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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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",

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

1. INTRODUCTION

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

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

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

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

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

Understanding the ecological requirements of small cryptic cetaceans is a major challenge, and standard visual surveys are not always a viable option (Mellinger et al. 2007). Franciscanas are one of the smallest dolphin species, they form small groups, rarely display aerial behaviors, and only expose a small part of their body during relatively short surfacings (Wells et al. 2013, Cremer et al. 2018; Actis et al. 2018). 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., Pirotta 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

2. METHODS

2.1. Study area

Babitonga Bay (26º02'-26º28 'S – 48º28'-48º50' W, Fig. 1), Santa Catarina State, southern Brazil, is approximately 160 km² wide, with 6 meters average water depth, and some extremely shallow areas, which become exposed at low tide (Vieira et al. 2008). The waters in the bay are supplied from several rivers, but its physical-chemical characteristics are spatially homogenous (IBAMA 1998). It has a semi-diurnal regime of micro tides, meaning two well-defined daily cycles of floods and ebbs during spring tides, reaching a maximum amplitude of less than 2 m (Vieira et al. 2008). Bathymetric and morphosedimentary maps of Babitonga Bay can be viewed in Vieira et al. (2008). Since the grounding of the narrow southern channel for construction of an access road to the São Francisco do Sul Island in 1937 (thick black segment in Fig. 1), the only connection to the open ocean is through a 28 m deep channel to the north.

2.2. Sampling design and methods

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

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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

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

2.3. Data analysis

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

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

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 presenceand 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 UTMY. 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 UTMY 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

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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 presencewas 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

3.2. Distribution

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

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

some oscillation in the east-west direction (Fig. 6). During the night they expanded

eastwards, occupying the entire surroundings of the islands. During the afternoon the

pattern was towards the opposite direction, with foraging in the innermost portion of

the bay, up to its west margin, in an extensive area of shallow water and muddy banks

(Fig. 6). In both seasons, the dawn period showed the biggest patches of 'very high'

importance for foraging, indicating that the feeding behavior is more intense in that

period, followed by the night in winter and the afternoon in spring (Fig. 5 and 6).

4. DISCUSSION

4.1. Cyclic patterns of habitat use

There was a clear diel cyclic pattern in the presence of franciscanas across the

study area. In the areas where their occurrence was more intense, they were more

likely to occur during the early hours of the day (Fig. 3). This means that in the main

area of occurrence of franciscanas the highest densities of calls in the early hours of

the day and late afternoon (individuals are more clustered), and in the rest of the day

the density of calls decreases in this area and increases in other areas, that is, reducing

the difference in the density of calls between the different areas of occurrence

(individuals are more dispersed). That is possibly a reaction to environmental cycles,

which modify the abiotic conditions of ecosystems, with biological organisms

corresponding, like fishes and squids that are preys of dolphins.   (Aschoff 2013).

Behavior patterns in response to diel cycles can be diurnal, nocturnal or twilight

(Fernandez-Betelu et al. 2019). In coastal environments, tidal cycles can also cause

environmental changes that can result in periodic movements of many species,

including cetaceans (Gibson 2003). Similarly to what happens in Anegada Bay,

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

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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

19

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

4.2.   Sympatry with the Guiana dolphin

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

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

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

4.3. Spatio-temporal patterns of occurrence and foraging

The distribution of the franciscanas was predominant in the central region of the bay, with greater dispersal in winter than in spring, with little to no detections in the 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 (Pirotta et al. 2014), cyclic of 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, Pirotta 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 (Pinheiro & 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.

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References

709 Ainslie, M. A. & McColm, J. G. 1998. A simplified formula for viscous and chemical
710 absorption in sea water. Journal of the Acoustical Society of America, 103(3): 1671-
711 1672.

712 Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions
713 on Automatic Control, 19: 716-723.

714 Akamatsu, T., Wang, D., Wang, K. & Naito, Y. 2005. Biosonar behaviour of free-
715 ranging porpoises. Proceedings of the Royal Society B. 272797–801
716 http://doi.org/10.1098/rspb.2004.3024

717 Alonso, M. B., Eljarrat, E., Gorga, M., Secchi, E.R., Bassoi, M., Barbosa, L., Bertozzi,
718 C. P., Marigo, J., Cremer, M. J., Domit, C., Azevedo, A., Dorneles, P. R., Torres, J. P.
719 M., Lailson-Brito, J., Malma, O. & Barceló, D. 2012. Natural and anthropogenically-
720 produced brominated compounds in endemic dolphins from Western South Atlantic:
721 Another risk to a vulnerable species. Environmental Pollution, 170: 152-160.

722 Amaral, K. B., Danilewicz, D., Zerbini, A., Di Beneditto, A. P., Andriolo, A., Alvares, D.
723 J., Secchi, E., Ferreira, E., Sucunza, F., Borges-Martins, M., Santos, M. C. O., Cremer,
724 M., Denuncio, P., Ott, P., Moreno, I. B. 2018. Reassessment of the franciscana
725 *Pontoporia blainvillei* (Gervais & d'Orbigny, 1844) distribution and niche characteristics
726 in Brazil. Journal of Experimental Marine Biology and Ecology, 508: 1-12.
727 https://doi.org/10.1016/j.jembe.2018.07.010

728 Aschoff, J. 2013. Biological rhythms. Springer Science & Business Media.

Azevedo, A. F., Carvalho, R. R, Kajin, M., Van Sluys, M., Bisi, T. L., Cunha, H. A. & Lailson-Brito Jr, L. 2017. The first confirmed decline of a delphinid population from Brazilian Waters: 2000-2015 abundance of *Sotalia guianensis* in Guanabara Bay, Southeastern Brazil. Ecological Indicators, 79: 1-10.

Azevedo, A. F., Fragoso, A. B. L., Lailson-Brito Jr., J. & Cunha, H. A., 2002. Records of the franciscana (*Pontoporia blainvillei*) in the southwestern Rio de Janeiro and northernmost São Paulo state coasts - Brazil. Latin American Journal of Aquatic Mammals, 1(1): 191-192.

Baptista, L. F. &. Gaunt, S. L. L. 1997. Bioacoustics as a tool in conservation studies. In: Behavioral Approaches to Conservation in the Wild (J.R. Clemmons & R. Buchholz eds.) Cambridge Univ. Press, Cambridge. pp 212-242.

Barcellos, D. D. & Santos, M. C. de O. 2021. Echolocation characteristics of franciscana dolphins (*Pontoporia blainvillei*). Marine Mammal Science, 1–11. https://doi.org/10.1111/mms.12796

Bearzi, M. 2005. Dolphin sympatric ecology. Marine Biology Research, 1: 165-175.

Becker, A. & Suthers, I. M. 2014. Predator driven diel variation in abundance and behaviour of fish in deep and shallow habitats of an estuary. Estuarine, Coastal and Shelf Science, 144: 82–88.

