

1 **Effects of vessel traffic on relative abundance and behaviour of cetaceans: the case of the**
2 **bottlenose dolphins in the Archipelago de La Maddalena, north-western Mediterranean sea.**

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19 **Abstract**

20 Many studies have shown that vessel traffic has both long and short term negative effects on marine
21 mammals. Although there has been a great expansion of recreational vessel traffic in the
22 Mediterranean Sea in recent decades, few studies focused on this problem. Here, Bayesian models
23 were used to explore the influence of vessel traffic on behaviour and relative abundance patterns of
24 bottlenose dolphin in the Archipelago de La Maddalena (Italy), a coastal area included within the
25 Pelagos Sanctuary. Results showed that season, moon phase and presence of calves had an effect on
26 the number of adult dolphins per sighting, and that there were differences in occurrence in the sub-
27 areas. On the contrary, the number of vessels was negatively related to the number of adult dolphins
28 and their mean dive intervals (MDI). In particular, when more than three recreational boats were
29 present in the area, dolphins surfaced more frequently per unit time and behaviours such as feeding
30 and socializing were not detected. On the contrary, longer mean dive were found when fishing boats
31 were present. Our results provide additional support for the need to consider disturbance such as
32 vessel traffic in management plans for cetacean conservation.

33

34 **Keywords:** Bayesian models; conservation; disturbance; Pelagos Cetacean Sanctuary; surfacing
35 rate; *Tursiops truncatus*.

36

37 **Introduction**

38 Nowadays cetacean populations are facing several threats including depletion of resources
39 (Stefánsson, 1997), interactions with commercial fisheries (Gilman et al. 2007), degradation of
40 habitat (Simmonds & Nunny, 2002), diseases produced by pollution (Wafo et al. 2005), and
41 physical and acoustic disturbance (Roussel, 2002) caused particularly by increased boating and
42 shipping traffic.

43 Particularly, the bottlenose dolphin (*Tursiops truncatus*) is exposed to a wide variety of
44 these threats, due to its occurrence in coastal waters. Its coastal ecotype is present in the
45 ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea
46 and contiguous Atlantic area) region (Notabartolo di Sciara, 2002). This species is protected by the
47 EU Habitats Directive 92/43/EEC and it has recently been classified as vulnerable (VU A2cde) in
48 Mediterranean waters (Bearzi et al. 2012).

49 Effects of vessel traffic on animals can be described by considering short-term responses
50 and also their long-term ramifications. In particular, short-term responses are indicated by changes
51 in respiration patterns, surface active behaviours, swimming velocity, inter-individual spacing,
52 approach and avoidance, and displacement from the area of interaction (Nowacek & Wells, 2001;
53 Lusseau, 2003; Buckstuf, 2004; Pirota et al. 2015a; Campana et al. 2015). These responses have
54 been suggested as being related to noise (Bejder et al. 1999) or a reaction to physical presence, or a
55 combination of both (David, 2002).

56 Although there has been a great expansion of recreational vessel traffic and shipping in the
57 Mediterranean in recent decades (Dobler, 2002), only three studies have focused on behavioural
58 changes related to boat traffic in this area (David, 2002). Underhill (2006), Papale et al. (2001) and
59 Rako et al. (2013) all reported modifications in the diving pattern of bottlenose dolphins, in
60 Sardinian, Sicilian and Adriatic waters, respectively.

61 In the waters of Northern Sardinia, located in the Pelagos Cetacean Sanctuary, the

62 bottlenose dolphin is one of the most common cetacean species (Notabartolo di Sciara, 2002). In
63 particular, in the Archipelago de La Maddalena, Pennino et al. (2013) photo-identified 71
64 individuals, and defined 22 as resident (individuals sighted in all seasons during that one year and at
65 least five times).

66 In this area, tourism is the main industry, with around 150,000 visitors each year and with
67 traffic of about 5,000 leisure boats. Moreover, in the summer months (from June to September) boat
68 traffic increases, prompting displacement of the resident animals to other areas (Pennino et al.
69 2015).

70 To interpret and mitigate potential impacts of vessel traffic on the local population of
71 bottlenose dolphins, it is essential to assess short-term responses in terms of changes in the
72 distribution and behaviours.

73 In this context, the primary goal of our study was to evaluate whether the interaction of
74 vessel traffic with dolphins in the Archipelago de La Maddalena has an effect on the relative
75 abundance of the local dolphin population. In order to do so we modelled the number of adult
76 individuals sighted with respect to number and type of vessels, environmental, spatial and temporal
77 covariates, using Bayesian methods.

78 Our secondary goal was to describe whether and how dolphin behaviour varied with the
79 presence of vessel traffic. Firstly, we tested the impact of different levels of vessel traffic on the
80 variation in dolphin behaviour, using an analysis of similarity (ANOSIM). This technique was
81 implemented to identify differences in behaviour categories by combining permutation tests with
82 the general Monte Carlo randomization approach. Secondly, Bayesian models were used to assess
83 whether variation in the intersurfacing interval of dolphins were related to habitat features, vessel
84 traffic or a combination of both effects.

