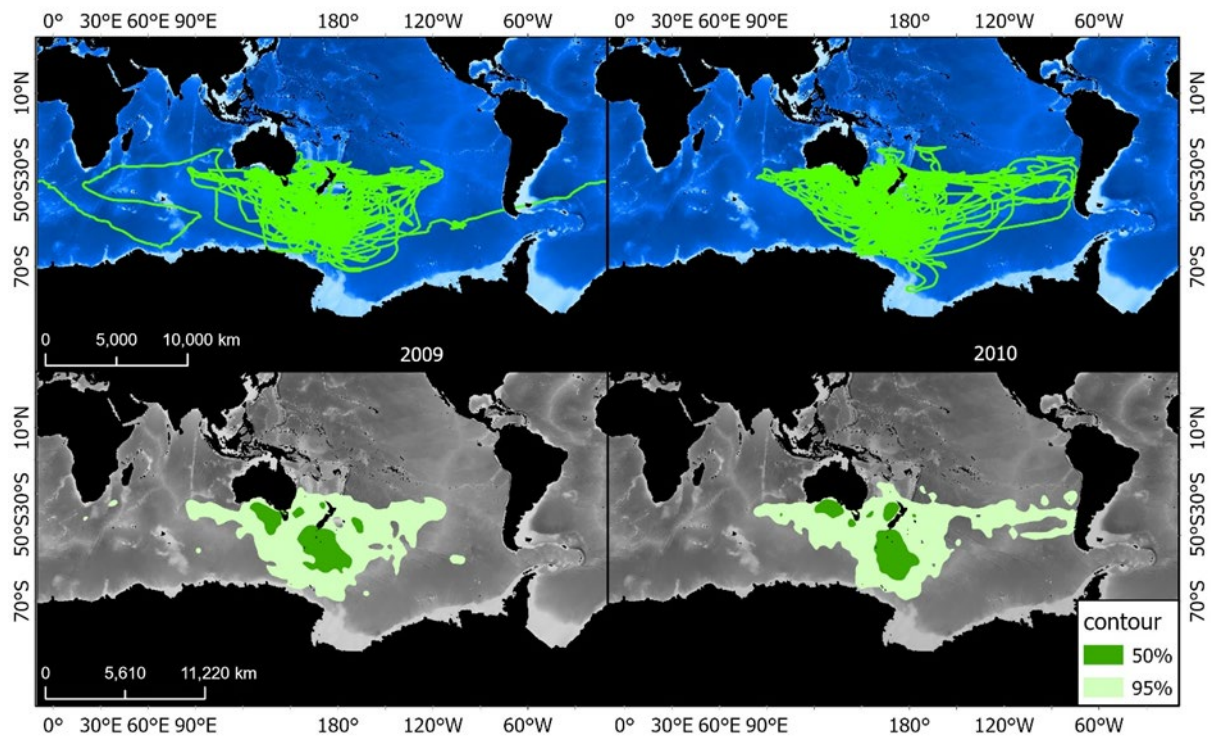
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