Bilgmann, K., Parra, G. J., Holmes, L., Peters, K. J. Jonsen, I. D. & Möller, L. M. 2019. Abundance estimates and habitat preferences of bottlenose dolphins reveal the importance of two gulfs in South Australia. Scientific Reports – Nature, 9: 8044. https://doi.org/10.1038/s41598-019-44310-3

Bordino, P., Thompson, G. & Iniguez, M., 1999. Ecology and behaviour of the franciscana dolphin *Pontoporia blainvillei* in Bahía Anegada, Argentina. The Journal of Cetacean Research and Management, 1(2): 213-222.

Bouchet, P. J., Meeuwig, J. J., Salgado Kent, C. P., Letessier, T. B. & Jenner, C. K. 2015. Topographic determinants of mobile vertebrate predator hot spots: current knowledge and future directions: landscape models of mobile predator hotspots. Biological Reviews, 90: 699–728. https://doi.org/10.1111/brv.12130

Brookes, K. L., Bailey, H. & Thompson, P. M. 2013. Predictions from harbor porpoise habitat association models are confirmed by longterm passive acoustic monitoring. The Journal of the Acoustical Society of America, 134: 2523.

Cañadas, A., Sagarminaga, R., De Stephanis, R., Urquiola, E. & Hammond, P. S. 2005. Habitat preference modelling as a conservation tool: Proposals for marine protected areas for cetaceans in southern Spanish waters. Aquatic Conservation: Marine and Freshwater Ecosystems, 15: 495–521.

Carlén, I., Thomas, L., Carlström, J., Amundin, M., Teilmann, J., Tregenza, N., Tougaard, J., Koblitz, J.C., Sveegaard, S., Wennerberg, D., Loisa, O., Dähne, M., Brundiers, K., Kosecka, M., Kyhn, L.A., Ljungqvist, T.B., Pawliczka, I., Koza, R., Arciszewski, B., Galatius, A., Jabbusch, M., Laaksonlaita, J., Niemi, J., Lyytinen, S.,

Gallus, A., Benke, H., Blankett, P., Skóra, K.E. & Acevedo-Gutiérrez, A. 2018. Basin-scale distribution of harbour porpoises in the Baltic Sea provides basis for effective conservation actions. Biological Conservation, 226: 42-53. https://doi.org/10.1016/j.biocon.2018.06.031

Carlström, J. 2005. Diel variation in echolocation behavior of wild harbor porpoises. Marine Mammal Science, 21: 1-12. https://doi.org/10.1111/j.1748-7692.2005.tb01204.x

Castro, F. R., Mamede, N., Danilewicz, D., Geyer, Y., Pizzorno, J. L. A., Zerbini, A. N., & Andriolo, A. 2014. Are marine protected areas and priority areas for conservation representative of humpback whale breeding habitats in the western South Atlantic? Biological Conservation, 179: 106–114. https://doi.org/10.1016/j.biocon.2014. 09.013

Cremer, M. J. & Simões-Lopes, P. C. 2008. Distribution, abundance and density estimates of franciscana, *Pontoporia blainvillei* (Cetacea: Pontoporiidae), in Babitonga Bay, southern Brazil. Revista Brasileira de Zoologia, 25(3): 397-402.

Cremer, M. J. 2007. Ecologia e conservação de populações simpátricas de pequenos cetáceos em ambiente estuarino no sul do Brasil. (PhD Thesis) – Universidade Federal do Paraná, Curitiba. 212 p.

Cremer, M. J. 2015. Os mamíferos marinhos da Baía da Babitonga. Editora Univille, São Francisco do Sul, Santa Catarina. 102p.

Cremer, M. J., Sartori, C. M., Holz, A. C., Schulze, B., Santos, N. Z., Alves, A. K. M. & Paitach, R. L. 2013. Franciscana strandings on the north coast of Santa Catarina State and insights into birth period. Biotemas, 26(4): 133-139.

Cremer, M. J., Hardt, F. A. S., Tonellojunior, A. J. & Simões-Lopes, P. C. 2011. Distribution and status of the Guiana Dolphin *Sotalia guianensis* (Cetacea, Delphinidae) Population in Babitonga Bay, Southern Brazil. Zoological Studies, 50(3): 327-337.

Cremer, M. J., Holz, A. C., Sartori, C. M., Schulze, B., Paitach, R. L. & Simões-Lopes, P. C. 2018. Behavior and ecology of endangered species living together: long-term monitoring of resident sympatric dolphin populations. In: Rossi-Santos, M. R. & Finkl, C. W. (eds), Advances in Marine Vertebrate Research in Latin America. https://doi.org/10.1007/978-3-319-56985-7_17

Cremer, M. J., Pinheiro, P. C. & Simões-Lopes, P. C. 2012. Prey consumed by Guiana dolphin *Sotalia guianensis* (Cetacea, Delphinidae) and Franciscana dolphin *Pontoporia blainvillei* (Cetacea, Pontoporiidae) in an estuarine environment in southern Brazil. Iheringia (Série Zoologia), 102(2): 131-137.

Crespo, E. A. 2009. Franciscana dolphin *Pontoporia blainvillei*. In: Perrin, W. F., Würsig, B. & Thewissen, J. G. M. (eds), Encyclopedia of marine mammals New York, NY: 608 Academic Press. 2nd ed. pp. 466–469.

Dähne, M., Verub, U. K. Brandecker, A. Sibert, U. & Benke, H. 2013. Methodology and results of calibration of tonal click detectors for small odontocetes (C-PODs). Journal of the Acoustical Society of America, 134: 2514–2522.

809 Danilewicz, D., Secchi, E. R., Ott, P. H., Moreno, I. B., Bassoi, M. & Borgesmartins, M.
810 B. 2009. Habitat use patterns of franciscana dolphins (*Pontoporia blainvillei*) off
811 southern Brazil in relation to water depth. Journal of the Marine Biological Association
812 of the United Kingdom, 89(5): 943-949.

813 Di Beneditto, A. P., Ramos R. & Lima. N. R. W. 2001. Sightings of *Pontoporia blainvillei*
814 (Gervais & D'Orbigny, 1844) and *Sotalia fluviatilis* (Gervais, 1853) (Cetacea) in
815 Southeastern Brazil. Brazilian Archives of Biology and Technology, 44(3): 291-296.

816 Dias. C. P., Cremer, M. J., Azevedo, A. F. & Cunha, H. A. 2013. Baixa diversidade
817 mitocondrial sugere filopatria das toninhas *Pontoporia blainvillei* (Gervais & d´Orbigny
818 1844) da Baía da Babitonga, SC. Abstract book of the II Encontro de Mastozoólogos
819 do Rio de Janeiro, Teresópolis, Rio de Janeiro.

820 Domit, C., Rosa, L., Sasaki, G., & Londono, M. C. R. 2009. Cetáceos no
821 monitoramento ambiental de atividades portuárias: Sentinelas do ambiente marinho.
822 ADEMADAN; Secretaria de Ciência e Tecnologia para inclusão Social (MCT). (Eds).
823 Gestão ambiental Portuária: Subsídios para o Licenciamento das Dragagens. 1a ed.
824 Curitiba: Serzegraf, 1, 308–322.