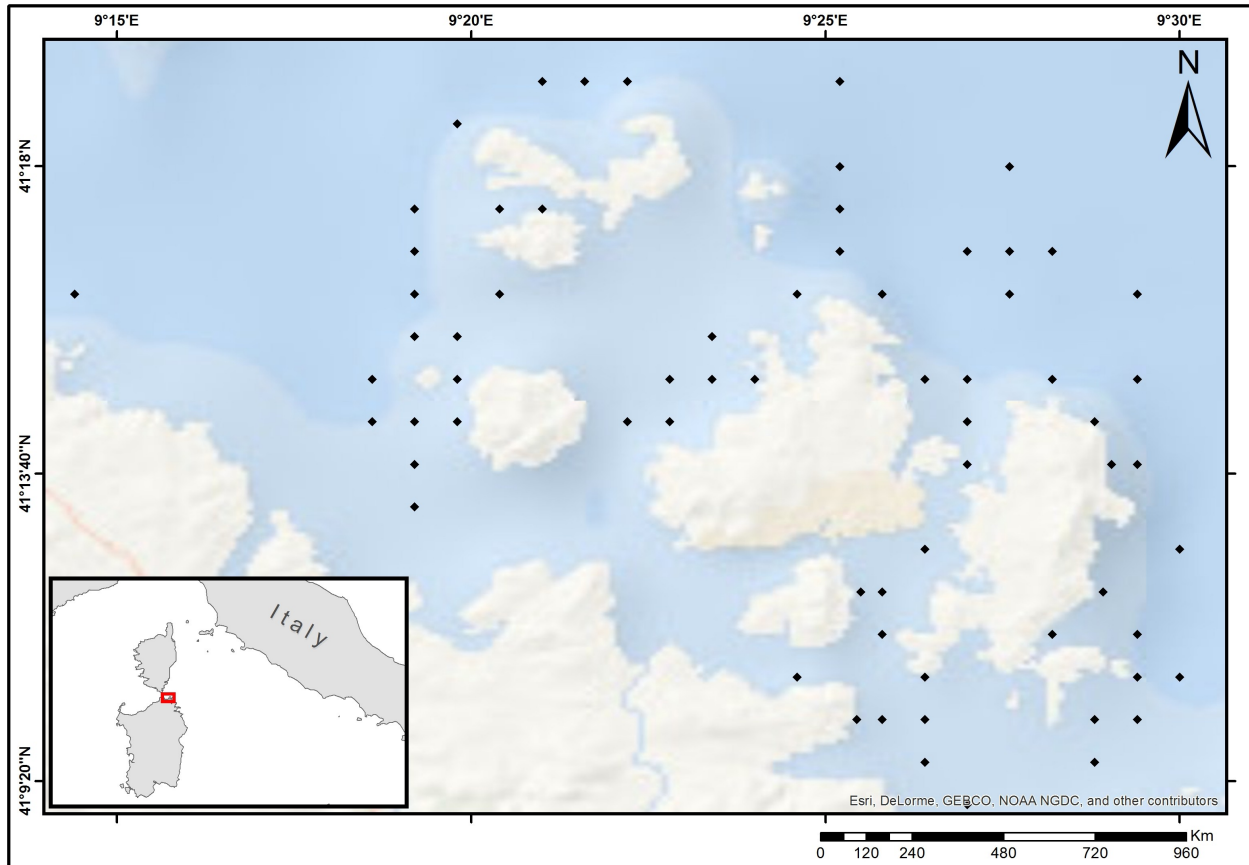
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87 **Materials and methods**

88 **Study area**

89 This study was carried out in waters within 3 miles of the coast of Archipelago de La
90 Maddalena (41° 13' 0" N, 9° 24' 0" E) (*Figure 1*).



91 *Figure 1*: Map of the study area, the Archipelago de La Maddalena, Sardinia (Italy) with bottlenose
92 dolphin sightings.
93

94 The entire area is included within a National Park located in the strait of Bonifacio, between the
95 islands of Sardinia and Corsica, and is part of the Pelagos Cetacean Sanctuary established by Italy,
96 France and Monaco in 1999. The Sanctuary is a vast marine protected area extending over 90,000
97 km² of sea surface in a portion of the north-western Mediterranean Sea comprised between south-
98 eastern France, Monaco, north-western Italy and northern Sardinia, and encompassing Corsica and
99 the Tuscan Archipelago (Notarbartolo di Sciara et al. 2008).

100 The Maddalena area is characterized by rocky and sandy bottoms extensively covered with

101 *Posidonia* (*Posidonia oceanica*) sea-grass beds, with water depth ranging from 0 to 70 m. The
102 location of the Archipelago inside the "Bocche of Bonifacio" causes a high level of hydrodynamism
103 that, associated with the shallow depth of the channel and limited tidal range, is responsible for the
104 very clean water which characterizes the area (Pennino et al. 2013).

