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1 **Critically endangered franciscana dolphins in an estuarine area: fine-scale**
2 **habitat use and distribution from acoustic monitoring in Babitonga Bay,**
3 **southern Brazil**

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14
15 **Running page head:** Franciscana dolphin habitat use and distribution

16
17 **Abstract**

18 Franciscana dolphins in Babitonga Bay represent the only population of this critically
19 endangered species that is confined to an estuary, which also home a population of
20 Guiana dolphins. Surrounded by large cities and harbors, Babitonga Bay presents
21 intense human activities and potential impacts that may threaten the dolphins.
22 Understanding their habitat use and distribution can inform the implementation of
23 conservation actions and mitigation of such impacts. Here we used acoustic data from
24 sixty fixed passive acoustic monitoring stations, implemented between June and
25 December 2018. The relationship between the occurrence of franciscanas and
26 environmental variables was investigated with generalized additive mixed models. The
27 selected model presented 51% of explained deviance and included “time of day”,

28 “intensity of presence of Guiana dolphins”, “maximum slope”, and “bottom sediment”,
29 among other less statistically significant variables. A daily distribution pattern was
30 identified, with franciscanas remaining in the areas of greatest occurrence especially
31 in the morning and seemed to prefer sandy bottom and flatter areas. Areas intensively
32 used by Guiana dolphins were avoided. Additionally, we mapped their distribution
33 using “Empirical Bayesian Kriging” to identify the main areas of occurrence and for
34 foraging. Franciscanas are consistently predominant in the innermost region of the
35 estuary, without expressive use of the entrance channel, but with a wider range in
36 winter than in the spring. The area around the islands, between the north and south
37 banks, represents an important foraging area, a behavior more frequent during dawn
38 and night. This study provides important insights into critical habitats and behavioral
39 patterns of critically endangered franciscanas in Babitonga Bay.

40

41 **Keywords:** passive acoustic monitoring, critical habitat, diel distribution, *Pontoporia*
42 *blainvillei*, threatened species, conservation, sympatry, *Sotalia guianensis*.

43

44 1. INTRODUCTION

45 Information on habitat use and distribution of wild animal populations can guide
46 management of conflicting human activities, allowing promotion of conservation
47 strategies (Hastie et al. 2003, Cañadas et al. 2005). Because designating the entire
48 distribution ranges of highly mobile species, such as marine mammals, as protected
49 areas can be practically impossible, identifying priority areas which are essential to
50 their survival, such as those used for foraging and breeding, is of great importance
51 (Hoyt 2012).

52 The franciscana dolphin (*Pontoporia blainvillei*) is endemic to the Southwestern
53 Atlantic Ocean, and occurs from Espírito Santo, in Brazil (18°25' S), to the Argentinian
54 Patagonia (42°35' S; Crespo 2009). With high risk of extinction mainly due to high
55 accidental mortality from entanglement in fishing nets (Pinheiro & Cremer 2003), the
56 species is listed as “Vulnerable” globally by the IUCN (Zerbini et al. 2017), and is
57 considered “critically endangered” by the Government of Brazil (MMA 2014). Their
58 habitat use is poorly known, with information limited to how that relates to bathymetry
59 at a relatively coarse spatial resolution. Fine scale habitat use and temporal movement
60 dynamics have not yet been well studied (e.g., Danilewicz et al. 2009, Amaral et al.
61 2018, Sucunza et al. 2019). The species is mainly found in coastal habitats on the
62 continental shelf, between the surf zone and the 50 m depths, predominantly up to 30
63 m deep (Danilewicz et al. 2009). Some individuals are occasionally seen visiting bays
64 and river deltas (Bordino et al. 1999, Di Benedetto et al. 2001, Azevedo et al. 2002,
65 Failla et al. 2004, Santos et al. 2009, Zappes et al. 2018).

66 The only known distinct franciscana population residing exclusively in an
67 estuarine habitat is found in Babitonga Bay, southern Brazil (Cremer & Simões-Lopes
68 2008, Cremer et al. 2018). With only 50 individuals, there is evidence of a high degree

69 of isolation, corroborated by satellite telemetry data, photo-identification and genetic
70 analyses (Dias et al. 2013, Sartori et al. 2017, Cremer et al. 2018, Wells et al. 2021).
71 This population is considered as a demographically independent management unit for
72 conservation purposes (Nara et al., 2022). In addition to accidental catches in gillnets
73 (Pinheiro & Cremer 2003), habitat degradation by chemical pollution (Alonso et al.
74 2012), and the construction and expansion of ports, including underwater blasting work
75 and dredging, likely compromise the health of the bay's ecosystem and, consequently,
76 the survival of this dolphin population (Cremer et al. 2018, Paitach et al. 2019).

77 Visual surveys have indicated a heterogeneous distribution of franciscanas in
78 Babitonga Bay, with dolphins typically occurring in the innermost regions of the estuary
79 and concentrating around the islands in its central portion (Cremer & Simões-Lopes
80 2008, Paitach et al. 2017, Cremer et al. 2018). Factors already recognized to influence
81 their habitat use include variations in tidal cycles, which probably reflects prey
82 availability fluctuation, and the presence of sympatric Guiana dolphins (*Sotalia*
83 *guianensis*) (Paitach et al. 2017, Cremer et al. 2018). The Guiana dolphin population
84 has 150 individuals and is also considered resident, although unlike franciscanas, they
85 commonly move out of the bay (Cremer et al. 2018). There is a high distribution overlap
86 between these two cetacean populations, although their core areas do not overlap
87 (Cremer et al. 2018).

88 Understanding the ecological requirements of small cryptic cetaceans is a major
89 challenge, and standard visual surveys are not always a viable option (Mellinger et al.
90 2007). Franciscanas are one of the smallest dolphin species, they form small groups,
91 rarely display aerial behaviors, and only expose a small part of their body during
92 relatively short surfacings (Wells et al. 2013, Cremer et al. 2018; Actis et al. 2018).
93 Furthermore, visual observations, whether from vessels or aircrafts, are restricted to

94 daylight periods and require very good weather conditions. Like most cetaceans they
95 produce sounds when diving, which allows acoustic sampling (Tyack & Clark 2000).

96 Passive acoustic monitoring (PAM) allows the autonomous logging of
97 underwater sounds generated by cetaceans and can be an efficient alternative to
98 visual surveys for detecting their presence (Van Parijs et al. 2009). PAM can be used
99 to investigate various ecological and behavioral aspects of cetaceans, can sample
100 habitat during poor weather conditions or at night, and may have relatively low
101 associated costs (Mellinger et al. 2007). Cetacean echolocation click trains detected
102 in PAM stations distributed in an area of interest, for example, illustrate how PAM can
103 be used to identify potential foraging areas and periods (e.g., Pirodda et al. 2014, Tubbs
104 et al. 2020, Paitach et al. 2021). PAM have been widely used worldwide for studies on
105 cetacean distribution, migrations, behavior, habitat use, and identification of impacts
106 and threats (e.g., Verfuß et al. 2007, Mellinger et al. 2007, Van Parijs et al. 2009,
107 Jaramillo-Legorreta et al. 2016, Carlén et al. 2018). For franciscanas, PAM has only
108 been used to describe their acoustic repertoire and sound production characteristics
109 (Tellechea et al. 2017, Barcellos & Santos 2021, Paitach et al. 2021).

110 For our study, we used an array of PAM devices for sampling franciscana
111 sounds during winter and spring in Babitonga Bay. Our objectives were to identify the
112 main environmental variables related to how that population use the habitat in the bay,
113 including in the presence of Guiana dolphins, and to map franciscana distribution and
114 foraging areas that could inform conservation strategies and management of human
115 activities. We hypothesized that franciscanas vary their seasonal and diel distribution,
116 and that the distribution patterns are linked to environmental features and niche
117 partitioning with Guiana dolphins.

118

119 **2. METHODS**

120 **2.1. Study area**

121 Babitonga Bay (26°02'-26°28 'S – 48°28'-48°50' W, Fig. 1), Santa Catarina
122 State, southern Brazil, is approximately 160 km² wide, with 6 meters average water
123 depth, and some extremely shallow areas, which become exposed at low tide (Vieira
124 et al. 2008). The waters in the bay are supplied from several rivers, but its physical-
125 chemical characteristics are spatially homogenous (IBAMA 1998). It has a semi-diurnal
126 regime of micro tides, meaning two well-defined daily cycles of floods and ebbs during
127 spring tides, reaching a maximum amplitude of less than 2 m (Vieira et al. 2008).
128 Bathymetric and morphosedimentary maps of Babitonga Bay can be viewed in Vieira
129 et al. (2008). Since the grounding of the narrow southern channel for construction of
130 an access road to the São Francisco do Sul Island in 1937 (thick black segment in Fig.
131 1), the only connection to the open ocean is through a 28 m deep channel to the north.