825 Failla, M., Iniguez, M. A., Tossenberger, V., & de Haro, C. 2004. "Bioecology of
826 Franciscana (*Pontoporia blainvillei*) in Northern Patagonia, Argentina," Report
827 SC/56/SM24 56th Annual Meeting of the Scientific Committee of the International
828 Whaling Commission, Sorrento, Italy, 4 p.

829 FAO. 2021. Fishing operations. Guidelines to prevent and reduce bycatch of marine
830 mammals in capture fisheries. FAO Technical Guidelines for Responsible Fisheries
831 No.1, Suppl. 4. Rome. https://doi.org/10.4060/cb2887en

832 Fernandez-Betelu, O., Graham, I.M., Cornulier, T. & Thompsom, P. M. 2019. Fine
833 scale spatial variability in the influence of environmental cycles on the occurrence of
834 dolphins at coastal sites. Scientific Reports – Nature, 9: 2548.
835 https://doi.org/10.1038/s41598-019-38900-4

836 Gerhardinger, L. C., Godoy, E. A., Jones, P. J., Sales, G., & Ferreira, B. P. 2011.
837 Marine protected dramas: The flaws of the Brazilian national system of marine
838 protected areas. Environmental Management, 47: 630–643.
839 https://doi.org/10.1007/s00267-010-9554-7

840 Gerhardinger, L. C., Herbst, D. F., Cunha, S. & Duarte, M. 2020. Diagnóstico da
841 Ictiofauna do Ecossistema Babitonga. Revista CEPSUL: Conservação e
842 Biodiversidade Marinha.

843 Gibson, R. N. 2003. Go with the flow: tidal migration in marine animals. In: Jones M.B.,
844 Ingólfsson A., Ólafsson E., et al. (eds). Migrations and Dispersal of Marine Organisms.
845 Hydrobiologia, 503: 153-161. http://dx.doi.org/10.1007/978-94-017-2276-6_17

846 González-García, L., Pierce, G. J., Autret, E. & Torres-Palenzuela, J. M. 2018. Multi-
847 scale habitat preference analyses for Azorean blue whales. PLoS ONE
848 13(9):e0201786.

Hardt, F. A. S., Cremer, M. J., Tonello, J. A. J., Bellante, A., Buffa. G., Buscaino, G., Mazzola S., Barreto, A. S., Martinelli, L. A. & Zuppi, G. M. 2013. Use of carbon and nitrogen stable isotopes to study the feeding ecology of small coastal cetacean populations in southern Brazil. Biota Neotropica, 13(4): 90-98.

Hastie, G. D., Barton, T. R., Grellier, K., Hammond, P. S., Swift, R. J., Thompson, P. M. & Wilson, B. 2003. Distribution of small cetaceans within a candidate Special Area of Conservation; implications for management. The Journal of Cetacean Research and Management, 5(3): 261–266.

Hastie, G. D., Wilson, B., Wilson, L. J., Parsons, K. M. & Thompson, P. M. 2004. Functional mechanisms underlying cetacean distribution patterns: hotspots for bottlenose dolphins are linked to foraging. Marine Biology, 144: 397–403.

Hastie, T. J. & Tibshirani, R. J. 1990. Generalized additive models. Chapman & Hall/CRC, New York/Boca Raton.

Hazen, E. L., Scales, K. L., Maxwell, S. M., Briscoe, D. K., Welch, H., Bograd, S. J., Bailey, E. Benson, S. R., Eguchi, T., Dewar, H., Kohin, S., Costa, D. P., Crowder, L. B. & Lewison, R. L. 2018. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science Advances, 4(5): 1–7, eaar3001. https://doi.org/10.1126/sciadv. aar3001

Herbst, D. F., Gerhardinger, L. C., Vila-Nova, D. A., Carvalho, F. G. & Hanazaki, N. 2020. Integrated and deliberative multidimensional assessment of a subtropical coastal-marine ecosystem (Babitonga bay, Brazil). Ocean & Coastal Management, 196: 105279. https://doi.org/10.1016/j.ocecoaman.2020.105279

Holz, A. C. 2014. Caracterização do ambiente acústico subaquático e uso de habitat pela toninha, *Pontoporia blainvillei*, na Baía da Babitonga, litoral norte de Santa Catarina, Brasil. (Master Thesis), Universidade da Região de Joinville – UNIVILLE, Joinville. 76p.

Hoyt, E. 2012. Marine protected areas for whales dolphins and porpoises: A world handbook for cetacean habitat conservation. London: Routledge.

IBAMA – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, 1998. Proteção e controle de ecossistemas costeiros: manguezal da Baía da Babitonga. Coleção Meio Ambiente: Série Estudos – Pesca. Brasília: Edições IBAMA, 146p.

Jaramillo-Legorreta, A., Cardenas-Hinojosa, G., Nieto-Garcia, E., Rojas-Bracho, L., Ver Hoef, J., Moore, J., Tregenza, N., Barlow, J., Gerrodette, T., Thomas, L. & Taylor, B. 2016. Passive acoustic monitoring of the decline of Mexico's critically endangered vaquita. Conservation Biology, 31: 183-191. https://doi.org/10.1111/cobi.12789

Jaramillo-Legorreta, A. M., Cardenas-Hinojosa, G., Nieto-Garcia, E., Rojas-Bracho, L., Thomas, L., Ver Hoef, J. M., Moore, J., Taylor, B., Barlow, J. & Tregenza, N. 2019. Decline towards extinction of Mexico's vaquita porpoise (*Phocoena sinus*Royal Society Open Science, 6(7): 190598. https://doi.org/10.1098/rsos.190598

889 Jefferson, T. A., Hung, S. K., & Wursig, B. 2009. Protecting small cetaceans from
890 coastal development: Impact assessment and mitigation experience in Hong Kong.
891 Marine Policy, 33: 305–311.

892 Krivoruchko, K. 2012. "Empirical Bayesian Kriging". ArcUser Fall.

893 Leeney, R. H., Carslake, D. & Elwen. S. H. 2011. Using Static Acoustic Monitoring to
894 Describe Echolocation Behaviour of Heaviside's Dolphins (*Cephalorhynchus*
895 *heavisidii*) in Namibia. Aquatic Mammals, 37(2): 151-160.
896 https://doi.org/10.1578/AM.37.2.2011.151

897 Lin, T., Chou, L. & Akamatsu, T. 2013. Tidal influences on the habitat use of Indo-
898 Pacific humpback dolphins in an estuary. Marine Biology, 160: 1353-1363.
899 http://dx.doi.org/10.1007/s00227-013-2187-7

900 Madsen, P., Carder, D., Beedholm, K. & Ridgway, S. 2005. Porpoise clicks from a
901 sperm whale nose - convergent evolution of 130 kHz pulses in toothed whale sonars?.
902 Bioacoustic, 15: 195–206.