105 Only 18 fishing boats are authorized to practice artisanal fishing activities within the
106 National Park. In accordance with park regulations, fishing is permitted throughout the year, except
107 for a closure during 45 days every winter. Most fishing uses bottom-set fishing gear, such as
108 trammel nets, whilst other gear, such as traps, is sporadically used. The net mesh size is chosen
109 based on the main target species and on the season (Pennino et al. 2015).

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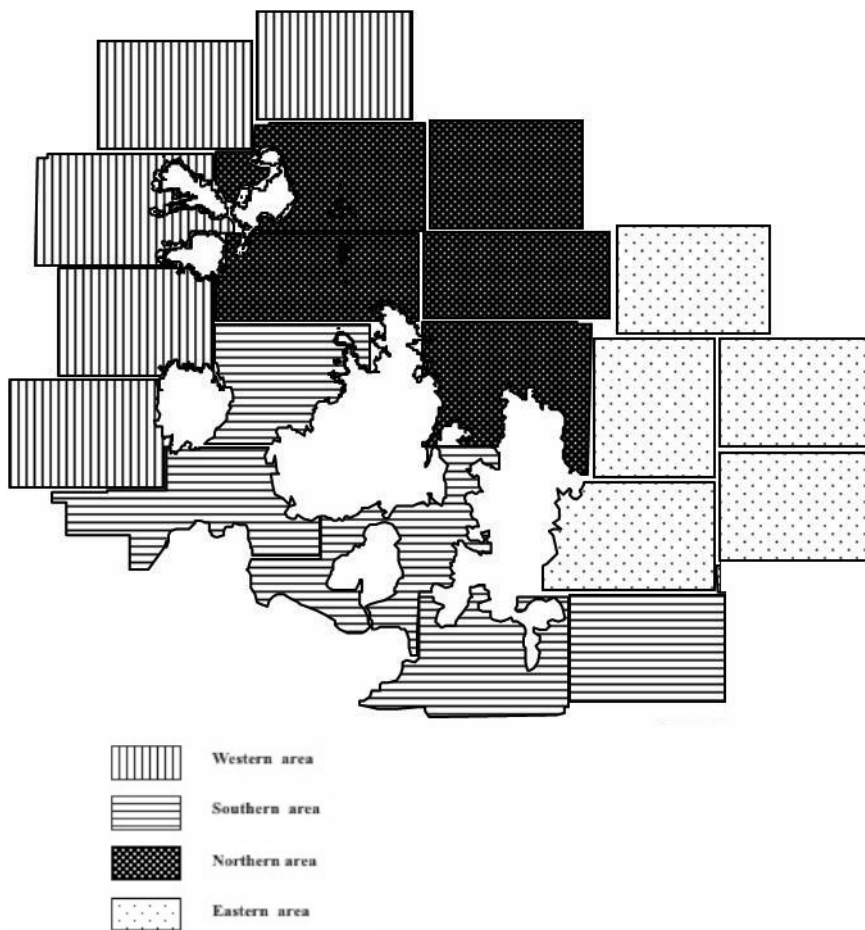
111 **Sampling methods**

112 The study area was divided into four sub-areas of equal dimension (northern, western,
113 southern, and eastern, see *Figure 2*) and each was monitored following systematic transects in a
114 boat travelling at a speed of 8 to 10 kts. Surveys of five hours duration were performed always at set
115 times, namely in the morning (6:00-10:00) and afternoon (16:00-20:00), on a 5.5 m Zodiac
116 inflatable boat. In addition, to ensure that all behaviours were visible across the study area, surveys
117 were only performed when the sea state was less than Douglas sea force 3 and in clear weather
118 conditions with no precipitation.

119 Data collected included sighting date, location (the monitored sub-area), depth and type of
120 seabed, number and type of vessels (sailing, fishing, recreational and ferry boats) present, dolphin
121 school size, and dolphin behaviour. During monitoring, data on environmental variables and boat
122 presence were collected every 15 minutes. Two expert observers conducted visual surveys
123 concurrently on the same boat but on opposite sides. Data were included in the database only when
124 there was an agreement between the two concurrent observers. Specifically, if the number of sighted
125 dolphins was substantially different (i.e. more than 2 dolphins) the sighting was not included in the

126 database, while in cases in which the difference was small (i.e. just 1 dolphin) the lower number of
127 dolphins was included in the database. Similarly, if any difference was recorded in the behaviour,
128 the dive time of the focal animal was used to confirm the selection of the behaviour category.

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146 *Figure 2: Map of the study area divided into four sub-areas of equal dimension (northern, western,*
147 *southern, and eastern).*

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150 A school was defined as a group of bottlenose dolphins sighted within an approximate 100 m radius
151 (Wells et al. 1987). Individuals were identified as belonging to three arbitrary age classes based on
152 visual assessment using the average adult size: (1) adult (a bottlenose dolphin approximately 3 to
153 4.5 m long), (2) juvenile (about two thirds of an adult), and (3) calf (newborn with evident fetal
154 folds or individual about one-half the size of an adult in constant association with a single adult –

155 presumably its mother) (Bearzi et al. 1997). Behavioural data were collected using the predominant
156 group activity sampling method (Mann, 1999), with the group activity being scored every 5
157 minutes. To standardize data collection, behavioural activity was sampled for at least 45 minutes
158 unless contact with the group was lost before that time.