132

133 **2.2. Sampling design and methods**

134 Acoustic monitoring was done using C-PODs (Chelonia Limited©, UK), i.e.,
135 autonomous acoustic loggers designed to log trains of tone-like pulses between 20
136 and 160 kHz. Such devices have an omni-directional hydrophone (i.e., records in all
137 directions) and are ideal to record narrow-band high frequency (NBHF; i.e. peak
138 frequency at 130 kHz and no essential energy below 100 kHz) sonar click trains of
139 franciscanas, but also the broadband clicks of Guiana dolphins (Paitach et al. 2021).
140 C-PODs were fitted into custom-made cages, designed to protect them from net
141 entanglement, with none or negligible interference in the acoustic recordings (Paitach
142 et al. 2021).

143 A systematic grid was designed for deploying sixty PAM stations. Deployment
144 sites were determined at semi-random within the survey area, constrained to locations
145 with an average depth of 4 m or deeper (maximum depth sampled 22.3 m), and were
146 at least 1,600 m apart in the access channel and 800 m in other areas (Fig. 1) to
147 proportionally address the expected distribution of franciscanas in those areas (c.f.
148 Cremer et al. 2018); i.e., In areas where a higher density of franciscanas is expected,
149 the distance adopted was the lesser possible—without the risk of a franciscana being
150 detected in more than one PAM station simultaneously—for a fine-scale coverage..

151 It is virtually impossible that a franciscana has been detected by more than one
152 C-POD of the grid at the same time, and difference in detection rate between PAM
153 stations basically depends on the density of individuals in the area. For the
154 transmission loss of NBHF sounds, with a source level of 190 dB (i.e., similar to harbor
155 porpoises; Villadsgaard et al., 2007) and a detection threshold of a C-POD of 120 dB,
156 the theoretical detection range of a franciscana should be around of 400 m on-axis of
157 the sonar beam—off-axis this distance drops to a few meters (Nick Tregenza, Chelonia
158 Ltd., personal communication, 2017). In practice, however, this distance should be
159 considerably less, as it is an estuarine environment with high turbidity and
160 topographical complexity, which greatly reduce NBHF sound propagation.

161 Acoustic samples were collected from June 26 to December 24, 2018, with a
162 varying number of days monitored at each station. In total, 35 C-PODs were used, with
163 a maximum of 20 C-PODs operating simultaneously. A subset of C-PODs (usually 20)
164 was replaced every approximately 30 days by others with fresh batteries and SD cards,
165 always using new PAM station. To minimize systematic bias from possible differences
166 in C-PODs detection potential due to temporal degradation (Dähne et al. 2013),
167 devices were randomly placed at each deployment, as recommended by Carlén et al.
168 (2018). The design aimed at sampling each position for 30 days in the winter and 30

169 days in the spring, on average. Ten C-POD subsets were defined with three station
170 positions each, considering the closest possible positions for each group, and each of
171 these positions was sampled at each exchange, ensuring that the distribution of the
172 monitored points remained as homogeneous as possible in the area over the study
173 period.

174

175 **2.3. Data analysis**

176 Franciscana sonar click trains were identified using KERNO click train classifier
177 in CPOD.exe (Chelonia Limited, UK). That software identifies NBHF-type sounds with
178 higher robustness and lower levels of false positives than classifiers based on
179 individual clicks (Dähne et al. 2013, Roberts & Read 2014). Only click trains classified
180 by KERNO as having a “high” or “moderate” probability of being generated by
181 franciscanas were analyzed. The “Detection Positive Minutes” per hour (DPM/h;
182 number of minutes with at least one franciscana click train within an hour) were
183 extracted and was used here as a proxy for the intensity of franciscanas presence.

184 The C-POD has a limited number of logged pulses per minute (4,095) to avoid
185 data overload and, consequently, saturation of the memory card and battery
186 consumption. After that limit, the logging is interrupted and only resumed in the
187 following minute. Ambient noise, such as the sound of rain, moving bottom sand, or
188 produced by living organisms such as shrimp and fish, which may generate pulsed
189 sounds that can be logged by the C-PODs. Excessive noise data were evaluated with
190 the ‘Detections and Environment’ tool in CPOD.exe—corresponding to 2.4% of the
191 collected data—and disregarded to ensure sampling homogeneity.

192

193 **2.4. Habitat use**

194 For modelling of franciscanas' habitat use on a fine scale, the intensity of their
195 presence around PAM stations, expressed as DPM/h, was modelled as a function of
196 environmental variables. Generalized Additive Models (GAMs; Hastie & Tibishirani
197 1990) were applied using R software v.4.0.3 (R Core Team 2020) to accommodate the
198 possibly complex relationships between franciscanas presence and variables. Because
199 the data set to be modelled was large (n = 64,745), models were fitted using function
200 "bam" (mgcv R package; Wood 2017) which allows relatively fast model fitting.
201 Preliminary inspection was conducted to ensure that the data contained information
202 useful for inference on habitat use. Maps and graphics illustrating sampling distribution
203 balance over space and time confirmed the adequacy of the data (Supp. material).

204 Environmental variables (Table 1) were obtained for each PAM station using
205 ArcGIS Pro 2.3 (<https://www.esri.com>), with input data from morphosedimentary and
206 topographic databases (provided by Vieira et al. 2008). Tidal conditions for each
207 monitoring hour were attributed to PAM stations using tide tables published by the
208 Directorate of Hydrography and Navigation of the Brazilian Navy for the port of São
209 Francisco do Sul. The DPM/h of the Guiana dolphin was also included as a variable.
210 The classification procedure for this species was like that for franciscanas, with virtually
211 zero risk of miss-specification (see Paitach et al. 2021).

212 Linear correlation and concurvity, a measure of non-linear relation between
213 smooth terms within a GAM, were verified for a preliminary model that includes all
214 available variables. Pearson coefficients equal or stronger than 0.5 (positive or
215 negative) were used for identifying correlated variables. All measures of depth (Table
216 1) were linearly correlated to each other, to slope measures and to geographic location,
217 UTMX and UTM Y. Aspect and TCI were linearly correlated to each other. Correlated
218 variables were not included in the same model.

219 Preliminary models indicated that residual autocorrelation could be a problem.
220 Correlation structures presented a cyclic pattern with an apparent peak every 24 units
221 apart. Therefore, a 2-D smoother (Wood 2017) for easting (i.e., “UTMX”) and northing
222 (i.e., “UTMY”) combined, with a different tensor for each hour of the day, was added to
223 all models to account for autocorrelation. This approach allowed the spatial
224 heterogeneity in the data to be explicitly modelled as a function of time and space.
225 Also, a first-order autoregressive error structure function (AR1) was added in the
226 models. For each model, the AR1 correlation parameter ρ was calculated by fitting
227 models without correlation structure and measuring the first lag in the autocorrelation
228 function (“acf”, R function). In the present modelling framework, the AR correlation
229 structure corresponded to a GEE (Generalized Estimating Equations; Ziegler, 2011)
230 approximation which, in practice, increased the uncertainty in the estimated
231 smoothers. That means that p-values for smooth terms became larger when compared
232 to corresponding models without AR1 structure. Since the data set was formed by time
233 series, with observations representing repeated measurements for each location, a
234 smooth term for each sampled PAM station as a random variable was used in all
235 models.

236 Smooth functions were used to model the relationship between continuous
237 variables and the response value. Except for the 2-D smoother for easting and northing
238 combined with a tensor for each hour of the day and a cyclic spline for hour of day
239 (“Hourday”), thin plate regression splines were used (R package “mgcv”; Wood 2017).
240 The dimension basis (i.e., parameter k on smooth functions, mgcv R package) was set
241 to a maximum of seven for all tested smoother of variables, to both avoid overfitting
242 and prevent smooth functions impossible to interpret biologically. For variables
243 “Aspect” and “Maximum Slope”, that parameter was further decreased to five, because

244 preliminary modelling showed fitted smoothers of hard biological interpretation, i.e.,
245 with several peaks.

246 Model variables were selected in a forward step approach, based on minimum
247 Akaike Information Criterion (AIC; Akaike 1974): the initial model presented a 2-D
248 smooth function for UTMX and UTM Y with a different tensor for each hour of the day,
249 a smooth function for “Point” as a random variable, and a cyclic smooth term for “Hour
250 of day”. In the first round of variable selection, models with only one additional variable
251 were fitted, and the one presenting the smallest AIC score was considered as the initial
252 model in the following step. In each step, only one additional variable was separately
253 added to the model selected in the previous step. Those steps were repeated until the
254 AIC could not be improved by the addition variables, and so the resulting model was
255 retained as the most efficient to describe the variation in the presence of franciscanas.