903 Melcón, M. L., Failla, M., & Iñiguez, M. A. 2012. Echolocation behavior of Franciscana
904 dolphins (*Pontoporia blainvillei*) in the wild. The Journal of the Acoustical Society of
905 America, 131, 448-453. https://doi.org/10.1121/1.4710837

906 Mellinger, D. K., Stafford, K. M., Moore, S. E., Dziak, R. P. & Matsumoto, H. 2007. An
907 Overview of Fixed Passive Acoustic Observation Methods for Cetaceans.
908 Oceanography, 20(4): 36-45.

909 Méndez-Fernandez P., Pierce. G. J., Bustamante, P., Chouvelon, T. Ferreira, M.,
910 González, A. F., López, A, Read, F. L., Santos, M. B., Spitz, J, Vingada, J. V. &
911 Caurant, F. 2013. Ecological niche segregation among five toothed whale species off
912 the NW Iberian Peninsula using ecological tracers as multi-approach. Marine Biology,
913 160: 2825–2840.

914 MMA – Ministério do Meio Ambiente, 2014. Lista Oficial de Espécies Brasileiras
915 Ameaçadas de Extinção. Ministério do Meio Ambiente (Official List of Brazilian Species
916 Threatened by Extinction. Ministry of the Environment.). MMA / SBF. Brasília.

917 New, L. F., Harwood, J., Thomas, L., Donovan, C., Clark, J. S., Hastie, G., Thompson,
918 P.M., Cheney, B., Scott-Hayward, L. & Lusseau, D. 2013. Modeling the biological
919 significance of behavioral change in coastal bottlenose dolphins in response to
920 disturbance. Functional Ecology, 27: 314–322.

921 Nara, L., Cremer, M. J., Farro, A. P. C., Castaldo Colosio, A. C., Barbosa, L. A.,
922 Bertozzi, C. P., Secchi, E. R., Pagliani, B., Costa-Urrutia, P., Gariboldi, M. C., Lazoski,
923 C. & Cunha, H. A. 2022. Phylogeography of the Endangered Franciscana Dolphin:
924 Timing and Geological Setting of the Evolution of Populations. Journal of Mammalian
925 Evolution, 29: 609–625. https://doi.org/10.1007/s10914-022-09607-7

926 Nichol, L. M., Hall, A. M., Ellis, G. M., Stredulinsky, E., Boogaards, M. & Ford, J. K. B.
927 2013. Dietary overlap and niche partitioning of sympatric harbour porpoises and Dall's
928 porpoises in the Salish Sea. Progress in Oceanography, 115: 202–210.

929 Oliveira, T. M. N., Tureck, C. R., Bassfeld, J., Faria, J., Brasil, K. & Torrens, B. M. O.
930 2006. Integridade Ambiental da Baía da Babitonga: Características Físico-químicas,
931 Microbiológicas e Ecotoxicidade [Babitonga Bay Environmental Integrity: Physico-
932 chemical, Microbiological and Ecotoxicity Characteristics]. In: M. J. Cremer, P. R. D.
933 Morales, & T. M. N. Oliveira (eds.), Diagnóstico Ambiental da Baía da Babitonga,
934 (UNIVILLE, Joinville, Brazil), p. 20-80.

935 Oliver, M. A. & Webster, R. 1990. Kriging: a method of interpolation for geographical
936 information systems. International Journal of Geographical Information Systems, 4(3):
937 313-332. https://doi.org/10.1080/02693799008941549

938 Paitach, R. L. 2015. Feeding and spatial ecology of franciscanas (*Pontoporia*
939 *blainvillei*) and Guyana dolphins (*Sotalia guianensis*) in Babitonga Bay, Southern
940 Brazil. (Master Thesis), Universidade Federal de Santa Catarina. Florianópolis, 142p.

941 Paitach, R. L., Simões-Lopes, P. C. A. & Cremer, M. J. 2017. Tidal and seasonal
942 influences in dolphin habitat use in a southern Brazilian estuary. Scientia Marina, 81(1):
943 49-56.

944 Paitach, R. L.; Alves, A. K. M.; Schulze, B; & Cremer, M. J. 2019. Scientometrics of
945 aquatic mammals of the Babitonga Ecosystem: conservation subsidies. Revista
946 CEPSUL - Biodiversidade e Conservação Marinha, 8: eb20190014

947 Paitach, R. L.; Amundin, M., Teixeira, G. & Cremer, M. J. 2021. Echolocation variability
948 of franciscana dolphins (*Pontoporia blainvillei*) between estuarine and open-sea
949 habitats, with insights into foraging patterns. The Journal of the Acoustical Society of
950 America 150, 3987-3998 (2021) https://doi.org/10.1121/10.0007277

951 Parra, G. J. 2006. Resource partitioning in sympatric delphinids: space use and habitat
952 preferences of Australian snubfin and Indo-Pacific humpback dolphins. Journal of
953 Animal Ecology, 75: 862-874. https://doi.org/10.1111/j.1365-2656.2006.01104.x

954 Pierpoint, C. 2008. Harbour porpoise (*Phocoena phocoena*) foraging strategy at a high
955 energy, near-shore site in south-west Wales, UK. Journal of the Marine Biological
956 Association of the United Kingdom, 88: 1167–1173.

957 Pinheiro, L. & Cremer, M. J. 2003. Etnoecologia e captura acidental de golfinhos
958 (Cetacea: Pontoporiidae e Delphinidae) na Baia da Babitonga, Santa Catarina.
959 Desenvolvimento e Meio Ambiente (UFPR), 8: 69-76.

960 Pirotta, E., Thompson, P. M., Miller, P. I., Brookes, K. L., Cheney, B., Barton, T. R.,
961 Graham, I. M. & Lusseau, D. 2014. Scale-dependent foraging ecology of a marine top
962 predator modelled using passive acoustic data. Functional Ecology, 28: 206-217.
963 https://doi.org/10.1111/1365-2435.12146

964 R Core Team. 2020. R: A language and environment for statistical computing. R
965 Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

966 Rayment, W., Dawson, S. & Slooten, L. 2009. Use of T-PODs for acoustic monitoring
967 of *Cephalorhynchus dolphins*: a case study with Hector's dolphins in a marine

protected area. Endangered Species Research, 10: 333-339. https://doi.org/10.3354/esr00189

Rayment, W., Dawson, S., Scali, S. & Slooten, L. 2011 Listening for a needle in a haystack: passive acoustic detection of dolphins at very low densities. Endangered Species Research, 14: 149−156.

Richardson, W. J., Greene Jr, C. R., Malme, C. I. & Thomson, D. H., 1995. Marine mammals and noise. London: Academic Press.