159 The behaviour of dolphins was classified in the field into one of four exclusionary
160 categories, according to Mann & Smuts (1999), and Chilvers & Corkeron (2001):

161 1. *Foraging* – Rapid surfaces, frequent direction changes, fast swimming, chasing fish, and
162 observed fish catches.

163 2. *Socializing* – Physical contact, splashing, chases, pokes, and play, with little consistent
164 directional progress.

165 3. *Travelling* – Swimming in a constant direction with regular surfacing intervals.

166 4. *Surface activities* – Acceleration on the sea surface, breaching and tail slap.

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168 In addition, the dive time (mean time between breaths) of a focal animal was recorded
169 during each survey. The selection of the focal animal was carefully conducted each time to ensure
170 reliability of re-sighting the individual within a survey session. We chose focal animals that would
171 not be confused easily with other members of the group and that were therefore likely to be
172 consistently re-sighted. A focal animal typically had a distinctive dorsal fin and saddle patch (Ford
173 et al. 1994). Animals were followed for a minimum of 15 minutes, because earlier work has shown
174 that shorter surveys tend to bias estimates of respiration rate (Kriete, 1995).

175 In order to avoid harassment of bottlenose dolphins, we observed them from a safe and
176 respectful distance, avoiding approaching them closer than 10 m. If bottlenose dolphins approached
177 the boat, we maintained its course, avoiding abrupt changes in direction or speed to prevent running
178 over or injuring the animals.

179

180 **Statistical analysis**

181 A total of nine potential fixed-effects have been considered to explain the relative
182 abundance of bottlenose dolphins and these are listed in *Table 1*.

183 Except for the variables “depth” and “number of vessels”, which are continuous, the other
184 explanatory variables are all categorical: season, sub-area, time of day (morning, afternoon), moon
185 phase, type of seabed, type of vessel (sailing, fishing, recreational and ferry boats) and presence of
186 calves (*Table 1*).

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188 **Table 1.** Summary of variables included in Bayesian models as potential fixed-effects influencing
189 the relative abundance of bottlenose dolphin (*Tursiops truncatus*) excluding calves.

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Variable	Description	Units
Season	Season when the sighting was performed	Winter, spring, summer, autumn
Location	Sub-area where the sighting was performed	Northern, western, southern, eastern
Time	Time when the sighting was performed	Sunrise, morning, afternoon, sunset
Presence of calves	Occurrence of calves during the sighting	Yes/no
Number of vessels	Number of vessels sighted during the sighting	1, 2, 3, 4, 5, 6, 7
Type of vessel	Typology of the vessel sighted	Sailing, fishing, recreational, ferry boats
Moon phase	Moon phase of the sighting day	crescent, full moon, waning, new moon
Type of seabed	Seabed substrate at the survey location	Sand, mud, rock, gravel
Depth	Mean depth of the sighting location	In metres

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192 Collinearity between explanatory variables was checked using a draftsman's plot and the
193 Pearson correlation index. Variables were not highly correlated ($r < 0.6$), and thus all have been
194 considered in further analyses.

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196 ***Modelling relative abundance of dolphins***

197 The variation of the relative abundance of dolphins was modeled by a hierarchical
198 Bayesian approach, specifically a Poisson model with log-linear intensity. We used a Bayesian
199 approach, as it allows both the observed data and model parameters to be considered as random
200 variables, resulting in a more realistic and accurate estimation of uncertainty (Banerjee et al. 2004).

201 Specifically, the expected number of adult dolphins in each sighting (i.e., excluding calves)
202 was modelled with respect to the variables mentioned in *Table 1*. In addition, a random factor that
203 represents the observer's effect for each sighting was included as possible predictor. Indeed, the
204 remaining potential source of variation in the number of dolphins sighted could be due to the
205 observers themselves. These differences can be caused by observer's behaviour (caused by random
206 aspects, such as the personal experience) or unobserved survey characteristics. Ignoring such non-
207 independence of the data may lead to invalid statistical inference. Then, in order to remove this bias
208 a random observer effect was included.

209 Following the Bayesian reasoning, once the model has been determined, the next step is to
210 estimate its parameters, and assign to them a prior distribution. In particular, for the parameters
211 involved in the fixed effects, we use non-informative Gaussian distributions $N(0, 100)$, where 0 is
212 the mean and 100 the standard deviation.

213 All possible combinations of variables described in *Table 1* were tested using both
214 backwards and forwards approaches to select relevant variables. Specifically, we used the Deviance
215 Information Criterion (DIC), a well-known Bayesian model-choice criterion for comparing complex

216 hierarchical models (Spiegelhalter et al. 2002). DIC is inversely related to the compromise between
217 fit and parsimony.

218 Bayesian models were fitted using the integrated nested Laplace approximation (INLA)
219 methodology and software (Rue et al. 2009) implemented in R software (R Development Team,
220 2015).

