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Tracking reveals limited interactions between Campbell Albatross and fisheries during the breeding season

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1 **TRACKING REVEALS LIMITED INTERACTIONS**
2 **BETWEEN CAMPBELL ALBATROSS AND FISHERIES**
3 **DURING THE BREEDING SEASON**

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20 **Abstract**

21 The last century has seen a significant decline in global seabird populations that can, in part,
22 be attributed to fisheries mortality. Understanding overlap between seabird distribution and
23 fisheries is one important element in assessing the risk of bycatch, and may be achieved by
24 tracking the movements of individual birds and fishing vessels. Here we assess the spatio-
25 temporal overlap between the vulnerable Campbell Albatross *Thalassarche impavida* and
26 large (>28m) commercial fishing boats in New Zealand's Exclusive Economic Zone (EEZ).
27 We used bivariate Gaussian bridge movement models to compute spatio-temporal utilization
28 distributions, both from high-resolution bird-borne GPS loggers and the Vessel Monitoring
29 System, to estimate potential interactions with fisheries during the breeding season. During
30 incubation and chick brooding, 49.7% of the 28,814.9 hours Campbell Albatrosses spent
31 foraging were within New Zealand's EEZ, utilizing 6.7% of the available area. Within the
32 EEZ, albatrosses only overlapped with fisheries vessels in a relatively small section in the
33 southern portion of these waters. Despite this spatial overlap, there was no evidence that
34 albatrosses and fishing vessels were in the same location simultaneously. When accounting
35 for the broader ecological footprint of fishing vessels, which can influence bird behaviour for
36 up to 30 km, we found albatross–vessel overlap in 8.4% of foraging trips. Overall, the low
37 levels of spatial overlap could be a result of preference for foraging in areas without fishing
38 activity or competitive exclusion by other species. While higher resolution data from both
39 birds and vessels will improve our ability to detect the true nature of interactions, as opposed
40 to just overlap, the current threat of bycatch during the breeding season appears
41 comparatively low. Our results reinforce the importance of a multi-scale approach to risk
42 assessment, as results that rely solely on large-scale spatial overlap may overestimate risk
43 associated with fisheries. However, as Campbell Albatross spend approximately half of their

44 time foraging outside New Zealand's EEZ, conservation and fisheries management for this
45 species requires a multi-national focus.

46 Key words: seabird-fishery interactions, Campbell Albatross, New Zealand EEZ, bivariate
47 Gaussian Bridge movement models, spatio-temporal overlaps, bycatch

48 **Introduction**

49 Population declines in seabirds, particularly albatrosses and petrels, have been attributed to
50 fisheries-related mortality from accidental bycatch (Brothers 1991; Nel et al. 2002; Sullivan
51 et al. 2006; Rolland et al. 2010; Anderson et al. 2011). Globally, it is estimated that tens of
52 thousands of seabirds are killed every year – levels of mortality which are unsustainable.
53 However estimates of fisheries-related mortality vary greatly by location and among species
54 (Lewison and Crowder 2003; Anderson et al. 2011), and risk of bycatch is known to vary
55 within species as a function of sex, age, and inter-individual differences in foraging site
56 preference and behaviour (Nel et al. 2002; Votier et al. 2010; Tuck et al. 2015).

57 Conservation efforts to reduce seabird bycatch have been aided by identifying regions of
58 seabird-fishery overlap to inform mitigation measures. Recently, bird-borne tracking has been
59 used in tandem with spatially explicit fisheries data to better quantify the nature and extent of
60 spatio-temporal overlap (Votier et al. 2010; Granadeiro et al. 2011; Torres et al. 2011; Catry
61 et al. 2013; Torres et al. 2013a; Votier et al. 2013; Bodey et al. 2014; Collet et al. 2015;
62 Patrick et al. 2015). Various scales of analysis have been applied to seabird-fisheries overlap
63 and have highlighted contrasting results, in some cases due to the resolution of the data as
64 well as our limited ability to distinguish between interactions and overlap events (e.g. (Torres
65 et al. 2013a). Thus, combining and contrasting multiple spatial and temporal scales may

66 provide complementary information necessary to enhance our understanding of the true
67 nature of seabird– fishery interactions.

68 In the present study, we examine the spatial and temporal overlap between fisheries vessels
69 and the vulnerable Campbell Albatross *Thalassarche impavida*. Following a decline of 72%
70 from 1966-1984 (Waugh et al. 1999), the population has been comparatively stable, with
71 some suggestion of a slight decrease (Sagar 2014). In common with other species of
72 albatross, the steep population decline coincided with increased fisheries effort in the
73 Southern Ocean and variation in abundance has been attributed to the development of long-
74 line and trawl fisheries within the foraging range of these birds (Waugh et al. 1999; Moore
75 2004; Sagar 2014). Campbell Albatross, and the closely related Black-browed Albatross *T.*
76 *melanophris*, were regularly drowned by trawl fisheries and caught by longline vessels
77 (Murray et al. 1993; Croxall and Gales 1998; Gales et al. 1998). Thus, our goal was to
78 estimate the degree of spatio-temporal overlap between fisheries and breeding Campbell
79 Albatross within New Zealand’s Exclusive Economic Zone (EEZ), to provide an updated
80 understanding of bycatch risk in these waters and compare results at multiple spatio-temporal
81 resolutions.