256

257 **2.5. Distribution**

258 The distribution of franciscanas and of their foraging activity were investigated
259 through interpolation of spatial data (i.e., “kriging”) using software ArcGIS Pro 2.3
260 (Geostatistical Analyst; Geostatistical Wizard; <https://www.esri.com>). Kriging is a
261 geostatistical interpolation method that assumes that the distance or direction between
262 the points in the sample reflects a spatial correlation that can be used to explain the
263 variation in the surface (Oliver & Webster, 1990). Without imposing a priori
264 environmental variables, the spatial autocorrelation of a specified number of points is
265 modeled in semi-variograms which are used to estimate density at each location
266 (Oliver & Webster 1990). More specifically, Empirical Bayesian Kriging (EBK) was
267 used. While other kriging methods require several projection parameters to be
268 manually adjusted, EBK automatically calculates these parameters at each predicted

269 location using a subset process and data simulations. The method also differs from
270 other kriging methods by taking the standard error introduced by the estimate of the
271 underlying semi-variogram into account, propagating that uncertainty when generating
272 predictions in locations not surveyed (Oliver & Webster 1990, Krivoruchko 2012).
273 Semi-variogram parameters were estimated using restricted maximum likelihood
274 (REML), which is indicated for small data sets to avoid overestimating densities at
275 restricted areas (Krivoruchko 2012).

276 Two variables were separately used to generate distribution maps: 1) Detection
277 Positive Hours (DPH) was used to identify the main areas of franciscana occurrence;
278 and 2) adjusted Feeding Buzz Ratio (FBR) was used to identify foraging areas. The
279 DPH was obtained using the KERNO classifier and a similar selection criteria as the
280 DPM used in the analysis of habitat use, however with hours as period of interest (i.e.,
281 coarser temporal resolution). All click trains recorded throughout the study were
282 exported and classified as “feeding buzzes”, based on an Inter-Click Interval (ICI) of
283 less than 10 ms (Carlström 2005, Paitach et al. 2021). FBR values were then
284 calculated as the ratio between number of buzzes and number of non-buzz click trains
285 (with ICI > 10ms). A weighted metric of the importance of the foraging areas was
286 obtained by adjusting FBRs by the intensity of franciscanas occurrence (i.e.,
287 multiplying the FBR by the DPH).

288 Seasonal (winter and spring) and diel (dawn = 00:00-05:59, morning = 06:00-
289 11:59, afternoon = 12:00-17:59, and night = 18:00-23:59) maps were produced. The
290 midday and midnight cut-off limits were chosen to allow some understanding for
291 distribution patterns within the light and dark periods. Those periods can be more easily
292 used for illustrating management strategies related to the time of the day. Average
293 values of DPH and adjusted FBR were calculated separately for each day (for season
294 maps), and for each period of the day (for diel period maps), and then averages for all

295 sampled days were calculated for each PAM station. Days with less than 24 hours of
296 data collected or periods of the day with less than 6 hours collected were not
297 considered in this analysis. Since the FBR values are adjusted, biological interpretation
298 can be difficult. Therefore, maps for FBR values were grouped into classes of
299 importance. Outliers were removed and the resulting scale of values was divided into
300 four equally sized classes. The lowest class was disregarded (low importance), and
301 the others were 'moderate', 'high', and 'very high' importance for foraging.

302

303 **3. RESULTS**

304 Out of the 60 monitoring stations planned throughout the study area, only 6 were
305 not sampled in winter, and 11 in spring, due to loss of equipment. PAM stations were
306 monitored for an average of 28 days (minimum of 3, and maximum of 57 days) in winter
307 and 24 (minimum of 2 and maximum of 91) in spring. A total of 66,350 hours of acoustic
308 recordings were collected in 182 days, both seasons considered. After data filtering
309 (i.e., removing data with excess noise) 64,745 hours were analyzed, including 7,432
310 (11.5%) with franciscana recordings.

311

312 **3.1. Habitat use**

313 The final selected habitat use model had 51% of explained deviance and fitted
314 the data well, except for high values of the response variable (Supp. material). Despite
315 the assumption of residual constant variance not being fully met, the negative binomial
316 distribution ($\theta = 0.092$) showed the most supported fit to the residuals and was adopted
317 for modelling. Residual autocorrelation was greatly reduced by the inclusion of an
318 autoregressive function in the model, yet still mildly present (Supp. material). For that

319 reason, the inclusion of variables in the final model must be interpreted carefully,
320 especially for variables with lower significance (i.e., large p-values). Coefficients for
321 factor variables and smooth functions included in the final model can be evaluated in
322 the Table 2.

323 The forward step variable selection resulted in the inclusion of smooth functions
324 for intensity of presence of the Guiana dolphins (“SG.DPM”) and maximum slope
325 (“Slope.max”), in addition to the compulsory smother in the initial model (i.e., “Point”
326 as a random variable; a 2D smoother for “UTMX” and “UTMY”, with a tensor for each
327 hour of the day; and a cyclic smoother for “Hour.day”) (Fig. 2). There was a clear cyclic
328 pattern in the occurrence of franciscanas across the study area, indicating that in the
329 areas where their presence was more intense, they were more likely to occur during
330 the early hours of the day. Areas with very high values of intensity of presence of
331 Guiana dolphins were avoided by the franciscanas, but to a lesser extent, they seemed
332 to be tolerated. Franciscanas seem to avoid steeper areas within the range of slopes
333 in Babitonga Bay.

334 The final model also included factor variables “Month”, “Sediment”, “Tide.type”
335 and “Tide.state”. Because of multiple factor variables, partial effects for each
336 combination of factor levels would require several plots. Boxplots of values adjusted
337 for the intensity of the presence of franciscana (Pb.DPM) for each selected factor
338 variable are shown individually (Fig. 3). The presence of franciscanas seems to vary
339 slightly over the months of study, but a clear seasonal pattern was not observed. The
340 presence of franciscanas in Babitonga was associated with the granulometry of the
341 bottom sediments, with a greater presence over sandy bottoms and less presence over
342 mud bottoms. Despite contributing to improving the model AIC, it is not clear how tide
343 variables were related to the variations of presence of franciscanas, since the levels
344 were not precisely estimated, as indicate by large p-values (Supp. material).

345

346 **3.2. Distribution**

347 Predictive maps of occurrence and foraging areas were generated for each
348 season (Fig. 4). The distribution of franciscanas was predominant in the innermost
349 region of the estuary, close to the community of Vila da Glória, without a marked use
350 of the open sea access channel. In the winter their distribution expanded, extending to
351 the mouth of the Palmital River (northwest axis), the entrance to Saguaçú Lagoon
352 (west margin), and the Linguado Channel (south axis), and further along the northeast
353 margin of the bay. In the spring the distribution was predominantly in the central region
354 of the bay, between the north and south margins. The area with the highest density in
355 winter was located slightly towards the west than in spring, which remained closer to
356 the north-central margin. The area between the north margin and the islands
357 represents important franciscana foraging areas, both in winter and spring, but in
358 winter the area between the islands and the south margin were also important for
359 foraging. In winter, the northeastern margin, and the area close to the mouth of the
360 Palmital River (northwest axis) also appear to be areas used for foraging, which were
361 not seen in the spring.

362 Areas of occurrence and important for foraging for franciscanas varied slightly
363 throughout the diel periods in both seasons (winter: Fig. 5; spring: Fig. 6). The central
364 area of the bay, between the islands and the north margin, remained as the core area
365 of franciscanas throughout the day, in both seasons, while areas with less intensity of
366 use varied throughout the day in each season. In winter, foraging was more
367 concentrated near the core area during the morning and afternoon, and at night it
368 expanded southwards, to a region close to the community of Laranjeiras, which was
369 intensified at dawn (Fig. 5). In the spring the foraging areas were more restricted, with

370 some oscillation in the east-west direction (Fig. 6). During the night they expanded
371 eastwards, occupying the entire surroundings of the islands. During the afternoon the
372 pattern was towards the opposite direction, with foraging in the innermost portion of
373 the bay, up to its west margin, in an extensive area of shallow water and muddy banks
374 (Fig. 6). In both seasons, the dawn period showed the biggest patches of 'very high'
375 importance for foraging, indicating that the feeding behavior is more intense in that
376 period, followed by the night in winter and the afternoon in spring (Fig. 5 and 6).

377

378 **4. DISCUSSION**

379 **4.1. Cyclic patterns of habitat use**

380 There was a clear diel cyclic pattern in the presence of franciscanas across the
381 study area. In the areas where their occurrence was more intense, they were more
382 likely to occur during the early hours of the day (Fig. 3). This means that in the main
383 area of occurrence of franciscanas the highest densities of calls in the early hours of
384 the day and late afternoon (individuals are more clustered), and in the rest of the day
385 the density of calls decreases in this area and increases in other areas, that is, reducing
386 the difference in the density of calls between the different areas of occurrence
387 (individuals are more dispersed). That is possibly a reaction to environmental cycles,
388 which modify the abiotic conditions of ecosystems, with biological organisms
389 corresponding, like fishes and squids that are preys of dolphins. (Aschoff 2013).
390 Behavior patterns in response to diel cycles can be diurnal, nocturnal or twilight
391 (Fernandez-Betelu et al. 2019). In coastal environments, tidal cycles can also cause
392 environmental changes that can result in periodic movements of many species,
393 including cetaceans (Gibson 2003). Similarly to what happens in Anegada Bay,
394 Argentina (Bordino et al. 1999), the franciscanas in Babitonga Bay were found to

395 present movement patterns related to the tides, moving towards the mouth of the bay
396 during ebb and in the opposite direction during the flood, following the current flow
397 (Paitach et al. 2017). In the present study, although the tide was selected as an
398 important factor for the habitat use, it was not possible to clearly identify a pattern. In
399 fact, the tidal cycles effects on dolphin habitat use patterns can vary seasonally, and
400 cetaceans appear to be less influenced by tides in open areas than in narrow channels
401 (Pierpoint 2008, Fernandez-Betelu et al. 2019).