221

222 ***Identifying changes in dolphin behaviour***

223 In order to assess if there are differences in the type of behaviour observed with respect to
224 the number of boats we performed an analyses of similarity (ANOSIM). Firstly, the number of
225 boats was split in three different categories: low (0-2), medium (3-5) and high (6-8). Secondly, we
226 created a matrix for each category of behaviour (foraging, socializing, traveling, surface activities)
227 standardized per hour, for each survey. Specifically, we count how many times a particular
228 behaviour was recored for each hour of a sighting, as well the number of boats. Dissimilarity
229 matrices were computed with the Morisita index (Morisita, 1959), that is commonly used for count
230 data, with the “*vegdist*” function of the “*vegan*” package (Oksanen et al. 2014) of the R software.

231 The ANOSIM technique tests for differences in behaviour frequency by combining
232 permutation tests with the general Monte Carlo randomization approach (Hope, 1968). The null
233 hypothesis (H_0) was that there are no differences in behaviour frequency between traffic boat
234 categories. To test the null hypothesis, a test statistic, R , that contrasts the variation between pre-
235 defined categories of number of boats with variation within categories, is computed. The R value is
236 compared to a predicted permutation distribution, given H_0 is true. This distribution is calculated by
237 a chosen number of random permutations of the samples; in this study we used 10,000. If H_0 is true,
238 the observed R value will fall within the range of the computed permuted distribution. The R values
239 fall between 0 and 1, such that a value close to 1 indicates high separation between levels of the

240 grouping factor, while a value close to 0 indicate no separation between levels of the grouping
241 factor. For this purpose the “anosim” function of the “vegan” package of the R software was used.

242

243 *Assessing changes in dolphin mean dive intervals*

244 Dive intervals were defined as the time elapsed between 2 surfacings of the focal animal,
245 e.g. the time between 2 breaths. One mean value for dive intervals (hereafter MDI) of the focal
246 animal was calculated for each survey. In order to assess whether dolphin MDI variability was
247 related to habitat features and/or to the vessel traffic, we modelled the MDI (μ_i) using a Bayesian
248 General Linear Model. In particular, the expected values of μ_i in each survey were related to the
249 independent variables: number of vessels, type of vessel, depth of the location, moon phase, zone,
250 season and time, according to the general formulation:

$$251 \quad \mu_i = \alpha + X\beta$$

252 where α is the intercept and β is the vector of the regression coefficients and X is the matrix of
253 covariates for each survey i .

254 Vague Gaussian distributions for the parameters involved in the fixed effects were used, in
255 order to allow empirically derived distributions. As for the other Bayesian GLMs, this model was
256 fitted using both backwards and forwards stepwise procedures and the goodness-of-fit of each
257 model was also assessed using the DIC.

258 **Results**

259 Between July 2007 and July 2009 a total of 207 surveys was performed and 93 sightings
260 were recorded (*Figure 1*). In particular, 47 out 206 surveys were conducted in the western area, 56
261 in the northern, 48 in the eastern and 55 in the southern area.

262 *Relationships between dolphin relative abundance and variables*

263 The Bayesian model of the dolphin relative abundance selected for its best fit (based on the

264 lowest DIC) includes season, moon phase, sub-area, number of vessels, type of vessels and presence
 265 of calves.

266 The observer random effect, depth, type of the seabed and time of the sighting were not retained in
 267 the final model. *Table 2* presents a numerical summary of the posterior distributions of the fixed
 268 effects for this final model.

269

270 **Table 2.** Numerical summary of the posterior distributions of the fixed effects for the best model of
 271 dolphin relative abundance. This summary contains the mean, the standard deviation and a 95%
 272 credible interval, which is a central interval containing 95% of the probability under the posterior
 273 distribution.

274

Variable	Mean	Sd	Q _{0.25}	Q _{0.95}
Intercept	1.61	1.13	1.23	2.11
Season(Summer)	-1.29	1.58	-3.22	-1.04
Season(Winter)	1.32	1.08	1.10	1.78
Season(Spring)	-1.63	1.27	-2.61	-1.02
Zone(Eastern)	-1.68	1.29	-2.82	-1.06
Zone(Northern)	-1.49	1.18	-2.09	-1.05
Zone(Western)	1.22	1.13	1.05	1.59
Moon(Full)	1.75	1.16	1.29	2.41
Moon(New)	1.09	1.29	1.01	1.36
Moon(Waning)	1.59	1.17	1.03	2.61
Number of vessel	-1.53	1.10	-1.84	-1.06
Type of vessel (Fishing)	1.40	1.13	1.06	1.75
Type of vessel (Recreational)	-1.75	1.10	-1.41	-1.10
Type of vessel (Ferry)	1.10	1.12	-1.37	1.12
Number of calves	1.59	1.12	1.25	2.03

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276

277 Results showed that winter is the season with the highest estimated dolphin relative
 278 abundance (posterior mean = 1.32; 95% CI = [1.10, 1.78]) with respect to the reference level
 279 (autumn season). Conversely, summer and spring seasons show lower estimated dolphin relative
 280 abundance than the reference level (respectively, posterior mean = -1.29; 95% CI = [-3.22, -1.04]
 281 and posterior mean = -1.63; 95% CI = [-2.61, -1.02]).