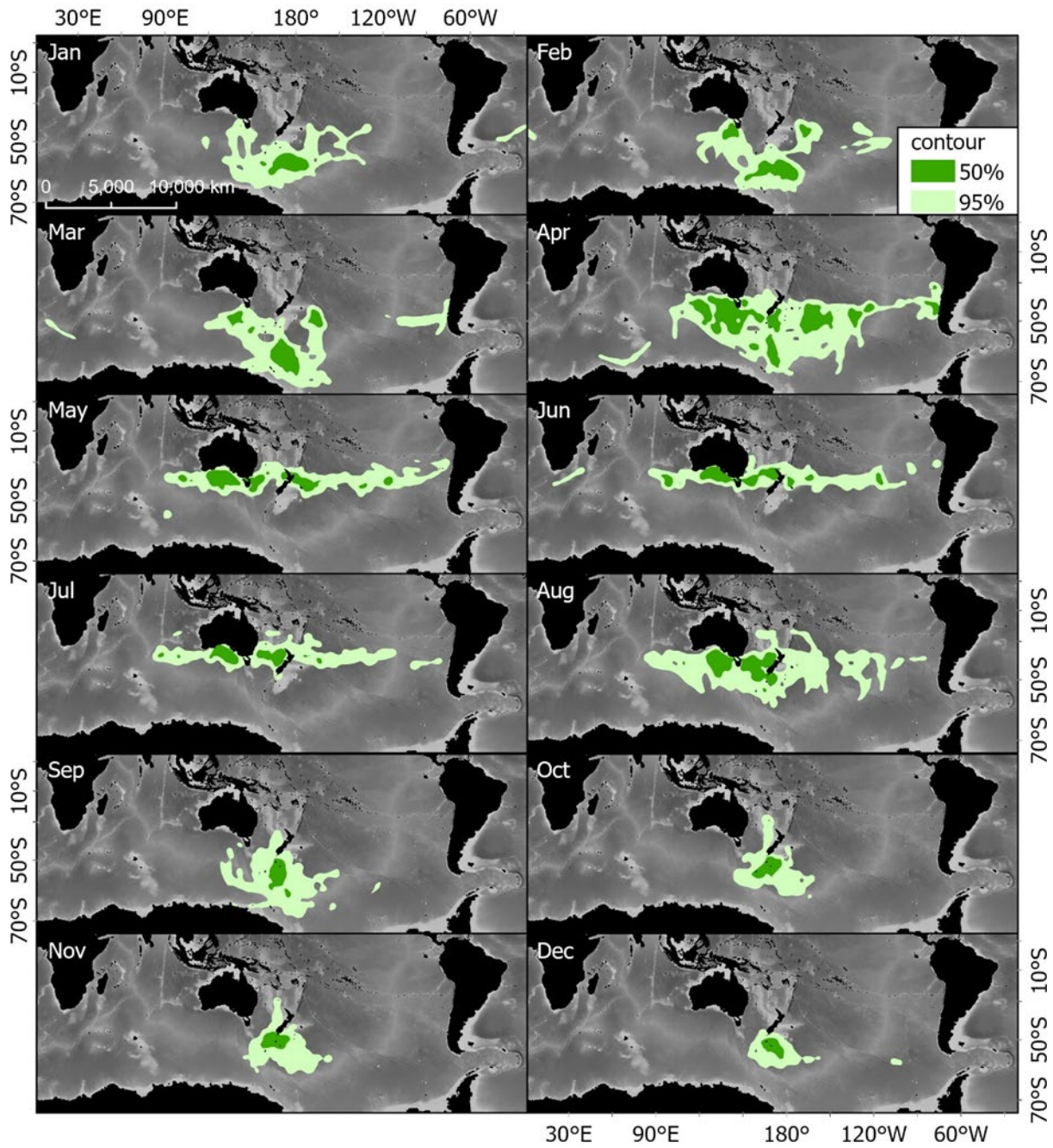