Roberts, B. & Read A. J. 2014. Field assessment of C-POD performance in detecting echolocation click trains of bottlenose dolphins (*Tursiops truncatus*). Marine Mammal Science, 31: 169-190. https://doi.org/10.1111/mms.12146

Ross, P. S., Barlow, J., Jefferson, T. A., Hickie, B. E., Lee, T., MacFarquhar, C., Parsons, C. E., Riehl, K., Rose, N., Slooten, E., Tsai, C., Wang, J., Wright, A. & Yang, S. C. 2011. Ten guiding principles for the delineation of priority habitat for endangered small cetaceans. Marine Policy, 35: 483–488.

Santos, M. C. D. O., Figueiredo, G. C., & Van-Bressem, M. F. 2017. Cetaceans using the marine protected area of "Parque Estadual Marinho da Laje de Santos", Southeastern Brazil. Brazilian Journal of Oceanography, 65: 605–613.

Santos, M. C. D. O., Oshima, J. E. F. & Silva, E. 2009. Sightings of franciscana dolphins (*Pontoporia blainvillei*): the discovery of a population in the Paranaguá estuarine complex, southern Brazil. Brazilian Journal of Oceanography, 57(1): 57-63.

Sartori, C. M., Paitach, R. L. & Cremer, M. J. 2017. Photo-identification of franciscanas (*Pontoporia blainvillei*) in Babitonga Bay, Santa Catarina state, Brazil. The Journal of Cetacean Research and Management, 16: 49-55.

Sucunza, F., Danilewicz, D., Andriolo, A., Azevedo, A. F., Secchi, E. R. & Zerbini, A. N. 2019. Distribution, habitat use, and abundance of the endangered franciscana in southeastern and Southern Brazil. Marine Mammal Science, 1-15.

Tardin, R. H., Maciel, I. S., Espécie, M. A., Melo-Santos, G., Simão, S. M., Alves, M. A. S. 2020. Modelling habitat use by the Guiana dolphin, *Sotalia guianensis*, in south-eastern Brazil: Effects of environmental and anthropogenic variables, and the adequacy of current management measures. Aquatic Conservation: Marine and Freshwater Ecosystems, 30: 775– 786. https://doi.org/10.1002/aqc.3290

Tellechea, J. S., Ferreira, M., & Norbis, W. 2017. Echolocation and burst clicks from franciscana dolphins (*Pontoporia blainvillei*) on the coast of Uruguay. Marine Mammal Science, 33(2), 687–694. https://doi.org/10.1111/mms.12383

Trites, A. W. 2009. Predator-prey relationships. In B. Wursig & W. F. Perrin (ed.), Encyclopedia of Marine Mammals. Academic Press, San Diego. Pp. 933-936.

Tubbs, S. E., Keen, E., Jones, A. L. & Thap, R. 2020. On the Distribution, Behaviour and Seasonal Variation of Irrawaddy Dolphins (*Orcaella brevirostris*) in the Kep

Archipelago, Cambodia. Raffles Bulletin of Zoology, 68: 137–149. https://doi.org/10.26107/RBZ-2020-0015

Tyack, P. & Clark, C. 2000. Communication and acoustic behavior of dolphins and whales In: Au, W., Popper, A. N. & Fay, R. R. (eds), Hearing by Whales and Dolphins. New York: Springer-Verlag. 156–224.

Van Parijs, S. M., Clark, C. W., Sousa-Lima, R. S., Parks, S. E., Rankin, S., Risch, D. & Van Opzeeland, I. C. 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Marine Ecology Progress Series, 395: 21–36.

Verfuss, U. K., Miller, L. A. & Schnitzler, H. U. 2005. Spatial orientation in echolocating harbour porpoises (*Phocoena phocoena*). Journal of Experimental Biology, 208(Pt 17): 3385–3394. https://doi.org/10.1242/jeb.01786

Verfuss, U. K., Honnef, C. G., Meding, A., Dähne, M., Mundry, R., & Benke, H. 2007. Geographical and seasonal variation of harbour porpoise (*Phocoena Phocoena*) presence in the German Baltic Sea revealed by passive acoustic monitoring. Journal of the Marine Biological Association of the United Kingdom, 87: 165-176. https://doi.org/10.1017/S0025315407054938

Verfuss, U. K., Miller, L. A., Pilz, P. K. & Schnitzler, H. U. 2009. Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). Journal of Experimental Biology, 212, 823–834.

Vieira, C. V., Horn Filho, N. O., Bonetti Filho, J. & Bonetti, C. 2008. Caracterização morfosedimentar e setorização do Complexo Estuarino da Baía da Babitonga/SC. Boletim Paranaense de Geociências, 62-63: 85-105. http://dx.doi.org/10.5380/geo.v62i0

Wedekin, L. L., Daura-Jorge, F. G., & Simões-Lopes, P. C. 2010. Habitat preferences of guiana dolphins, *Sotalia guianensis* (Cetacea: Delphinidae), in Norte bay, southern Brazil. Journal of the Marine Biological Association of the United Kingdom, 90: 1561–1570. https://doi.org/10. 1017/S0025315410001414

Wells, R. S., Bordino, P. & Douglas, D. C. 2013. Patterns of social association in the franciscana, *Pontoporia blainvillei*. Marine Mammal Science, 29: E520-E528. https://doi.org/10.1111/mms.12010

Wells, R. S., Cremer, M. J., Berninsone, L. G., Albareda, D., Wilkinson, K. A. Stamper, M. A., Paitach, R. L. & Bordino, P. (2021). Tagging, ranging patterns and behavior of franciscana dolphins (*Pontoporia blainvillei*) off Argentina and Brazil: Considerations for conservation. Mar. Mamm. Sci., 1-35.

Williamson, L., Brookes, K. L., Scott, B. E., Graham, I. M. & Thompson, P. M. 2017. Diurnal variation in harbour porpoise detection – potential implications for management. Marine Ecology Progress Series, 570: 223–232.

Wisniewska, D. M., Johnson, M., Teilmann, J., Rojano-Doñate, L., Shearer, J., Sveegaard, S., Miller, L. A., Siebert, U. & Madsen, P. T. 2016. Ultra-high foraging rates

of Harbor porpoises make them vulnerable to anthropogenic disturbance. Current Biology, 26: 1441-1446. https://doi.org/doi:10.1016/j.cub.2016.03.069

Wood, S. N. 2017. Generalized Additive Models: An Introduction with R (2nd ed.). CRC Press. https://doi.org/10.1201/9781315370279

Zappes, C., Gama, R., Domit, C., Gatts, C., & Di Beneditto, A. 2018. Artisanal fishing and the franciscana (*Pontoporia blainvillei*) in Southern Brazil: Ethnoecology from the fishing practice. Journal of the Marine Biological Association of the United Kingdom, 98(4): 867-877. https://doi.org/10.1017/S0025315416001788

Zerbini, A. N., Secchi, E., Crespo, E., Danilewicz, D. & Reeves, R. 2017. *Pontoporia blainvillei* (errata version published in 2018). The IUCN Red List of Threatened Species 2017: e.T17978A123792204. http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T17978A50371075.en

Ziegler, A. 2011. Generalized Estimating Equations. Springer. ISBN 978-1-4614-0498-9.