402 Franciscanas seem to avoid steeper areas within the range of bottom slopes in
403 Babitonga Bay. This may be linked to bathymetry also, since depth variables were not
404 included because of their correlation with geographic location (i.e., UTMX, UTMY).
405 Holz (2014) observed the influence of the average depth on the distribution of this
406 same population of franciscanas, with a preference for deeper areas, although non-
407 linear influences were not explored in this study and therefore conclusions should be
408 cautious. Amaral et al. (2018) also identified depth as limiting the distribution of the
409 species, without detecting slope effects. However, their study assess the topographic
410 slope of studied environments in a much wider spatial scale, which may have
411 weakened the power of analysis of this variable. In two gulfs in southern Australia, the
412 bottlenose dolphin (*Tursiops truncatus*) also prefers habitats associated with a flat
413 bottom topography (Bilgmann et al. 2019).

414 The heterogeneous distribution of franciscanas within Babitonga Bay was found
415 to be associated with sand in the bottom sediment. The species occurs mainly in
416 coastal regions, outside bays and estuaries, where sandy bottoms predominate, and
417 although the Babitonga' population is resident in an estuarine environment (Cremer &
418 Simões-Lopes 2008), the main prey observed in its diet (*Stelifer rastrifer*, frequency of
419 occurrence of 62%) are small fish typical of the coastal environment and that have

420 habits associated with sandy bottoms (Paitach 2015), demonstrating that the
421 population may still maintain preferences related to the usual distribution of the
422 species.. The preference of sandy bottom areas by franciscanas has already been
423 noted, especially in the spring, with an increase in the use of muddy areas in winter
424 (Paitach et al. 2017). These findings were based on visual sightings, but they are now
425 corroborated and expanded by the present study. When we look at the foraging areas
426 at dawn and night, there was an increase in the use of muddy bottom areas,
427 demonstrating that these areas are also important for the population in the spring. A
428 very similar result was observed for the harbour porpoise in the Moray Firth, Scotland,
429 where only sandy banks were identified as important foraging areas without including
430 time variables (Brookes et al. 2013), but when the diel cycles were investigated,
431 adjacent muddy areas were also found to be important habitats for them at night
432 (Williamson et al. 2017).

433 Studies on the habitat use of franciscanas throughout its distribution are rare,
434 partly explained by the difficulty of studying this species in the wild. Based on bycatch
435 data, Danilewicz et al. (2009) observed that the distribution of franciscanas in Rio
436 Grande do Sul reaches predominantly up to 30 meters in depth, although they occur
437 up to 50 meters depth. That study, however, did not investigate whether water depth
438 is an important factor related to the distribution of the species. More recently, Amaral
439 et al. (2018) analyzed the influence of environmental variables to predict the spatial
440 niche of franciscanas on a wide scale, verifying that depth and salinity can influence
441 the presence of franciscanas. Using aerial surveys of distribution over a wide area in
442 southeastern and southern Brazil, Sucunza et al. (2019) observed 54 groups of
443 franciscanas in waters with an average depth of 7.15 m. Although focused on a typical
444 estuarine population, the novel habitat use investigation presented here allow insights
445 into important environmental features to the species in general. The main insights are:

446 franciscana behavior can be variable throughout the day, with movement patterns
447 between specific areas; bottom topography is important for the presence of
448 franciscana, which prefer areas with some bottom irregularity; the bottom substrate is
449 also important, probably due to the types of prey available in each habitat; the presence
450 of other dolphins strongly influences the distribution of franciscanas.

451 The environmental cycles typically affect the food chain from lower trophic levels
452 to higher. Therefore, one expect these cycles to affect the prey and consequently the
453 dolphins. (Hastie et al. 2004). Predators must be able to take advantage of these
454 temporal changes in the aquatic environment to optimize feeding success (Lin et al.
455 2013). However, the distribution dynamics between predators and prey are
456 bidirectional—both sides in this relationship affect each other—so predators seek to
457 optimize prey capture and prey correspondingly to reduce risk of predation (Trites
458 2009, Becker & Suthers 2014). Thus, the trade-off between foraging success and
459 predator avoidance is decisive in the habitat use of a species (Trites 2009). The
460 franciscanas have no frequent predators in Babitonga Bay, such as large sharks and
461 orcas (Cremer 2015, Gerhardinger et al. 2020). Therefore, the availability of prey is the
462 main factor affecting its distribution. Franciscana in Babitonga Bay is considered a
463 generalist and opportunistic species, preying on the most abundant small fish species
464 in the environment (Cremer et al. 2012, Paitach 2015). However, considering the
465 bidirectionality of the predators-prey relationship mentioned above, it is expected that
466 competing predators will affect each other, a subject that will be discussed below in
467 the specific session on the sympatry between the franciscana and the Guiana dolphin.

468 Despite contributing to improving the model's AIC, it is not clear how many of
469 the factor variables are related to the presence of franciscanas. Many levels were not
470 precisely estimated, as indicate by large p-values (Supp. material). The modelling

471 approach adopted here was adequate to provide insights into the environmental
472 variables related to the presence of franciscanas within Babitonga Bay. However,
473 model fit was not perfect, although optimal with the selected variables, and therefore,
474 this ecological investigation could greatly benefit from further modelling exploration,
475 such as: inclusion of additional variables (e.g., prey availability), exploring more
476 complex interactions between variables, modelling habitat use for specific periods
477 (e.g., additional seasons), exploring models that accommodate more complex
478 autoregressive structures, and others as well.

479

480 **4.2. Sympatry with the Guiana dolphin**

481 The intensity of presence of Guiana dolphins was identified in the models as the
482 main variable related to habitat use of franciscanas in Babitonga Bay. Cremer (2007)
483 observed a high overlap in the spatial niche of these populations, but with no
484 competition for interference between them, which has been reaffirmed over the years
485 (Cremer et al. 2018). The Guiana dolphins also have larger areas of distribution in
486 seasons with less prey availability elsewhere (Wedekin et al. 2010) and in Babitonga
487 Bay (Cremer et al. 2011). Analysis of stomach content point to a high degree of prey
488 sharing between the species (Cremer et al. 2012, Paitach 2015). It is interesting to
489 note that although both species have wider amplitudes of the trophic niche in the cold
490 months, when the prey availability is lower (Cremer 2007), there is a decrease in the
491 trophic overlap between them, attenuating the effects of competition (Paitach 2015).
492 This may be the reason why our models showed some overlap between the two
493 species, with franciscana apparently indifferent to the presence of Guiana dolphins up
494 to an extreme extent (Fig. 3).

495 It is not possible to disregard the hypothesis that the franciscanas are silent
496 when Guiana dolphins are present, but according to the visual observations made have
497 over the years it is evident that franciscanas leave the area as soon as the Sotalia
498 approach (Cremer et al. 2018), what leads to believe that acoustic data actually
499 indicate an evasion of franciscanas from the area with the increase of Guiana dolphins
500 density, but this should be better investigated and validated in the future.

501 Different ecological processes may be involved in the niche partition between
502 ecologically similar species living in direct sympatry, such as differences in behavior
503 patterns and diet, differences in habitat use and temporal segregation in the use of
504 resources (Parra et al. 2006, Nichol et al. 2013, Méndez-Fernandez et al. 2013).
505 Considering the high overlap of the trophic and spatial niches, and the absence of
506 agonistic interactions between franciscanas and Guiana dolphins in Babitonga Bay
507 (Cremer et al. 2018), we suggest that the main factors that make possible the
508 coexistence of these two species are fine-scale differences in the habitat use with
509 temporal segregation in the foraging behavior. A fine-scale study of Guiana dolphin's
510 habitat use and other analytical approaches that integrate different spheres of the
511 realized niche of both species, would assist in elucidating that question. Joint
512 conservation strategies for sympatric species, ecologically similar and that share
513 limited resources, can benefit from the understanding of how such species affect or
514 influence each other (Bearzi 2005).

515

516 **4.3. Spatio-temporal patterns of occurrence and foraging**

517 The distribution of the franciscanas was predominant in the central region of the
518 bay, with greater dispersal in winter than in spring, with little to no detections in the
519 connection channel with the open sea in either season. This corroborates conclusions

520 from previous studies derived from visual observations (Cremer & Simões-Lopes 2008,
521 Cremer et al. 2018). However, we observed a much more acute use of the center-
522 south portion of the bay in relation to what was observed in previous studies. In fact,
523 franciscana preys are known to concentrate in the region of the bay (Cremer 2007,
524 Paitach 2015). In the present study, the central-southern portion of the distribution area
525 was most frequented at night and at dawn, and mainly for foraging purposes. The
526 innermost muddy banks in the western part of the estuary are also used for foraging,
527 especially on spring afternoons. Since foraging is expected to intensify when/where
528 individuals can maximize their food intake (Pirodda et al. 2014), cyclic use of such
529 areas can be related with the distribution of the Guiana dolphin. Not surprisingly, the
530 central-southern portion of the bay is considered the core area of Guiana dolphin
531 distribution (Cremer et al. 2011, Cremer et al. 2018).