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608

609 **Figure 1.** Upper panels: tracks of Campbell albatrosses in the breeding and nonbreeding seasons obtained using
610 GLS loggers fitted to breeding birds at Campbell Island in in 2009 (left) and 2010 (right). Lower panels: kernel
611 density plots, for 2009 (left) and 2010 (right).

612



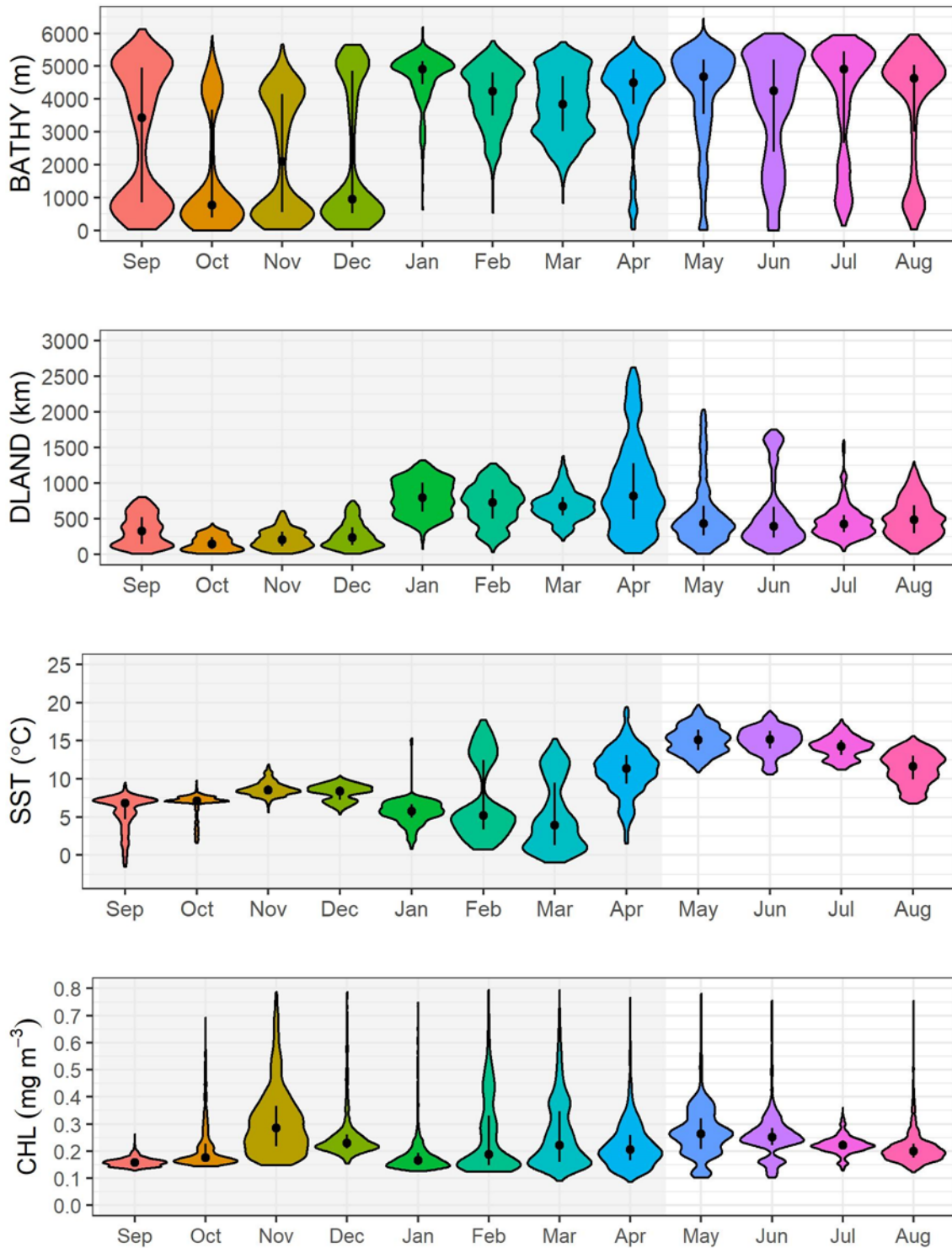
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614

615 **Figure 2.** Monthly kernel density plots for Campbell albatrosses derived from data obtained using GLS loggers

616 fitted to breeding birds at Campbell Island in 2009 and 2010, data from both years combined.

617



618

619 **Figure 3.** Monthly bathymetry (BATH), distance from land (DLAND), sea surface temperature (SST), and
 620 chlorophyll-*a* (CHL) at locations within the core (50% contour) distributions of Campbell albatrosses tracked
 621 using GLS loggers fitted to breeding birds at Campbell Island in 2009 and 2010, data from both years combined.