282

283 The eastern area is the zone that shows the lowest dolphin relative abundance (posterior
 mean = -1.68; 95% CI = [-2.82, -1.06]) with respect to the reference level (southern area), while the

284 western zone has the highest estimated relative abundance (posterior mean = 1.22; 95% CI = [1.05,
285 1.59]).

286 The full moon is the phase associated with the highest estimated relative abundance
287 (posterior mean = 1.75; 95% CI = [1.29, 2.41]) with respect to the reference level (crescent moon),
288 which is the phase that presents the lowest estimated relative abundance.

289 Presence of calves was associated with a higher estimated number of adult dolphins than
290 the reference level (No calves presence) (posterior mean 1.59; 95% CI = [1.29, 2.03]), while the
291 number of vessels showed a negative relationship with the estimated dolphin relative abundance
292 (posterior mean -1.53; 95% CI = [-1.84, -1.06]).

293 Finally, the fishing boat is the type of vessels associated with the highest estimated dolphin
294 relative abundance (posterior mean = 1.40; 95% CI = [1.06, 0.75]) with respect to the reference
295 level (sailing boats). On the contrary, recreational boats show the lowest estimated dolphin relative
296 abundance (posterior mean = -1.75; 95% CI = [-3.85, -1.10]). Ferry boats were associated with
297 higher estimated dolphin relative abundance compared to the reference level, but (to follow the
298 Bayesian terminology) this difference was not relevant (i.e. the CI spanned zero; posterior mean =
299 1.10; 95% CI = [-1.37, 1.12]).

300

301 ***Changes in dolphin behaviour***

302 The analysis of the four different categories of behaviour (foraging, socializing, traveling,
303 surface activities) shows a clear difference in behaviour between vessel traffic categories (low,
304 medium, high). The largest differences among vessel traffic categories were found for the foraging
305 ($R = 0.83$ $p < 0.0001$) and socializing ($R = 0.94$ $p < 0.0001$) behaviours. In both cases, 0 out of
306 10,000 permutations exceeded the observed value.

307 In particular when more than three recreational vessels were present in the area, these

308 kinds of behaviour were not recorded (*Figure 3*).

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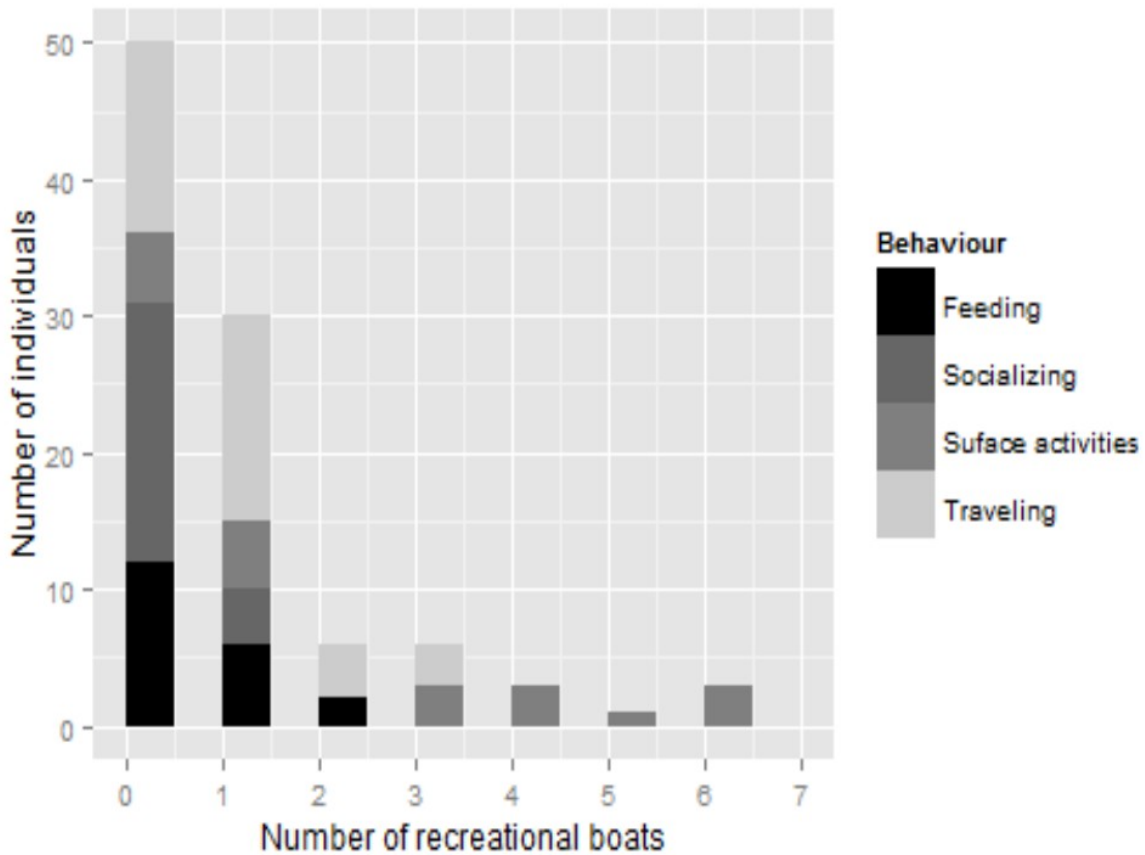
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325 *Figure 3*: Number of individuals of bottlenose dolphin (*Tursiops truncatus*) sighted during surveys
326 with respect to the number of recreational vessels recorded and dolphin behaviours observed.