82 We used two approaches to identify potential interactions between fisheries and Campbell
83 Albatross during the breeding season. First, we used a novel method, bivariate Gaussian
84 bridges (BGB), to estimate the space use of both birds and vessels during the complete time
85 of tracking. This allows us to calculate the area of the EEZ used by albatrosses and vessels, as
86 well as to estimate how often albatrosses and fisheries use the same area at multiple temporal
87 scales. These results can be aggregated over time, such as breeding stage or season, which
88 provides estimates similar to population-level or multi-species assessments of overlap
89 between fishing activity and species distribution (e.g. kernel density analysis by (Phillips et

90 al. 2006). If overlap between albatrosses and vessels occurs at the same time, this technique
91 produces results comparable to the fine-scale tracking data on Black-browed Albatross and
92 fisheries in waters around the Falkland Islands (Granadeiro et al. 2011, Catry et al. 2013).
93 However, instead of using straight-line interpolation (and its associated assumptions) with
94 (Torres et al. 2011) or without (Granadeiro et al. 2011) spatial buffers, we modelled motion
95 variance, both parallel and orthogonal, to depict movement and space use more accurately.
96 Second, since recent work has shown that birds may change their behaviour in response to
97 fishing vessels, even as far away as 30 km (Bodey et al. 2014, Collet et al. 2015), we
98 investigated events during which albatrosses were in proximity to fishing vessels and
99 explored differences in overlap as a function of the spatial scale over which fishing vessel
100 occurrence may affect bird behaviour. These seabird-vessel overlaps may indicate potential
101 interactions, as spacing between seabirds and vessels may fluctuate at shorter time periods
102 than were recorded (e.g. < 10 minutes). This is similar to the results estimated by buffering
103 known locations by distance and/or time (i.e. (Votier et al. 2010; Patrick et al. 2015)).
104 Whenever we identified such a potential interaction event, we investigated whether the
105 frequency of bird-boat interactions was explained by sex, stage of reproduction (incubation
106 and chick-brooding), and between two years. Because albatrosses have shorter foraging trips
107 during chick brooding, and therefore spend more time in the EEZ (Sztukowski 2016), we
108 expected that there would be more interactions with fisheries during this stage compared with
109 incubation. Furthermore, because female Campbell Albatrosses tend to use areas that are
110 closer to the New Zealand mainland than males (Sztukowski 2016), we hypothesise that
111 females are more likely to encounter fishing vessels within the EEZ. Therefore, by examining
112 albatross–fishery overlap as a function of variations in distance between birds and boats, we
113 may increase our understanding of the factors, such as breeding stage and sex, that impact

114 interactions at various spatial scales, with concomitant implications for assessing risk of
115 bycatch.

116 **Methods**

117 **Albatross tracking**

118 We studied the endemic Campbell Albatross on Campbell Island, New Zealand ($52^{\circ}32'24''\text{S}$,
119 $169^{\circ}8'42''\text{E}$) during two breeding seasons (10 November 2011 to 29 December 2011, and 19
120 October 2012 to 27 December 2012; hereafter referred to as study years 2011 and 2012
121 respectively). To record movement behaviour, we attached modified GT-600 i-gotU GPS
122 loggers (Mobile Action Technology, New Taipei City, Taiwan) to the central back feathers of
123 incubating and chick brooding adults using Tesa© tape. GPS loggers were modified by
124 removing the external plastic housing, and then sealed with heat shrink tubing (FiniShrink,
125 UK) to waterproof each unit. The loggers weighed 33 g, approximately 1.1% of albatross
126 body mass, and were set to record location every 10 minutes. Birds were re-captured on the
127 nest following one or more complete foraging trips, as determined by nest attendance
128 surveys. During capture, a small aliquot (~0.05 ml) of blood was taken from each individual
129 for molecular sexing (Avian Biotech, Truro, Cornwall) under permit from the New Zealand
130 Department of Conservation.

131 **Vessel monitoring system**

132 We acquired data on the distribution and movement of fishing vessels via ship-borne GPS
133 transponders provided by the New Zealand Ministry of Fisheries fishing vessel-monitoring
134 system (VMS). Data were obtained for the same temporal period and spatial extent as the bird
135 tracks (i.e., 10 November 2011 to 29 December 2011 and 19 October 2012 to 27 December
136 2012). These data covered all fishing vessels >28 m in length operating within the New
137 Zealand EEZ. Additionally, smaller vessels fishing for Orange Roughy (*Hoplostethus*

138 *atlanticus*) or New Zealand Scampi (*Metanephrops challengeri*) were also tracked. VMS
139 transponders record vessel identification, speed, and location every 1 to 2 hours; gear type
140 was not reported. Catch-effort data for our study period lacked the usual corresponding
141 information needed to combine datasets. Catch-effort data also have low accuracy of event
142 locations with unknown error (Torres et al. 2011), and thus were not used in our analyses.
143 VMS data for areas outside the New Zealand EEZ were not available. Our analyses are
144 therefore restricted to overlaps between albatrosses and VMS enabled vessels within the New
145 Zealand EEZ, representing 49.7% of the 28,814.9 hours during which we logged Campbell
146 Albatrosses on foraging trips.