532 The present study is the first to analyze the distribution of franciscanas
533 throughout the day and to preliminarily identify the main foraging areas in Babitonga
534 Bay, on seasonal and diel scales. Multiscale approaches have been shown to be very
535 useful in studies of distribution of highly mobile species that explore dynamic habitats
536 (González-García et al. 2018), such as the characteristics of the environment and
537 species dealt with here. In particular, the association of foraging with specific
538 environmental characteristics must be considered in the management of anthropic
539 disorders (New et al. 2013, Pirodda et al. 2014). In the present work, the distribution
540 analyzes were descriptive and did not aim to relate the foraging behavior with
541 environmental characteristics, however such an approach would be desirable in future
542 studies.

543

544 **4.4. Passive acoustic monitoring: potential and limitations**

545 The PAM approach and especially the use of C-PODs showed promising signs
546 of a very valuable tool for investigating spatio-temporal patterns of habitat use and
547 distribution of franciscanas. This is the first systematic effort of this nature for the
548 species. The processing of the large data volume obtained (more than 66,000 hours
549 of recordings) was facilitated through the C-POD system automated procedure, which
550 saves time and also reduces the potential subjectivity bias of the researcher due to
551 differences in human perception when evaluating acoustic signals and the exhaustion
552 that would cause a manual analysis of a dataset of this proportion. (Rayment et al.
553 2009).

554 A key assumption in the present study is that the heterogeneity observed in the
555 franciscana acoustic detections would reflect the density of these animals in the bay.
556 Failure to meet that could rise from when animals are present but not detected, but
557 comparative studies using visual and acoustic detections indicate that acoustic
558 detections are extremely robust to reflect the density of individuals and therefore,
559 depending on the species, dolphin silence periods may not be an issue (Verfuss et al.
560 2007). Similarly to harbour porpoises (*Phocoena phocoena*) in the wild, that click
561 almost continuously and with maximum silent intervals of less than 15 seconds
562 (Akamatsu et al. 2005), it is very likely that franciscanas also continuously echolocate
563 in the estuarine waters of Babitonga Bay, which presents a complex topography and
564 very high water turbidity with virtually no visibility (Oliveira et al. 2006, Vieira et al.
565 2008), but it is interesting that this assumption be validated when possible.
566 Furthermore, and because this is an isolated population (Dias et al., 2013; Cremer et
567 al. 2018), numbers of acoustic detections in the study area are not expected to be
568 influenced by emigration/immigration of individuals. Finally, since areas with an
569 average depth of less than 4 m, potentially dry at low tides, were under-sampled, it is
570 possible that in periods when lower detection numbers were recorded within the

571 sampled area (i.e., where the water was continuously deeper than 4m), animals might
572 have been in those shallower areas.

573 We assumed a homogeneous probability of detection of franciscanas by C-
574 PDOs over space and time. It is known, however, that sound propagation may be
575 influenced by spatial and temporal variations in the behavior of the dolphins (Verfuss
576 et al. 2009, Leeney et al. 2011), and by environmental conditions, such as water
577 temperature and salinity (Richardson et al. 1995). There is a trade-off between the
578 range and directionality of the sounds produced by dolphins during traveling and
579 foraging behaviors (Tyack & Clark 2000). Understanding how different behaviors can
580 affect detection probability of franciscanas by PAM can assist the accuracy of future
581 studies. Temperature and salinity affect the speed and absorption of sound in water
582 (Richardson et al. 1995, Ainslie & McColm, 1998), but considering a low variation of
583 these parameters in the study area we hypothesize that this bias is negligible.

584 Despite the protective cages, entanglement in nets became a problem
585 throughout the study, causing the loss of some equipment units, a problem that was
586 intensified during the spring and forced an early ending of survey after six months of
587 start. The loss of equipment occurred randomly, without any consistent damage to any
588 region sampled. In some cases, after the loss of C-POD, a new deployment was
589 carried out on site to complement the data collection. We recommend that future
590 studies employ more extensive effort into clearly communicating with fishing
591 communities, so that such incidents can be avoided or that the PAM devices are
592 returned in case of undesired misplacement.

593 The two seasons sampled in the present study, winter and spring, were
594 strategically selected to identify priority habitats for the franciscanas. The winter is the
595 season of least availability of food (Cremer 2007), and so the franciscana distribution

596 reflect its most critical places for foraging during a period of food scarcity. The
597 protection of foraging areas is essential for small cetaceans, which are particularly
598 vulnerable to environmental impacts that can reduce prey availability, due to their high
599 food requirements and apex position in the marine food webs (Ross et al. 2011,
600 Wisniewska et al. 2016). In turn, spring represents the main birthing period for the
601 franciscana population of Babitonga Bay (Cremer et al. 2013), so the area of
602 distribution of the population at this season is of great importance for the protection of
603 newborns. The protection of important breeding areas is essential for the conservation
604 of small cetaceans, since the stages of young life are particularly vulnerable to species
605 threats (Ross et al. 2011).

606

607 **4.5. Implications for management and conservation**

608 The endangered nature of the franciscana population of Babitonga Bay is
609 evident, with a restricted habitat, small population size, isolated and genetically distinct
610 from other populations (Cremer et al., 2018). Some anthropogenic activities in
611 Babitonga Bay constitute direct or indirect threats to the survival of this population of
612 franciscanas, such as overfishing, chemical pollution, intense vessel traffic and port
613 construction and maintenance activities (Cremer 2007, Paitach et al. 2019). Above all,
614 the cumulative and potentially synergetic effects of these different sources of
615 anthropogenic impact on coastal environments put the dolphins under strong pressure
616 and are often neglected by environmental authorities (Cremer 2007, Azevedo et al.
617 2017, Herbst et al. 2020). The establishment and operation of big ports represent a
618 major threat to marine biodiversity, causing acute disturbances and a chronic decrease
619 in environmental quality (Domit et al. 2009). Underwater blasting work, periodic
620 dredging of the seabed and intensification of sea traffic result in suspension of

621 sediments and thereby increase the bioavailability of contaminants, oil blades on the
622 surface, increased underwater noise and the risk of collision between cetaceans and
623 vessels, among other impacts that disrupt the natural communities, reduce the
624 availability of prey and compromise the entire health of the ecosystem (Domit et al.
625 2009, Jefferson et al. 2009, Herbst et al. 2020). It is known that franciscanas avoid
626 areas with known higher levels of underwater noise in Babitonga, which are close to
627 the existing ports (Holz 2014). It has also been observed that after activities requiring
628 the use of dredges, pile drivers and other heavy machinery, the Guiana dolphins
629 abandoned the São Francisco do Sul port inlet for years (Cremer et al. 2018).

630 Several new ports are planned within Babitonga Bay, of which at least three in
631 the areas identified as critical habitats for the franciscanas. In light of the results
632 presented here, some key aspects must be considered in environmental impact
633 studies, such as: 1) the importance of franciscana foraging areas as critical habitats
634 for their survival; 2) impacts caused to the population of Guiana dolphins can also result
635 in fundamental consequences for the franciscanas, since the Guiana dolphins core
636 area is strongly threatened by port expansion, and if such impacts materialize, it is
637 likely that there will be a shift in the distribution of this population to other areas,
638 probably increasing the pressure of competition on franciscanas.; 3) the exclusion of
639 artisanal fishing areas, due to the delimitation of the vessels' maneuvering areas in
640 ports, may displace the fishing fleet in areas of the bay that are important to the
641 franciscana, resulting in an increased risk of bycatch of this species; and 4) the
642 cumulative and potentially synergistic impacts caused by the new ports and those
643 already operating in the territory.

644 In Babitonga, dredging for the extraction sand from the bottom occurs
645 throughout the year (Herbst et al. 2020), and the uncontrolled removal of this substrate
646 can also be an indirect threat to the franciscanas, as indicated by the association

647 between the species' habitat and this type of substrate found in our study. The
648 operation of dredgers also generates substantial noise, which can be impactful for
649 franciscanas (Holz 2014). The licensing of new sand extraction areas needs to take
650 this potential negative impact into account and adopt the necessary mitigation
651 measures, such as avoiding critical franciscana habitats.

652 The franciscana bycatch in the artisanal fisheries, although not as frequent in
653 Babitonga Bay as in other areas within the range of the species, still represents an
654 important threat considering that the removal of any individual from this small
655 population can be critical to its sustainability (Pineiro & Cremer 2003, Cremer et al.
656 2018). Distribution and foraging maps presented here can guide the participatory
657 development and implementation of exclusion zones in areas and periods of greater
658 use by the franciscana. Unfortunately, there is no efficient mechanism for fisheries
659 management in Babitonga Bay, making it difficult to implement strategies to prevent
660 accidental captures, including fishing exclusion zones or the use of acoustic deterrent
661 devices on nets (FAO 2021).