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329 The *R*-values for the traveling ($R = 0.65$) and surface activities ($R = 0.72$) also show
330 differences, though lesser, among the vessel traffic categories, all with a significance level of $p <$
331 0.001 .

332

333 ***Changes in dolphin mean dive intervals***

334 The selected model for the MDI included as final relevant predictors the depth of seabed,
335 the number of vessels and type of vessel (*Table 3*). Depth of the seabed shows an increasing effect

336 with the MDI of dolphins (posterior mean = 0.35; 95% CI = [0.05, 0.75]); *i.e.* dolphins surfaced
 337 more frequently, per unit time in shallower water than in deeper waters.

338 Conversely, the number of vessels shows a negative effect with the MDI of dolphins
 339 (posterior mean = -0.45; 95% CI = [-0.65, -0.11]), which means that as the number of boats
 340 increased, dolphins surfaced less frequently (*Table 3*).

341 **Table 3.** Numerical summary of the posterior distributions of the fixed effects for the best model of
 342 mean dive interval (MDI) of dolphins. This summary contains the mean, the standard deviation and
 343 a 95% credible interval, which is a central interval containing 95% of the probability under the
 344 posterior distribution.

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Variable	Mean	Sd	Q _{0.25}	Q _{0.95}
Intercept	0.28	0.23	0.11	0.85
Number of vessel	-0.45	0.22	-0.65	-0.11
Type of vessel (Fishing)	0.44	0.11	0.14	0.66
Type of vessel (Recreational)	-0.36	0.09	-1.15	-0.09
Type of vessel (Ferry)	0.08	0.02	-0.22	0.12
Depth of the seabed	0.35	0.06	0.05	0.75

347

348 Fishing boat is the type of vessel associated with the highest estimated MDI (posterior
 349 mean = 0.44; 95% CI = [0.14, 0.66]) with respect to the reference level (sailing boats). On the
 350 contrary, recreational boats show the lowest estimated MDI (posterior mean = -0.36; 95% CI = [-
 351 1.15, -0.09]) with respect to the other type of vessels. Ferry boats were higher estimated MDI
 352 compared to sailing boats, but the difference was not relevant (*i.e.* the CI spanned zero; posterior
 353 mean = 0.08; 95% CI = [-0.22, 0.12]).

354

355 Discussion

356 This study revealed strong short-term responses from bottlenose dolphins both in terms of
 357 relative abundance and changes in behaviour.

358 In particular, results of this study indicate that the estimated number of dolphins relative
 359 abundance is negatively affected by the increasing number of vessels in the area. However, the

360 typology of the vessels also influences the number of the dolphins. Indeed, positive relationships
361 were found between numbers of sailing and fishing boats and numbers of dolphins, while a negative
362 relationship was seen with recreational boats. Larger vessels, such as ferry boats may be positively
363 related to the relative abundance of this species but, because of the low number of recorded
364 sightings the difference was not relevant in the Bayesian models. Positive relationships between
365 dolphin and artisanal fishing boats in this area have been already demonstrated both in terms of
366 foraging strategy specialization (Pennino et al. 2013) and fishery interactions (Pennino et al. 2015).

367 In addition, other variables appeared to have a relevant influence on dolphin relative
368 abundance in the Archipelago de La Maddalena. There is for example a seasonal effect on dolphin
369 relative abundance in the area. Our results are consistent with those obtained by Brotons et al.
370 (2008) in the Balearic Islands, Campana et al. (2015) in the Western Mediterranean Sea and
371 Pennino et al. (2015) in the same study area. Estimated dolphin relative abundance is highest in
372 winter and lowest in spring and summer. There are several possible reasons for this observed
373 seasonal variation, which may operate alone or in tandem. Firstly, natural seasonal movement by
374 dolphins could be related to prey availability or other habitat characteristics (*e.g.* salinity,
375 temperature, etc). Secondly, the increased nautical traffic in summer that distinguishes this area
376 could prompt displacement of these animals to areas where there are fewer recreational boats, to
377 avoid noise and the risk of collisions.

378 There was also spatial variation superimposed on the temporal patterns, with dolphin
379 relative abundance being highest in the western zone. This pattern in the relative abundance was not
380 directly related to the vessel traffic but could involve other variables, as mentioned before for the
381 seasonal effect. It will be necessary to explore the ecological and biological response of the species
382 to the habitat features in this area to clarify this hypothesis. However, the type of seabed and the
383 depth of the location monitored were not relevant in the Bayesian models and thus appear not to
384 influence the relative abundance of the species.