147 **Data Analysis**

148 *Spatio-temporal overlap between foraging albatrosses and fishing vessels within the EEZ*
149 We used bivariate Gaussian bridge (BGB) movement models to calculate the temporally
150 explicit space use of both foraging Campbell Albatrosses and fisheries vessels to examine
151 their encounter probabilities. The advantage of BGBs over classic measures of utilization
152 distributions, such as convex polygons, or kernel home range, is that they track movement
153 heterogeneity across time and use two directional components instead of one to gain more
154 precise estimates of the space utilized by individual animals/vessels. Moreover, space use
155 between any two locations can be computed separately, allowing for temporally explicit
156 estimates of the utilization distribution (Kranstauber et al. 2014). This allowed us to calculate
157 the spatial overlap between foraging albatrosses and fishing vessels contemporarily, and in
158 contrast to previous studies examining the interaction between seabirds and fisheries (e.g.
159 Granadeiro et al. 2011; Torres et al. 2011), we can determine space use directly from the
160 movement rather than relying on linear interpolation with or without a buffer zone. The use
161 of BGBs should thus provide more accurate results of spatio-temporal overlap.

162 To prepare the tracking data, we split the VMS data into separate fishing trips with the same
163 format as the albatross data; each fishing vessel trip was defined as a series of GPS fixes that
164 were separated by a maximum of 24 hours. To prevent computational issues with birds and
165 fishing vessels crossing the international dateline we shifted the dateline of the data by 180
166 degrees prior to all analyses.

167 *Coarse-scale spatio-temporal overlap between albatross and fisheries*

168 First, we calculated the total area utilized by each individual albatross and vessel to estimate
169 the total spatial overlap during the complete study period (10 November 2011 to 29
170 December 2011, and 19 October 2012 to 27 December 2012). This coarse-scale spatio-
171 temporal index is similar to population-level or multi-species assessments of overlap between
172 fishing activity and species distribution (e.g. Phillips et al. 2006). We calculated the total
173 space use of birds and fishing vessels during each foraging/fishing trip by computing BGBs
174 on each complete trip, assuming a spatial location error of the GPS-devices of 18m for both
175 the albatross data loggers and the VMS units of the vessels (Duncan et al. 2013). From these,
176 we extracted the 95% estimates of total space use with a spatial resolution of 5 km, and re-
177 projected them to an equal-area projection. We then combined the space use estimates for all
178 bird foraging trips and fishing vessel trips separately, and calculated the coarse-scale spatial
179 overlap of these population-level space use estimates.

180 *Fine-scale spatio-temporal overlap between albatross and fisheries*

181 Secondly, we investigated whether birds and vessels shared similar areas during the same
182 time period, creating a potential for interactions. To do so, we split the BGB for each
183 albatross and vessel trip into its smallest temporal units: the space use between two
184 consecutive locations (i.e. every ten minutes for albatrosses, every 2 hours for vessels). From
185 these, we extracted the 95% utilization distributions with a spatial resolution of one square

186 kilometre. For each potential encounter (utilization distributions with overlapping time
187 intervals), we calculated the spatial overlap of the distribution estimates to estimate the area
188 that was shared in space and time.

189 *Distance between GPS-fix locations for albatross and fishing vessels: Sex, stage and year*
190 *effects*

191 The assessment of spatio-temporal overlap using BGBs (above) estimates simultaneous space
192 use of foraging albatrosses and fishing vessels, however fisheries vessels can alter the
193 behaviour of foraging seabirds at greater spatial scales. It has been shown that Northern
194 Gannets (*Morus bassanus*) alter their behaviour as a response to the presence of fishing
195 vessels within a range of up to 11 km (Bodey et al. 2014), and Wandering Albatross
196 (*Diomedea exulans*) up to a distance of 30 km (Collet et al. 2015). To encompass the full
197 effects of fishing vessels of foraging Campbell Albatross, we determined potential interaction
198 events by calculating the distance to fishing vessels that were close in space and time using
199 known locations. This is similar to modelling fishing vessel activity using windows of time
200 and distance employed previously to avoid the assumptions associated with linear
201 interpolation (i.e. Votier et al. 2010) or adding buffers to known locations (Patrick et al.
202 2015). First, we calculated the rhomb line distance from every GPS-fix of an albatross to
203 every fishing vessel GPS-fix recorded within two hours (the temporal resolution of VMS
204 tracks). Analyses used the full data set as well as the subset of the data where albatross and
205 fishing vessel were <11 km apart, assuming a conservative effect of the fishing vessel (Bodey
206 et al. 2014); or <30 km apart (Collet et al. 2015).

207 To investigate the effect of sex and stage of reproduction on the likelihood of observing
208 potential interactions, we modelled the minimum observed distances between albatross and
209 any fishing vessel using linear mixed-effects models. The models included individual bird as

210 a random effect (to control for repeat samples from the same bird) with year, sex and stage of
211 reproduction (incubation and chick brooding) as fixed-level factors. We also fitted the two-
212 way interaction between sex and stage of reproduction, to determine whether any sex-specific
213 effects of fisheries varied as a function of breeding stage.