662 In recent years, many marine protected areas (MPA) have been designated with
663 the aim of managing human activities for the protection of marine mammals (Hoyt
664 2012). Dynamic approaches with flexible spatial and temporal limits of protection areas
665 have been recommended for mobile species such as dolphins (Castro et al. 2014,
666 Santos et al. 2017, Hazen et al. 2018, Tardin et al. 2020). However, there are many
667 difficulties for the creation or effective implementation and maintenance of MPA's in
668 Brazil (e.g., lack of staff and funding for monitoring and enforcement, deficient or
669 absent interinstitutional governance, excessive bureaucracy, and lack of political
670 incentives for any significant change (Gerhardinger et al. 2011). A proposal to create
671 an MPA in Babitonga Bay has been underway in the national environmental agency
672 (i.e., Chico Mendes Institute for Biodiversity Conservation – ICMBio, Brazilian Ministry

673 of the Environment's) for over ten years (Herbst et al. 2020). We suggest that this study
674 be considered for the establishment of a MPA in Babitonga Bay and for the elaboration
675 of the management plan or other similar instruments.

676

677 **4.6. Final considerations**

678 PAM with C-PODs has provided to be a useful method to get important
679 information for management of low density and threatened cetacean populations
680 worldwide, such as the vaquita (*Phocoena sinus*) (Jaramillo-Legorreta et al. 2016), the
681 Maui dolphin (*Cephalorhynchus hectori maui*) (Rayment et al. 2011), the Baltic harbour
682 porpoise (Carlén et al. 2018), and now the franciscanas of Babitonga Bay.
683 Unfortunately for vaquitas that information came too late, and the species is on the
684 brink of extinction (Jaramillo-Legorreta et al. 2019). Effective conservation actions need
685 to be implemented while the franciscana population in Babitonga Bay is still viable, or
686 this unique and critically endangered population may also be subject to premature
687 decline and extinction. This study provides new insights into their habitat use and
688 distribution, that should fundamentally be used to design conservation actions. The
689 challenge ahead is to identify effective ways to integrate the information on the
690 ecological needs of the franciscana into relevant public policies for the human activities
691 management.

692

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706

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1060 Table 1. Variables used for modelling habitat use of franciscana dolphins in Babitonga Bay.

Variables	Range of values	Explanation and Categories
UTMX	723237 – 741747	Longitude in UTM
UTMY	7086720 – 7101381	Latitude in UTM
Hour.of.day	cyclic	24-hour circadian cycle
Month	categorical	Months of the year, from June (6) to December (12)
Tide.state	categorical	Tidal cycles: flood, high, ebb and low
Tide.type	categorical	Type of tidal amplitude as a function of the Sun-Moon gravitational conjunction: syzygy = full and new moons; quadrature = first quarter and third quarter moons
Sg.DPM	0 – 60	Detection Positive Minutes of <i>Sotalia guianensis</i> per hour
Season	categorical	Austral seasons: winter = from June 20 to September 21; spring = from September 22 to December 20
Carbonate	categorical	Percentage of inorganic salts in the sediment within a radius of 400m: 0-10%; 10-20%; 20-30%; 30-40%
Organic.matter	categorical	Percentage of organic matter in the sediment within a radius of 400m: 0-2%; 2-4%; 4-6%; 6-8%; 8-10%
Sediment	categorical	Predominant texture of the bottom sediment within a radius of 400m: sand; sand with mud; mud with sand; mud
Deep.max	2 – 22.3	Maximum depth in meters within a radius of 400m
Deep.min	0.1 – 6.9	Minimum depth in meters within a radius of 400m
Deep.mean	1.8 – 10.7	Average depth in meters within a radius of 400m
Deep.range	1.5 – 18.1	Range between minimum and maximum depth within a radius of 400m
Slop.mean	0.179 – 3.364	Average slope in degrees within a radius of 400m
Slope.max	1.519 – 51.388	Maximum slope in degrees within a radius of 400m
Aspect	59.096 – 258.092	Average direction of the slope in degrees from north within a radius of 400m
TCI	0.0001 – 0.6613	Topographic complexity index calculated by multiplying scaled values for slope and aspect (Bouchet et al. 2015) averaged within a radius of 400m
Margin.distance	146.5 – 1952.5	Distance in meters from the nearest margin.
Margin.feature	categorical	Feature of the nearest margin: continent or island

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1063 Table 2. Parametric coefficients for factor variables and smooth terms included in the final
 1064 model of habitat use of franciscana dolphins in Babitonga Bay (AIC = 71430.59, Deviance
 1065 explained = 51%). edf = effective degrees of freedom, DPM: detection positive minutes,
 1066 significance level at 0.05 highlighted in bold.

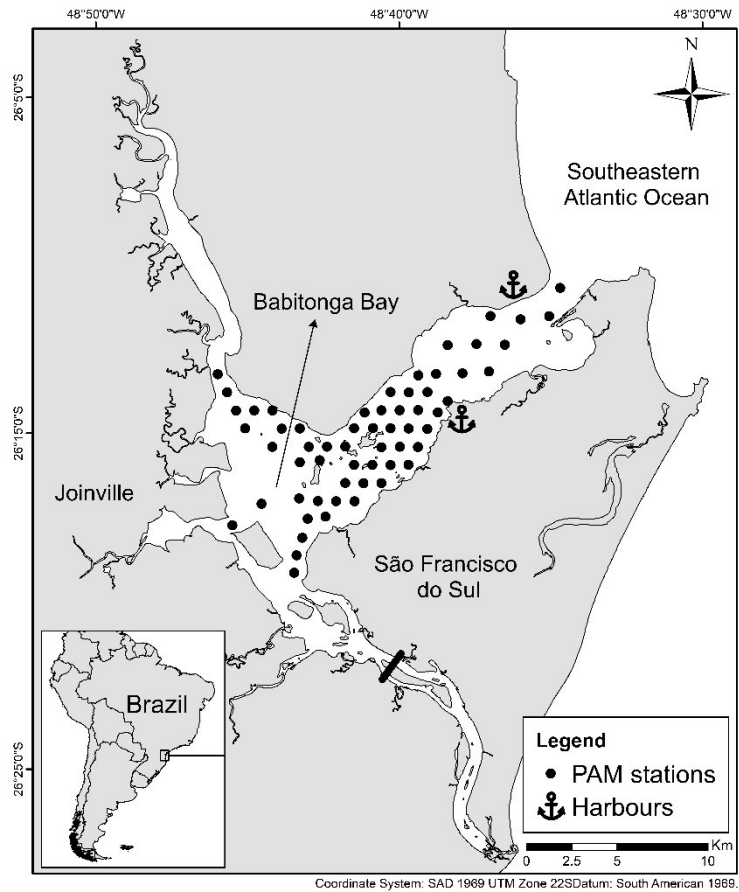
Parametric coefficients	Estimate	p-value (t-distribution)
Intercept	-3.253	< 0.001
Month – July	0.428	0.012
Month – August	0.685	< 0.001
Month – September	0.591	0.002
Month – October	0.119	0.516
Month – November	-0.006	0.974
Month – December	-0.404	0.123
Sediment – mud + sand	1.830	< 0.001
Sediment – sand	0.679	0.124
Sediment – sand + mud	1.776	< 0.001
Tide type – syzygy	0.103	0.060
Tide state – flood	-0.007	0.880
Tide state – high	0.021	0.673
Tide state – low	-0.073	0.147
Smooth terms	edf	p-value (F-statistic)
s(point)*	50.843	< 0.001
s(UTMX, UTMY, hour of day)**	**	**
s(hour of day)	3.281	< 0.001
s(Guiana dolphin DPM)	5.861	< 0.001
s(maximum slope)	3.695	< 0.001

*Random effect term for sampling point

**Coefficients for compulsory model term representing the interaction between eastings (UTMX), northings (UTMY) and of hour of day as a factor are omitted because of large number of levels (*i.e.*, 24), but are presented in the Supplementary material.