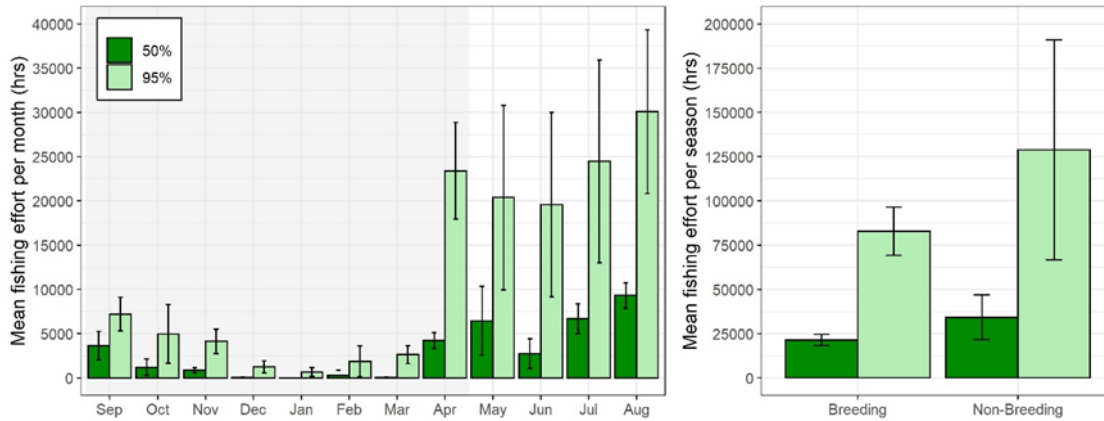
622 Points and lines show median and interquartile range, respectively. The distribution of the data for each month is

623 indicated by the shape, representing kernel density plots. Background shading indicates months within the
624 breeding season.

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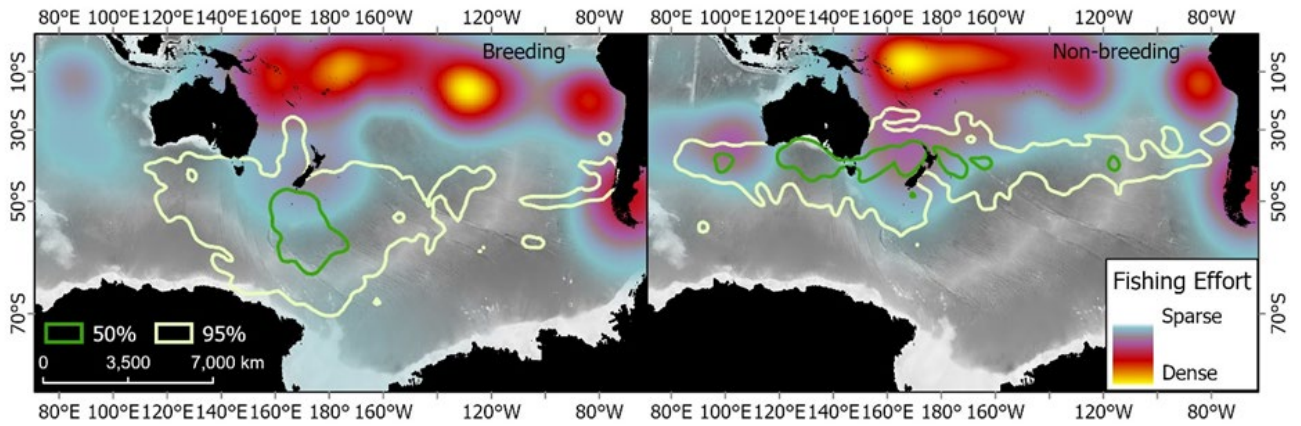
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629 **Figure 4.** Mean total fishing effort (based on data from Global Fishing Watch) per month and season within the
630 calculated monthly (left panel) and seasonal (right panel) core (50% contour) and home (95% contour) ranges of
631 Campbell albatross. Error bars indicate one standard deviation and background shading on the left panel
632 indicates months within the breeding season.