214 **Results**

215 Over the two breeding seasons, we collected data from 299 foraging trips made by 81
216 Campbell Albatrosses (43 males and 38 females; Table 1). The total area used by albatross
217 within the EEZ was 291,128.2 km² (6.7% of the EEZ, representing 32.0% of the total area
218 used by birds). The rest of their foraging took place in the Tasman Sea, Australian waters or
219 in international waters (Fig. 1). For the fishing vessels (n=83), a total of 320,510 VMS fixes
220 were recorded during the same period of time, of which 99.9 % were within the EEZ.
221 Subsequent results are thus based upon the EEZ only.

222 During their foraging trips, the albatrosses used a mean of $3,835.1 \pm 5,930.2$ km² (mean \pm
223 standard deviation; 95% home range) and travelled over distances of $1,577.0 \pm 2,222.5$ km
224 per trip (great-circle distances, see supplemental materials). Albatrosses spent 14,316.1 of the
225 28,814.9 hours within the EEZ (49.7 %).

226 **Coarse-scale spatio-temporal overlap between albatross and fisheries**

227 During the tracking period, we found that Campbell Albatrosses and vessels spatially
228 overlapped across 42,325.60 km² within the EEZ when overlaying the full 95% utilization
229 distributions (pooled data). Despite albatross using 6.7% of the EEZ, they overlapped with
230 fisheries vessels in just 0.97% of the EEZ, mostly in the south (Fig. 1).

231 **Fine-scale spatio-temporal overlap between albatross and fisheries**

232 When calculating whether shared space use by albatrosses and fisheries occurred at the same
233 time, we used the temporally explicit 95% utilization distributions and found no overlap
234 between vessels and birds (Table 1). Overall, albatrosses used of 291,128.2 km² within the
235 EEZ, and of this area, 42,325.6 km² were also utilized by fishing vessels (supplemental
236 materials).

237 **Distance between GPS-fix locations for albatross and fishing vessels: Sex, stage**
238 **and year effects**

239 The minimum distance between GPS-fix locations of albatrosses and fishing vessels on
240 foraging trips was significantly affected by breeding stage and year (Table 1). However,
241 when using all spatial and temporal distances within 11 km and two hours of at least one
242 vessel, albatrosses only overlapped during 17 of the 299 foraging trips (5.7%; Table 2).
243 These 17 trips were performed by 15 individual birds that were within 11 km and two hours
244 of a fishing vessel (range 1-8 vessels) at some stage during their foraging trip. Under this
245 analysis, year was marginally significant in the subset of foraging trips as all but one of these
246 foraging trips occurred in 2012. Fisheries overlap was most common during incubation and,
247 while sex had no significant effect, 12 of the 17 foraging trips with fisheries overlap were by
248 males, which may be due to sample size (Table 2). Under the scenario of a vessel footprint of
249 30 km, albatross foraging behaviour was potentially affected by fishing vessels on 25
250 foraging trips (8.4%) made by 21 individuals. Eighty percent of those foraging trips occurred
251 during incubation with a sex ratio of 9:16 (female:male). The maximum number of vessels an
252 individual potentially encountered increased from 8 within the 11 km footprint to 11 within
253 the 30km footprint. When testing the larger (30 km) footprint, sex, breeding stage and year
254 were not significantly associated with the minimum distance between albatrosses and fishing
255 vessels. In most cases, the period of overlap between Campbell Albatrosses and vessels lasted

256 less than 10% of the foraging trip within the EEZ (Table 2). However a few individuals spent
257 up to 65% of the foraging trip near vessels.

258 **Discussion**

259 We provide the first estimate of the degree of association between fisheries and breeding
260 Campbell Albatross using a novel BGB analysis at both coarse and fine spatio-temporal
261 scales. Despite Campbell Albatrosses utilizing 6.7% of the New Zealand EEZ, they only
262 overlapped with fishing vessels in a remarkably small section in the southern portion of the
263 EEZ (0.97% of the area). Furthermore, we found very limited spatio-temporal overlap
264 suggesting that albatrosses and vessels may occupy the same areas, but seldom at the same
265 time. These results suggest that during the breeding season the risk of fisheries bycatch for
266 Campbell Albatross is low within the New Zealand EEZ. In addition, this reveals that fishing
267 vessels are not always important as foraging opportunities for albatrosses. Below we discuss
268 the implications of these findings for studying seabird–fishery interactions in general and for
269 the Campbell Albatross in particular.

270 Spatial area of overlap between albatross and vessels within the EEZ not only varied strongly
271 depending upon the spatio-temporal resolution used, the assumed vessel footprint, and
272 showed variation by sex and breeding stage. When accounting for an 11 km footprint (Bodey
273 et al. 2014), we found overlap in 5.7% of trips, and these overlap periods generally lasted less
274 than 10% of the trip within the EEZ. However a few individuals show substantial the spatio-
275 temporal overlap and they may be at a higher risk of mortality. When we expanded this area
276 to 30 km, assuming that Campbell Albatrosses may behave like Wandering Albatrosses
277 (Collet et al. 2015), we found the potential for interactions increased to 8.4% of foraging
278 trips. We expected females to have a higher risk of fisheries interactions based on time spent
279 in proximity to the New Zealand mainland, where the highest fishing activities occur, but,

280 contrary to our expectations, 12 of the 17 foraging trips within 11 km of fisheries vessels
281 were by males. Further investigation is needed to determine if the skewed sex ratio is due to
282 the small number of foraging trips with seabird-fisheries overlap or represent different
283 survival probabilities as well as examining behavioural responses to assess if Campbell
284 Albatross are attracted to vessels, avoid them, or co-occur/use the same habitat.