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 *Sotalia guianensis* 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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Table 2. Parametric coefficients for factor variables and smooth terms included in the final model of habitat use of franciscana dolphins in Babitonga Bay (AIC = 71430.59, Deviance explained = 51%). edf = effective degrees of freedom, DPM: detection positive minutes, 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.
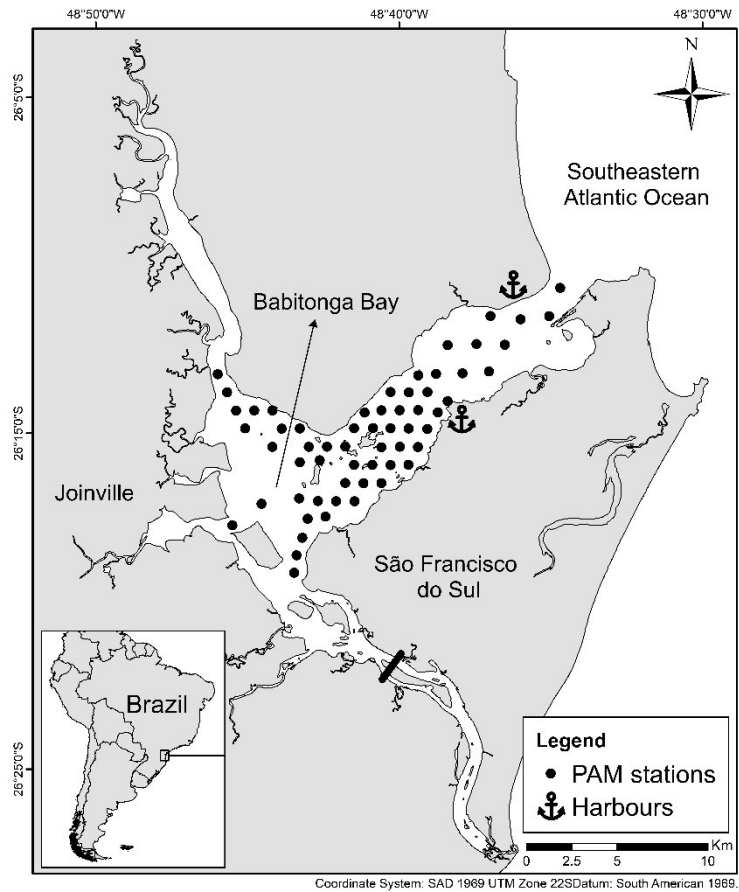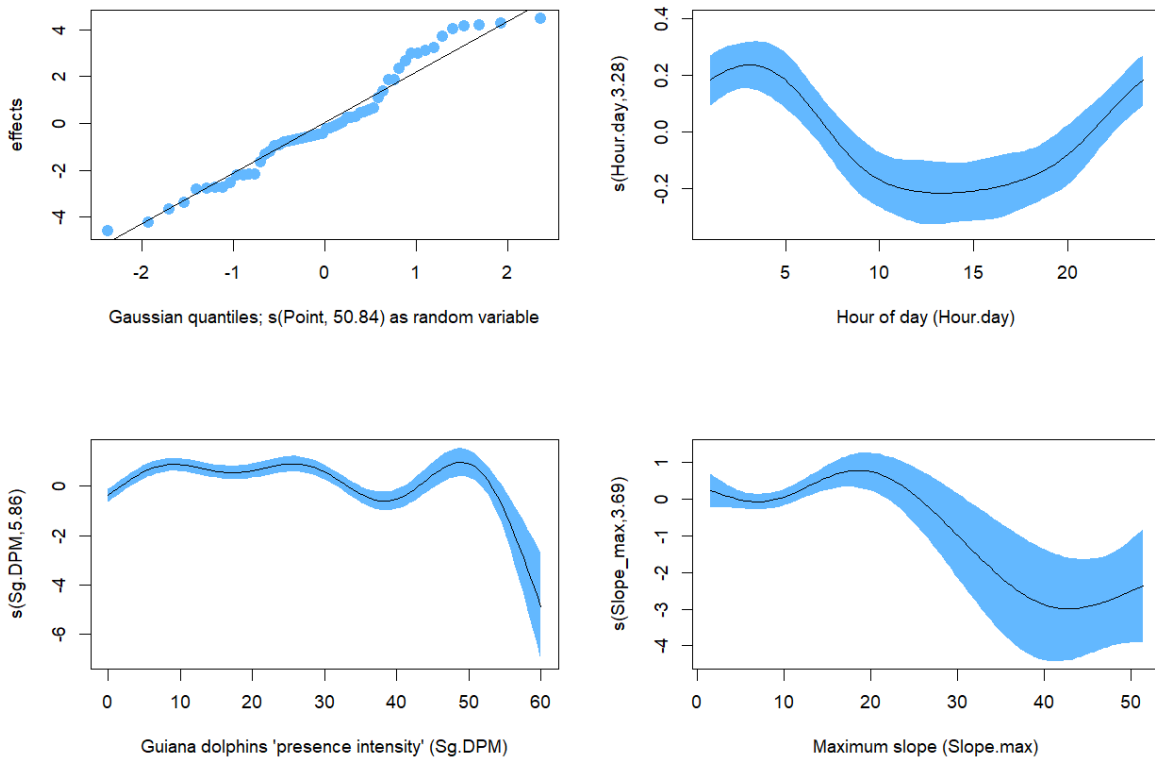
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1070   Figure 1. Distribution of sixty passive acoustic monitoring (PAM) stations deployed in

1071   Babitonga Bay, southern Brazil, for recording franciscana dolphins. A think black segment

1072   indicates the location where the historical south channel was grounded in 1937 for the