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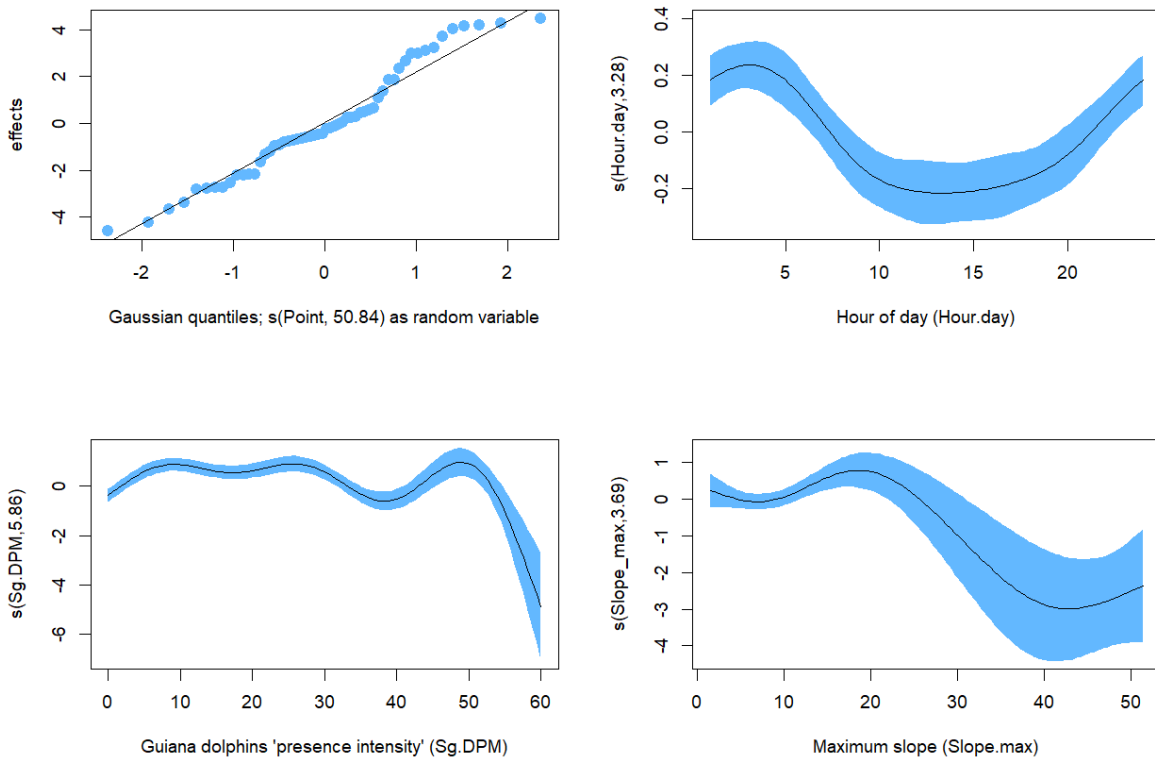
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1070 Figure 1. Distribution of sixty passive acoustic monitoring (PAM) stations deployed in
 1071 Babitonga Bay, southern Brazil, for recording franciscana dolphins. A thick black segment
 1072 indicates the location where the historical south channel was grounded in 1937 for the
 1073 construction of an access road to the São Francisco do Sul Island.

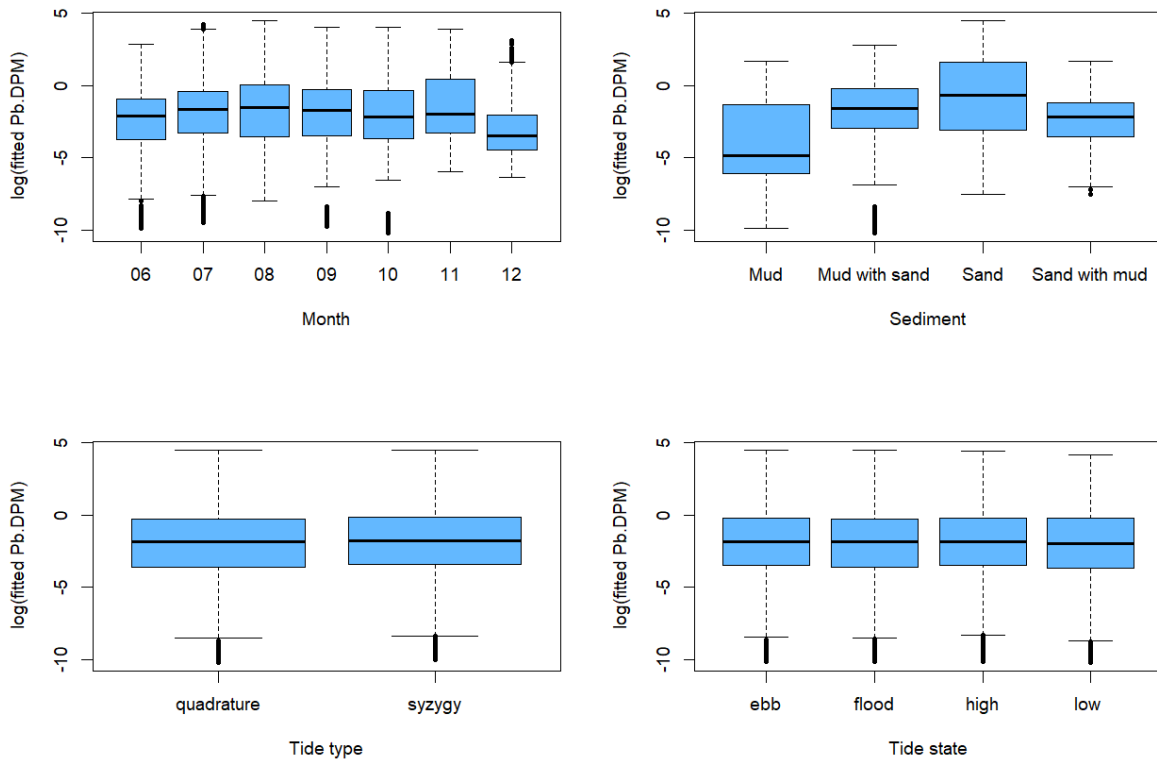
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1076 Figure 2. Smooth functions for variables hour of day, Guiana dolphin presence intensity and
 1077 slope, included in the final model for habitat use of franciscana dolphins in Babitonga Bay.
 1078 Degrees of freedom are shown inside parentheses.

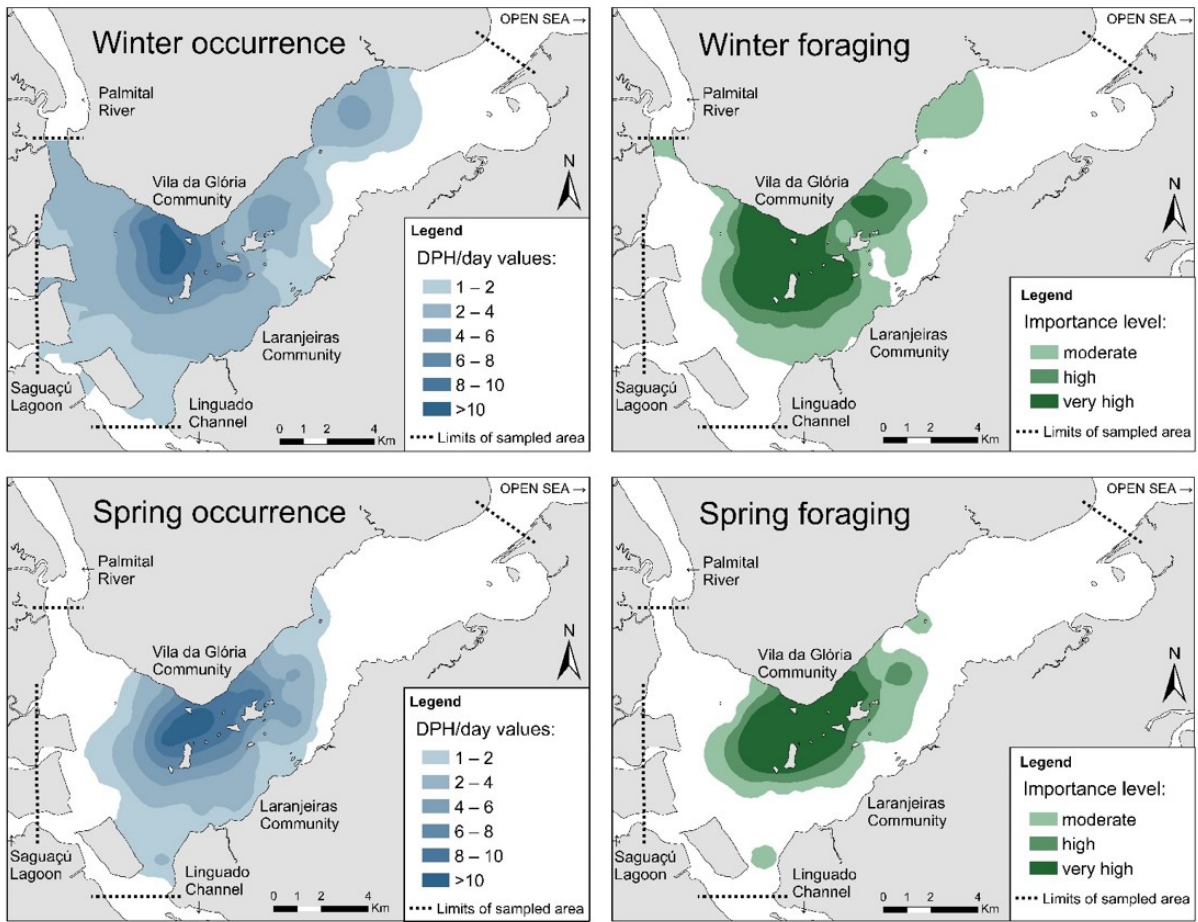
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1081 Figure 3: Boxplots for fitted values for different levels of the factor variables months,
 1082 sediment, tide type and tide state, included in the final model for habitat use of franciscana
 1083 dolphins in Babitonga Bay.