285 Campbell Albatross is a “High Risk” species within New Zealand waters, based upon a semi-
286 quantitative assessment of spatial overlap, observed captures, and fishing effort to assess
287 fisheries vulnerability (Ministry for Primary Industries 2014). Prior to 1998, information on
288 bycatch rates for Campbell Albatross was limited, as they were considered a subspecies of
289 Black-browed Albatross (Robertson and Nunn 1998; Sangster et al. 2013); thus bycatch rates
290 prior to 1998 were often a combination of Campbell and Black-browed Albatrosses. From
291 1989 to 1995, bycatch of Campbell Albatrosses in Australian waters was estimated at 780 per
292 year (Gales et al. 1998), and thus could have had serious impacts on the estimated 24,600
293 annual breeding pairs in 1995-1998 (Moore 2004; Sagar 2014). Bycatch rates in this longline
294 tuna fishery were higher (up to 1.26 birds per 1000 hooks) in summer than in winter, and
295 skewed toward juveniles. Murray et al. (1993) reported declines in bycatch in New Zealand
296 waters from 3662 seabirds in 1988 to 360 seabirds in 1992, suggesting mitigation measures
297 may have reduced bycatch. Alternatively individuals that associated with fishing vessels
298 could have been removed from the population, limiting the number of albatross around
299 vessels (Tuck et al. 2015). More recently, there were zero to three observed captures of
300 Campbell Albatross per year from 2004 to 2013 (Abraham E. R., Thompson F. N). Thus,
301 current annual estimates of potential fatalities for Campbell Albatrosses within New Zealand
302 waters range from 44 to 356 birds ((Ministry for Primary Industries 2014)); 0.20 – 1.69% of
303 the estimated breeding population 2006-2012 (Sagar 2014). Most of the bycatch is associated
304 with surface longline fisheries (Ministry for Primary Industries 2014). Observed captures

305 from trawls were associated with fisheries for Hoki (*Macruronus novaezelandiae*), Arrow
306 Squid (*Nototodarus sloanii*, *N. gouldi*), New Zealand Scampi and Southern Blue Whiting
307 (*Micromesistius australis*), and occurred outside the incubation and chick brooding stages
308 (Abraham and Thompson 2012). If we assume that there are 21,648 individuals foraging at
309 any one time, then over our study time period, we could expect up to 1803 albatross foraging
310 trips to overlap with fishing vessels within New Zealand's EEZ (8.4 % of trips within 30 km
311 footprint). Although it is unknown how many interactions with fishing vessels result in
312 mortalities, these low bycatch rates agree well with the low overlap rates and lack of spatio-
313 temporal overlap recorded in our tracking study. During the Austral summers of 2011/12 and
314 2012/13, Campbell Albatross spent about half their time foraging within the EEZ, however,
315 the rest of their foraging took place in areas without available vessel monitoring data, mostly
316 in the Tasman Sea or Australian waters. Thus, by focusing on VMS data within New
317 Zealand's EEZ we probably underestimate the frequency of overlap between Campbell
318 Albatross and fishing vessels, and our results are limited to the breeding season. Campbell
319 Albatross may be vulnerable to fisheries related mortality in areas not studied here, and at
320 different ages and breeding stages (Murray et al. 1993; Gales et al. 1998), but our tracking
321 data is consistent with other sources of data indicating that bycatch risk of adult Campbell
322 Albatross within the New Zealand EEZ is low during the breeding season.

323 There are a number of factors that may impact the nature of interactions between seabirds and
324 fisheries, including the presence and timing of discards, the use of mitigation measures,
325 weather, inter-species competition and the availability of other resources (Votier et al. 2008;
326 Dietrich et al. 2008; Jiménez et al. 2009; Favero et al. 2011; Croxall et al. 2013). On the
327 Patagonia Shelf, the frequency of Black-browed Albatross-fisheries interactions was
328 associated with wind conditions, season, time of day, and the presence of discards (Favero et
329 al. 2011). Management of discards, such as offal mincing, reducing discharge to sump water,

330 or waste holding/batch discharge, can reduce the abundance of seabirds around fisheries
331 vessels, with concomitant reductions in mortality risk (Abraham et al. 2009; Pierre et al.
332 2010). Additionally, mitigation measures, such as night setting, weighted lines and Tori lines,
333 have reduced bycatch rates and may also deter seabird-fisheries interactions (Løkkeborg
334 2003; Dietrich et al. 2008). Inter-species competition may also reasonably account for the
335 low interaction rates since fisheries within New Zealand's EEZ frequently kill other albatross
336 species. White-capped Albatross (*Thalassarche steadi*), for example, regularly attend fishing
337 vessels in New Zealand waters and may out-compete Campbell Albatross (Bartle 1991;
338 Torres et al. 2011). Annual variation in these factors combined with environmental variation
339 could account for annual influences found in our models; for example, the area utilized
340 during foraging trips was larger during 2012.