385 Our results also confirmed a relationship between moon phase and sightings, as already
386 reported for the short-beaked common dolphin (*Delphinus delphis*, Linnaeus, 1758) and Atlantic
387 spotted dolphin (*Stenella frontalis*, Cuvier, 1829) in the Azores. Indeed, the lunar cycle is likely to
388 be important in determining the behaviour of the many delphinid species that forage on vertically
389 migrating prey (Hernandez-Milian et al. 2008; Benoit-Bird et al. 2009).

390 The presence of calves was positively correlated with relative abundance of adult dolphins.
391 A higher occurrence of calves in large groups has been reported for several bottlenose dolphin
392 populations (Wells, 1991; Bearzi et al. 1997) and has been related to potential advantages including
393 enhanced calf assistance and protection, reduced maternal investment, and the benefit of learning
394 for its young members (Johnson & Norris, 1986).

395 Concerning the behavioural analysis, results showed that dolphins reduced the variety of
396 behaviour exhibited in the presence of boats, but also decreased mean dive intervals (MDI) when
397 the number of vessels increased. Other studies have also reported dolphins reacting to disturbances
398 by reducing the mean dive and moving faster, in areas such as the Pacific and Atlantic Oceans
399 (Nowacek et al. 2001; Lusseau, 2003; Lemon et al. 2006), north-east Scotland (Sini et al. 2005), but
400 also in the Mediterranean sea (Underhill, 2006; Papale et al. 2011).

401 Behaviours such as foraging and socializing, which usually imply longer MDI, were not
402 recorded where more than three boats are present. Nevertheless, our results showed that this pattern
403 is dependent on the typology of the vessel. Indeed, higher MDI values were recorded in presence of
404 fishing boats, probably correlated with feeding behaviour.

405 Depth of the seabed also influenced the mean dive intervals (MDI). Dolphins tend to have
406 shorter MDI in shallower water with respect to deeper waters. A likely explanation is that prey
407 distribution of dolphins is strongly affected by depth and consequently the predator distribution is
408 also related to depth (Massutí & Reñones, 2005). Also this pattern indirectly confirms the
409 interaction between dolphin feeding strategy and the local artisanal fisheries. Indeed, it is well

410 known that recruitment for most of the fish species in the Archipelago de La Maddalena, takes place
411 in shallow water near the coast (depth < 60 m.), where the trammel nets are set (Pennino et al.
412 2015). Consequently dolphins will undertake longer dives in deeper waters to catch their prey.

413

414

415 **Conclusion**

416 In this study, we found evidence consisting in changes in relative abundance and behaviour
417 of bottlenose dolphins in the presence of vessel traffic, potentially harmful due to increased stress
418 and energy costs and reduced feeding rate (although feeding rates appear to be higher in the vicinity
419 of fishing vessels). Given that the bottlenose dolphin is protected under EU Habitat Directive, with
420 a requirement to avoid activities harmful to dolphins these effects imply a need to develop and
421 enforce regulations for vessel traffic, especially for recreational boats in areas in which a resident
422 bottlenose dolphin population is present (Pennino et al. 2013) such as the National Park of the
423 Archipelago de La Maddalena that is also part of the Pelagos Sanctuary. The management of vessel
424 traffic clearly does not address all the other issues to which dolphins are subjected in this area, such
425 as prey limitation, fishery interactions and pollution. However, vessel traffic is a demonstrated
426 threat that lends itself to immediate mitigation. The number of recreational boats in the habitats
427 where dolphin relative abundance are higher should be monitored regularly and public awareness
428 raising programs should be implemented during seasonal peaks in tourist presence.

429 Future research could attempt further elucidation of age, sex and individual differences in
430 response to vessel traffic. Strong behavioural responses of animals to disturbance do not always
431 indicate population-level effects (Bejder et al. 2006; Lusseau et al. 2009, 2014; New et al. 2013;
432 Pirotta et al. 2015b). Indeed, inter-individual variability in site fidelity and availability of alternative
433 suitable habitats make it difficult to infer population level consequences. Thus, it will be important
434 to develop the link between short-term effects and population dynamics, which requires long-term

435 study and individual recognition of individuals, e.g. based on photo-identification.

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437

438 **Acknowledgements**

439 This study was part of the Tursiops Project of the Dolphin Research Centre of Caprera, La
440 Maddalena. Financial and logistical support was provided by the Centro Turistico Studentesco
441 (CTS) and by the National Park of the Arcipelago di La Maddalena. We thank the Natural Reserve
442 of Bocche di Bonifacio for the support provided during data collection. Our thanks go also to the
443 numerous volunteers of the Caprera Dolphin Research Centre and especially to Marco Ferraro,
444 Mirko Ugo, Angela Pira, and Maurizio Piras whose assistance during field observation and skills as
445 a boat driver were invaluable.

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