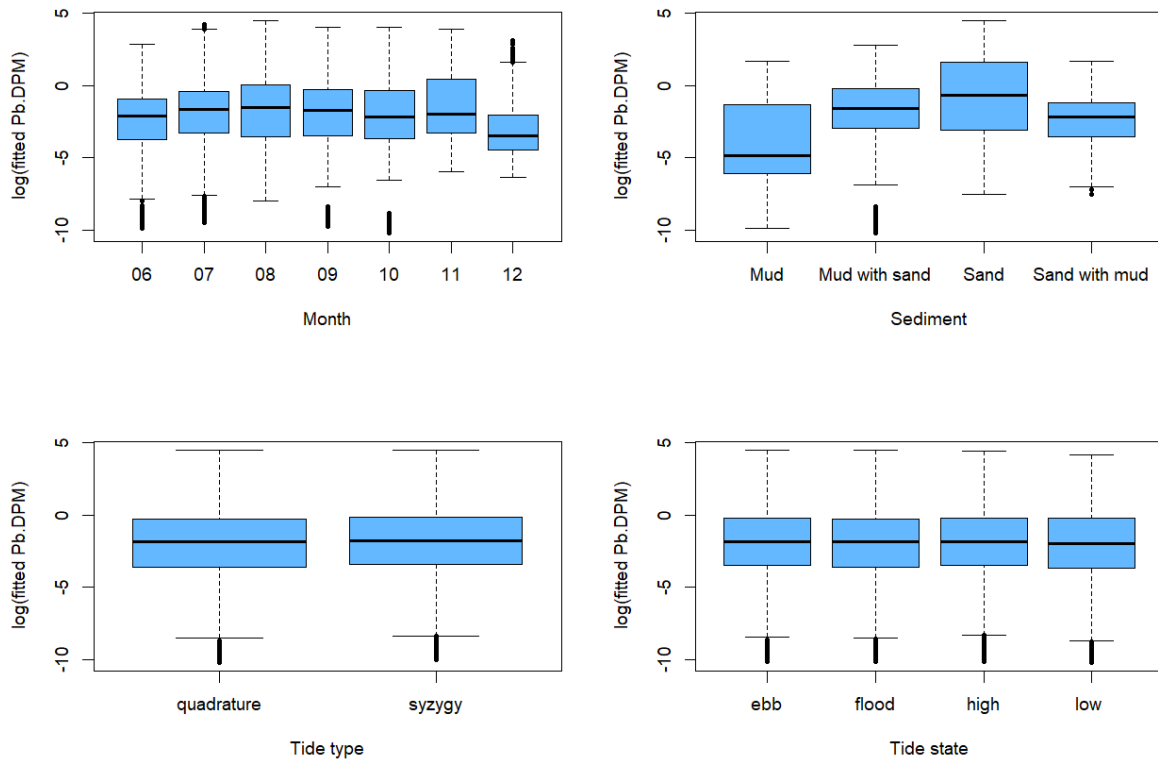1073   construction of an access road to the São Francisco do Sul Island.

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Figure 2. Smooth functions for variables hour of day, Guiana dolphin presence intensity and slope, included in the final model for habitat use of franciscana dolphins in Babitonga Bay. Degrees of freedom are shown inside parentheses.
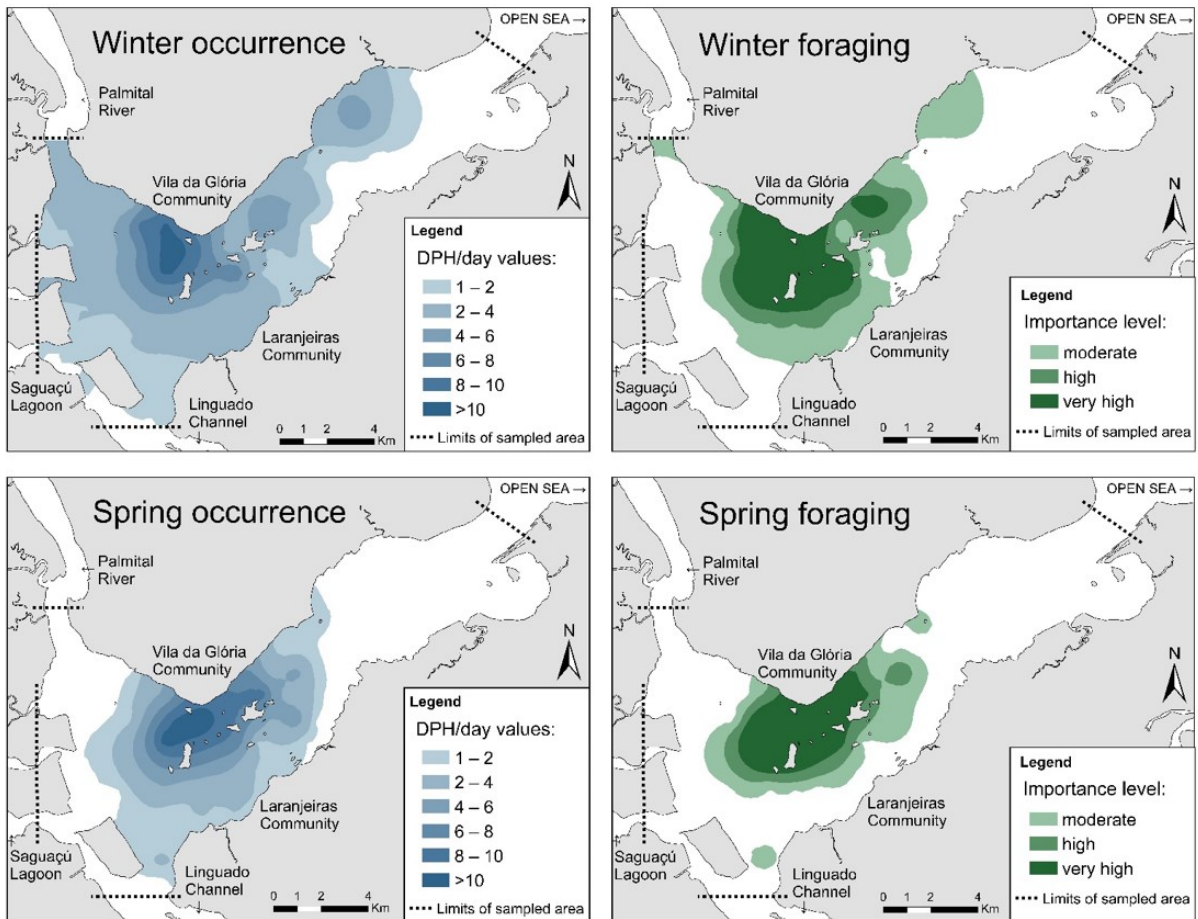
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Figure 3: Boxplots for fitted values for different levels of the factor variables months, sediment, tide type and tide state, included in the final model for habitat use of franciscana dolphins in Babitonga Bay.
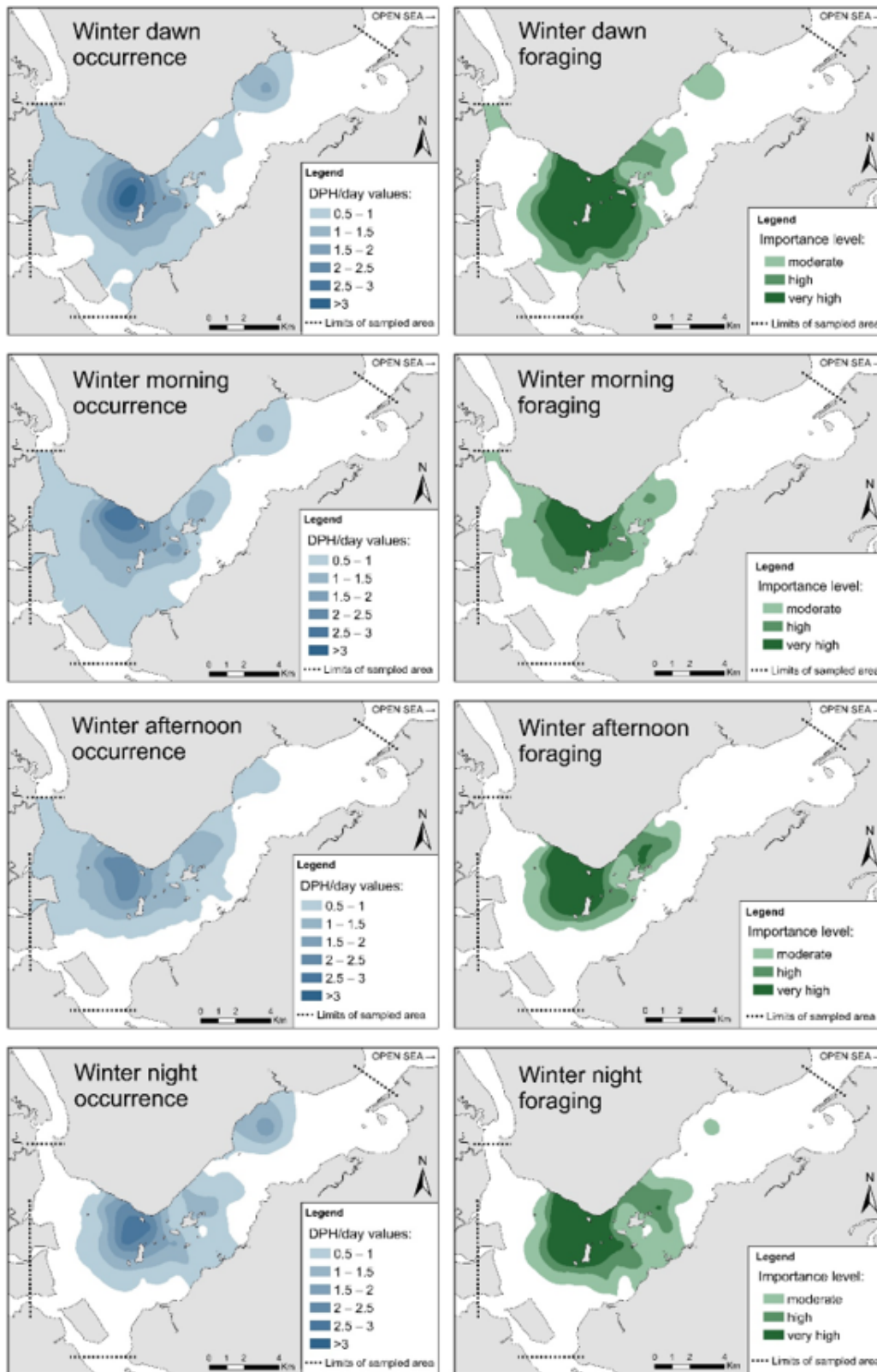
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1086   Figure 4: Occurrence of franciscana dolphins in Babitonga Bay (DPH/day = detection positive