341 **Conservation implications**

342 Our results suggest that, because of the limited overlap between Campbell Albatross and
343 fisheries in New Zealand waters during the breeding season, the risk of bycatch is relatively
344 low. Moreover, examining coarse-scale spatio-temporal overlap with fisheries may provide
345 an overestimate of risk if not accounting for fine-scale temporal components that may be
346 further reduced if behavioural state of the bird is added. These finer scale analyses of spatio-
347 temporal overlap may both improve risk assessments and provide insight into foraging
348 behaviour (Votier et al. 2010; Granadeiro et al. 2011; Croxall et al. 2013; Torres et al. 2013a;
349 Torres et al. 2013b). While BGBs provide an excellent new tool to examine movements and
350 overlaps between animals and fishing vessels, they require spatially and temporally explicit
351 data. The regional focus of our study was constrained due to lack of data, thus reinforcing the
352 need to increase the availability of high resolution fisheries data. Current estimates suggest
353 that the population of Campbell Albatross is slightly declining or stable (Waugh et al. 1999;
354 Sagar 2014). If declines continue without an increase in bycatch, other factors such as food

355 availability or environmental change should be carefully assessed. More importantly,
356 conservation and fisheries management for this species needs to occur across all age-classes
357 and on a multi-national scale, as juvenile Campbell Albatross may be more vulnerable to
358 bycatch, and adult albatrosses spend half of their time foraging outside New Zealand waters.
359 The timing and duration of mitigation measures could be improved by incorporating fine-
360 scale spatio-temporal distributions into dynamic ocean management, in which management
361 efforts to reduce bycatch change in response to spatial and temporal alteration in the ocean or
362 species movements rather than largely static marine conservation areas (Howell et al. 2008;
363 Hobday et al. 2010; Hobday et al. 2014).

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376 contributors) by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are
377 used herein under license.

378

379 **Compliance with ethical standards**

380 **Conflict of interest** The authors declare that they have no conflict of interest. All applicable
381 international, national, and/or institutional guidelines for the care and use of animals were
382 followed. All scientific procedures and site access were conducted under permit issued by the
383 New Zealand Department of Conservation and was approved by the animal ethics committee
384 at the Plymouth University. Great care was taken to minimize stress to the animals during
385 handling.

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Table 1. The effects of sex, breeding stage, and year on the minimum distance between Campbell Albatross and fishing vessels using linear mixed-effects models. Models included individual bird as a random effect (to control for repeat samples from the same bird).

| Distance Between Albatross and Fishing Vessels (Full Dataset) | | | | Distance Between Albatross and Fishing Vessels (Within 2 hours and ≤ 11 km) | | | |
|---|-------|---------|---------|--|----|---------|---------|
| | DF | F-value | p-value | | DF | F-value | p-value |
| Intercept | 17659 | 3882.03 | | Intercept | 21 | 23.94 | |
| Sex | 79 | 0.16 | 0.69 | Sex | 12 | 0.38 | 0.55 |
| | | | <0.000 | | | | |
| Stage | 17659 | 572.41 | 1 | Stage | 21 | 0.019 | 0.92 |
| Year | 17659 | 6.57 | 0.01 | Year | 12 | 4.73 | 0.05 |
| Sex*Stage | 17659 | 2.28 | 0.13 | | | | |

| Distance Between Albatross and Fishing Vessels (Within 2 hours and ≤ 30 km) | | | |
|--|----|---------|---------|
| | DF | F-value | p-value |
| Intercept | 55 | 59.39 | |
| Sex | 18 | 1.70 | 0.21 |
| Stage | 55 | 1.04 | 0.31 |
| Year | 18 | 0 | 0.98 |

Table 2. Interaction characteristics of foraging trips within 11 km or 30 km and 2 hours of fishing vessel location.