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636 **Figure 5.** Kernel density contours for Campbell albatrosses during the breeding (left panel) and non-breeding

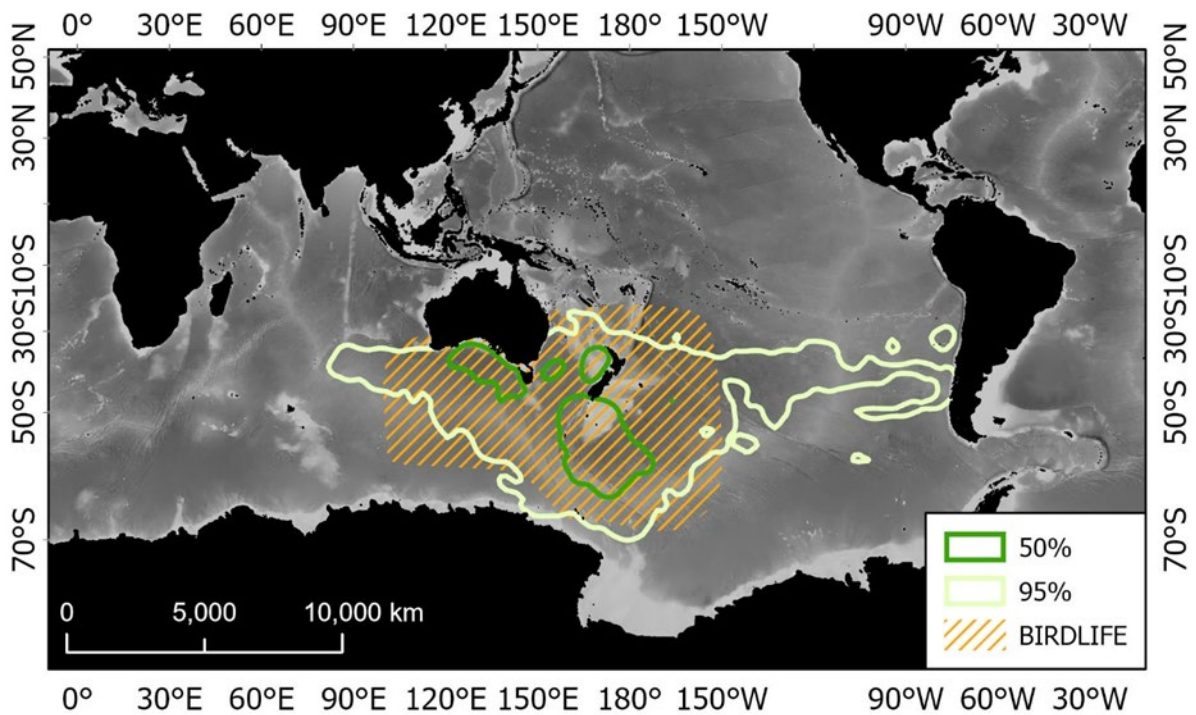
637 (right panel) season with core (50% contour) and home (95% contour) ranges, derived from data obtained using

638 GLS loggers fitted to breeding birds at Campbell Island in 2009 and 2010, data from both years combined.

639 Mean Global Fishing Watch effort data across four breeding (September-April) and five non-breeding (May-

640 August) seasons are shown as a heatmap.

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644 **Figure 6.** Kernel density contours (core - 50%, home - 95%) for Campbell albatrosses derived from data
 645 obtained using GLS loggers fitted to breeding birds at Campbell Island in 2009 and 2010, data from both years
 646 combined. Dark and light green colors denote) ranges, respectively. The hatched lines indicate the current range
 647 for the species available from BirdLife International (2020).

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