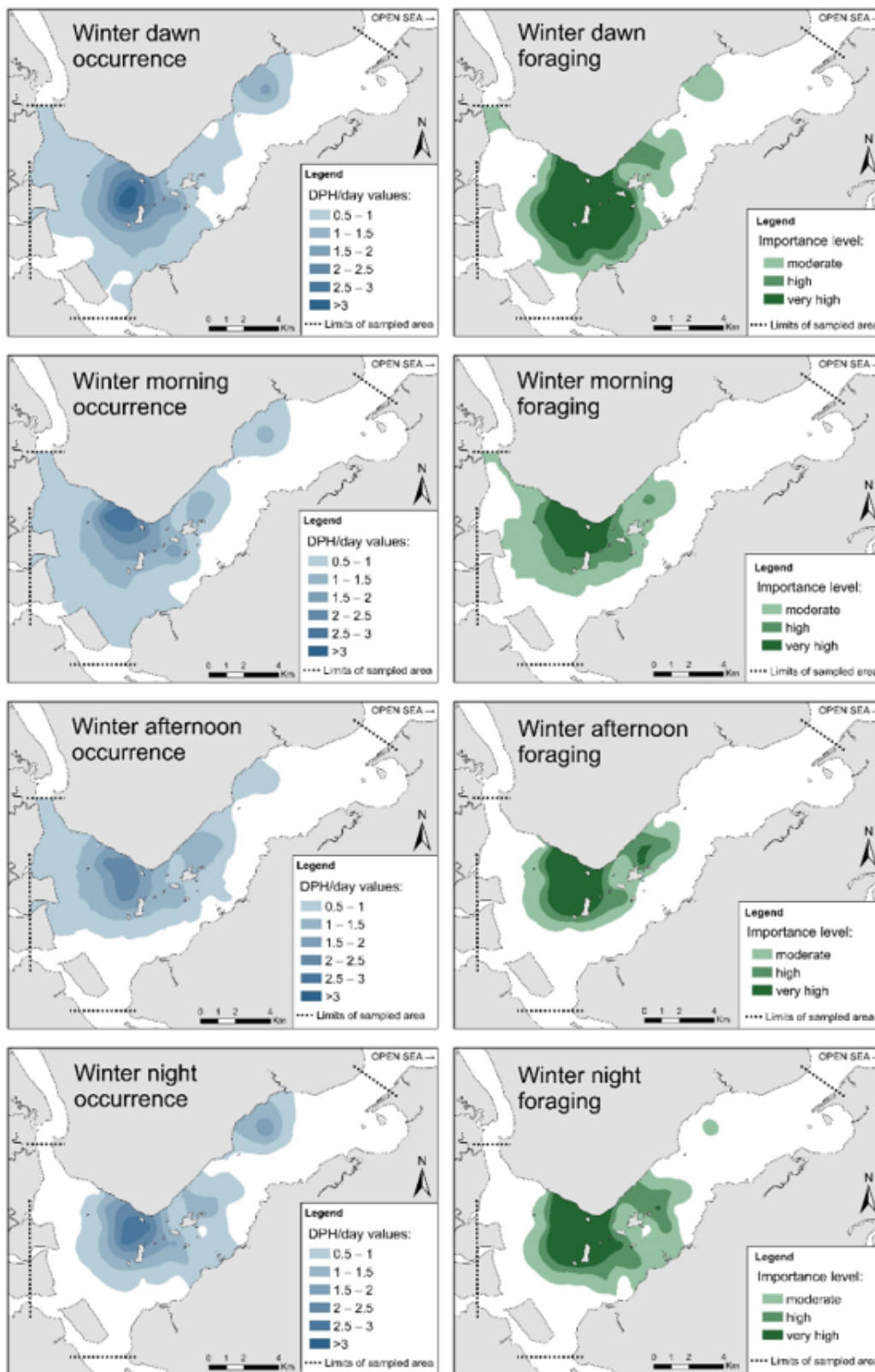
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1086 Figure 4: Occurrence of franciscana dolphins in Babitonga Bay (DPH/day = detection positive
 1087 hours per day) during winter and spring as well as foraging areas in each of those seasons.
 1088 Foraging importance level estimated by multiplying DPH/day by the Feeding Buzz Ratio (see
 1089 text for details).

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1092 Figure 5: Occurrence of franciscana dolphins in Babitonga Bay (DPH/day = detection positive

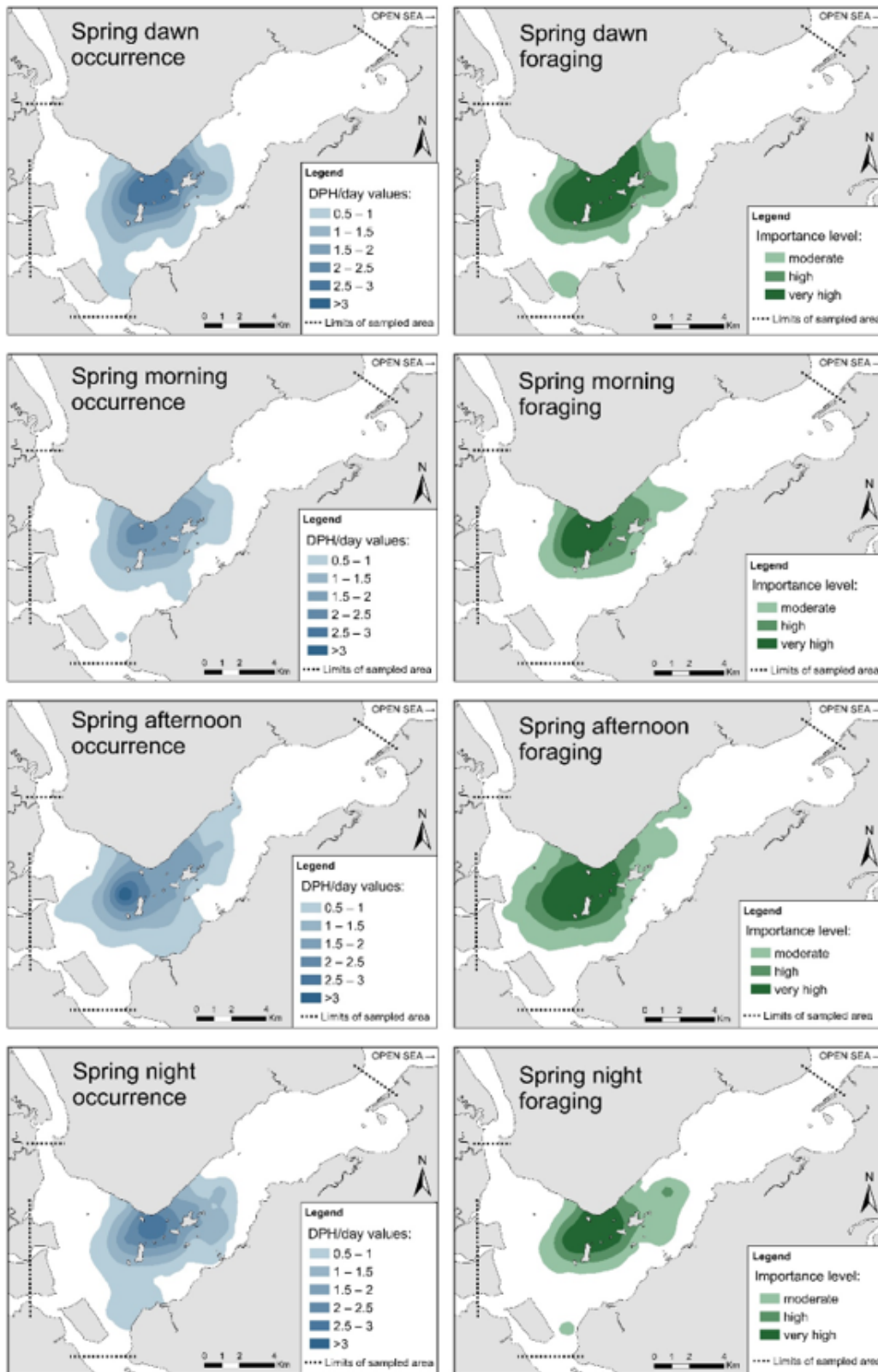
1093 hours per day) during winter as well as when foraging only in each period of the day (dawn =

1094 00:00-05:59, morning = 06:00-11:59, afternoon = 12:00-17:59, and night = 18:00-23:59).

1095 (DPH/day = detection positive hours per day).

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1099 Figure 6: Occurrence of franciscana dolphins in Babitonga Bay (DPH/day = detection positive
 1100 hours per day) during spring as well as when foraging only in each period of the day (dawn =

1101 00:00-05:59, morning = 06:00-11:59, afternoon = 12:00-17:59, and night = 18:00-23:59).

1102 (DPH/day = detection positive hours per day).