| Individual | Foraging Trip | Sex | Stage | Year | Within 11 km and 2 hours | | | Within 30 km and 2 hours | | |
|------------|---------------|--------|----------------|------|--------------------------|---------------------|--------------------|--------------------------|---------------------|--------------------|
| | | | | | Number of Vessels | Number of Locations | Proportion of Trip | Number of Vessels | Number of Locations | Proportion of Trip |
| 1 | 1 | Female | Incubation | 2011 | 0 | 0 | 0 | 1 | 7 | 0.00 |
| 2 | 2 | Female | Incubation | 2012 | 0 | 0 | 0 | 4 | 8 | 0.00 |
| 3 | 3 | Female | Incubation | 2012 | 8 | 103 | 0.04 | 11 | 232 | 0.09 |
| 3 | 4 | Female | Incubation | 2012 | 6 | 246 | 0.14 | 6 | 506 | 0.30 |
| 3 | 5 | Female | Chick Brooding | 2012 | 0 | 0 | 0 | 3 | 6 | 0.02 |
| 4 | 6 | Female | Incubation | 2012 | 0 | 0 | 0 | 3 | 32 | 0.02 |
| 4 | 7 | Female | Incubation | 2012 | 1 | 7 | 0.01 | 1 | 18 | 0.02 |
| 5 | 8 | Female | Incubation | 2012 | 1 | 3 | 0.00 | 7 | 46 | 0.03 |
| 6 | 9 | Female | Incubation | 2012 | 1 | 2 | 0.00 | 1 | 30 | 0.01 |
| 7 | 10 | Male | Chick Brooding | 2011 | 1 | 2 | 0.00 | 1 | 11 | 0.01 |
| 8 | 11 | Male | Incubation | 2012 | 0 | 0 | 0.00 | 4 | 28 | 0.01 |
| 9 | 12 | Male | Incubation | 2012 | 6 | 962 | 0.49 | 7 | 1274 | 0.65 |
| 10 | 13 | Male | Incubation | 2012 | 1 | 5 | 0.01 | 1 | 53 | 0.10 |
| 10 | 14 | Male | Chick Brooding | 2012 | 2 | 17 | 0.05 | 3 | 71 | 0.20 |
| 11 | 15 | Male | Incubation | 2012 | 1 | 11 | 0.01 | 1 | 20 | 0.01 |
| 12 | 16 | Male | Incubation | 2012 | 1 | 21 | 0.01 | 5 | 50 | 0.02 |
| 13 | 17 | Male | Chick Brooding | 2012 | 1 | 39 | 0.14 | 1 | 65 | 0.23 |
| 14 | 18 | Male | Incubation | 2012 | 1 | 15 | 0.01 | 2 | 32 | 0.01 |
| 15 | 19 | Male | Incubation | 2012 | 1 | 53 | 0.02 | 3 | 122 | 0.04 |
| 16 | 20 | Male | Incubation | 2012 | 1 | 1 | 0.00 | 1 | 12 | 0.00 |
| 17 | 21 | Male | Incubation | 2012 | 0 | 0 | 0 | 2 | 22 | 0.01 |
| 18 | 22 | Male | Incubation | 2012 | 0 | 0 | 0 | 1 | 5 | 0.00 |
| 19 | 23 | Male | Chick Brooding | 2012 | 0 | 0 | 0 | 1 | 16 | 0.04 |

| | | | | | | | | | | |
|----|----|------|------------|------|---|----|------|---|-----|------|
| 20 | 24 | Male | Incubation | 2012 | 3 | 23 | 0.02 | 6 | 107 | 0.07 |
| 21 | 25 | Male | Incubation | 2012 | 1 | 3 | 0.00 | 1 | 12 | 0.00 |

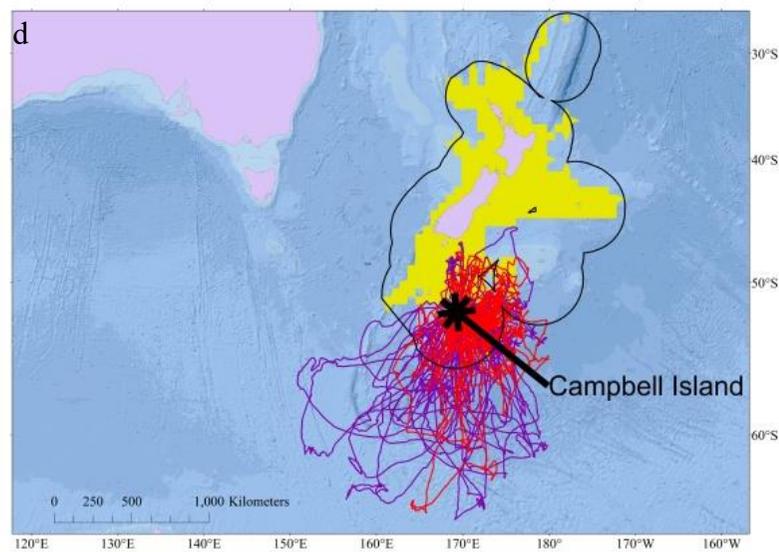
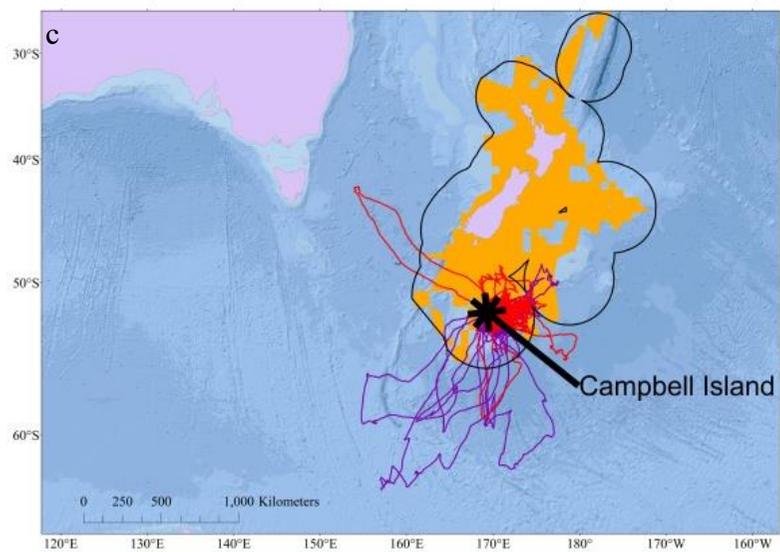
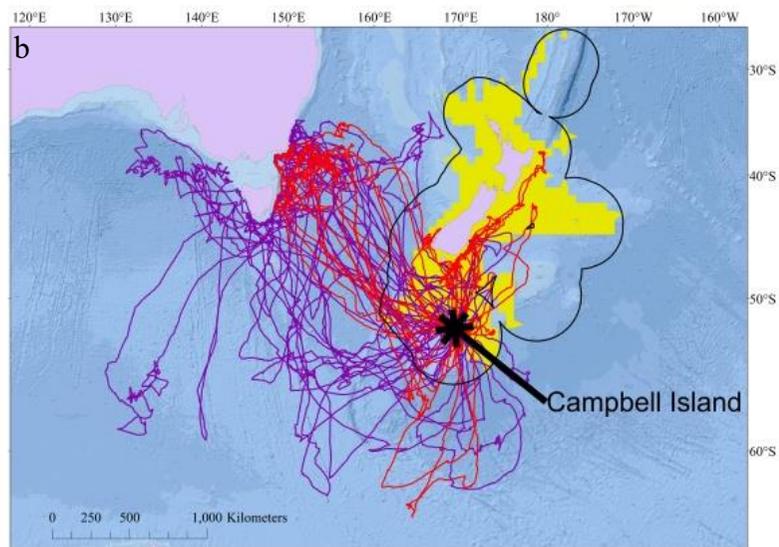
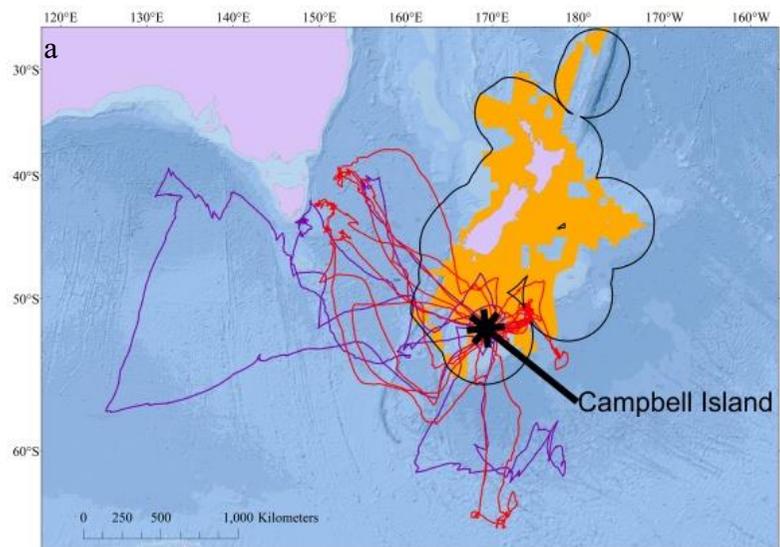