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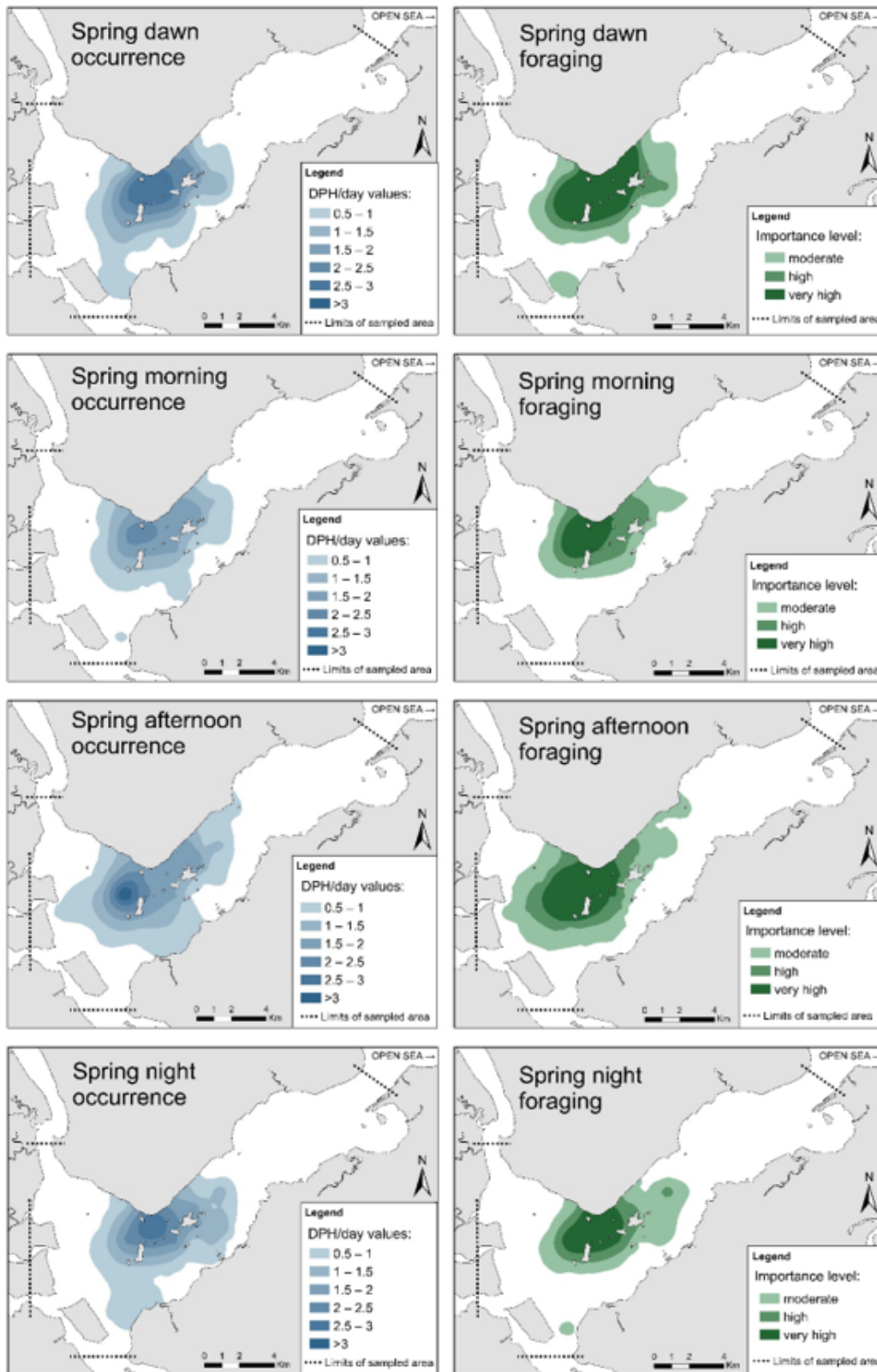Figure 5: Occurrence of franciscana dolphins in Babitonga Bay (DPH/day = detection positive

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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Figure 6: Occurrence of franciscana dolphins in Babitonga Bay (DPH/day = detection positive

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).