Fig. 1. Spatial overlap between fishing vessels (2011: orange, 2012: yellow) and foraging trips within New Zealand's Exclusive Economic Zone (black) during: a) incubation in 2011 (n=18), b) incubation in 2012 (n=41), c) chick brooding during 2011 (n=79) and d) chick brooding during 2012 (n=161). Foraging trips were undertaken by females (red) and males (purple). Vessel monitoring data were transformed into a polygon.

Supplemental material. Distance travelled and spatial utilization (area) per foraging trip (mean \pm standard deviation) for Campbell Albatrosses within New Zealand's Exclusive Economic Zone (EEZ). Data are sub-divided by sex and stage of reproduction (incubation or chick brooding).

| Sex | Year | Stage | Number of Trips | Number of Individuals | Area (km ²) | Distance Travelled (km) | Time Inside EEZ (hours) | Time Outside EEZ (hours) |
|--------|------|----------------|-----------------|-----------------------|-------------------------|-------------------------|-------------------------|--------------------------|
| Female | 2011 | Incubation | 12 | 11 | 2149.8 \pm 1222.7 | 2482.3 \pm 1858.5 | 23.4 \pm 33.5 | 48.7 \pm 100.2 |
| Female | 2012 | Incubation | 16 | 13 | 3048.7 \pm 2618.0 | 3892.9 \pm 3013.3 | 55.3 \pm 97.7 | 152.0 \pm 168.2 |
| Female | 2011 | Chick Brooding | 44 | 15 | 1172.7 \pm 737.2 | 639.4 \pm 602.8 | 35.1 \pm 19.1 | 17.0 \pm 28.6 |
| Female | 2012 | Chick Brooding | 80 | 27 | 1375.3 \pm 1088.3 | 843.6 \pm 784.8 | 23.2 \pm 18.5 | 15.4 \pm 22.0 |
| Male | 2011 | Incubation | 6 | 6 | 1570.7 \pm 870.4 | 3552.8 \pm 3441.1 | 25.3 \pm 20.3 | 166.2 \pm 101.7 |
| Male | 2012 | Incubation | 25 | 24 | 2466.5 \pm 1244.7 | 5558.9 \pm 4159.6 | 35.5 \pm 55.5 | 217.9 \pm 165.4 |
| Male | 2011 | Chick Brooding | 35 | 11 | 1112.6 \pm 656.5 | 805.0 \pm 875.9 | 35.8 \pm 31.9 | 27.0 \pm 28.5 |
| Male | 2012 | Chick Brooding | 81 | 27 | 1372.9 \pm 935.1 | 1117.3 \pm 973.0 | 20.5 \pm 16.3 | 34.5 \pm 31.4 |