Interaction between bottlenose dolphin (*Tursiops truncatus*) and trammel nets in the Archipelago de La Maddalena, Italy

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Abstract :

Interactions between bottlenose dolphins (*Tursiops truncatus*) and fisheries are an increasing problem in the Mediterranean and effective management measures are needed. In order to assess the impact of dolphin interactions on artisanal trammel nets, we examine 354 fishing operations performed in waters of the Archipelago de La Maddalena (Italy). We evaluate whether interactions were related to the species composition of the catch and, using the local commercial value of the target species, we assess whether there was a real economic loss for fishermen. Bayesian models and partial correspondence analysis were used to determine the extent to which dolphin interactions and habitat differences contributed to variation in the species composition of catches. CPUE for fishing operations with no dolphin interactions was significantly higher than that for operations with dolphin interactions, although clearly this does not confirm a direct causal link, and associated economic loss was estimated to be non-significant. Geographic location, season, depth of seabed, moon phase, and mesh size were all important factors affecting the amount and species composition of the catch. Our results suggest that it is likely that these differences in species composition are due to a mixture of habitat and dolphin-induced effects.

51 INTRODUCTION

52 Fish are among the most important natural resources of the world, but because
53 of technical improvements in catching power and development of trade,
54 fisheries have reached an unprecedented level of exploitation (Jackson *et al.*
55 2001; Ormerod 2003; Rocklin *et al.* 2009). The increasing trend in the
56 percentage of overexploited, depleted and recovering marine fish stocks
57 reduces the amount of prey available for natural predators (Bearzi 2002).

58

59 Food availability is a critical factor which limits the distribution and numbers of
60 animal populations in the oceans. The relationship between predators and their
61 prey can be disturbed by intensive commercial fishing (McMahon *et al.* 2005).
62 Take, for instance, the ecological crisis in the Barents Sea ecosystem over the
63 past 30 years, related to the overfishing of stocks of capelin (*Mallotus villosus*,
64 Müller, 1776) and herring (*Clupea harengus*, Linnaeus, 1758) (Hamre 2003).
65 Haug *et al.* (2002) showed that, following a collapse in the capelin stock in the
66 mid-90s, minke whales (*Balaenoptera acutorostrata*, Lacépède, 1804) foraging
67 in the northern Barents Sea switched from a capelin-dominated diet to a diet
68 almost completely comprised of krill (*Euphausia* spp.).

69

70 Steller sea lions (*Eumetopias jubatus*, Schreber, 1776) in the North Pacific
71 provide another example of how a marine mammal population can be affected
72 by overfishing of forage food supplies. Several studies have shown that Steller
73 sea lion in Alaskan waters and the Aleutian Islands were nutritionally stressed
74 because of a reduction in overall prey abundance (Trites & Donnelly 2003;
75 Merrick *et al.* 2011). As a result these predators have begun to diversify their

76 feeding behavior by introducing other types of prey into their diet (Milette &
77 Trites 2003).

78

79 In general, when faced with food shortages or poor quality food, marine
80 mammals will modify their behaviour to reduce nutritional stress and conserve
81 energy and body condition (Trites & Donnelly 2003) and, consequently, direct
82 competitive interactions with fishing activity have increased (Northridge 1984;
83 Fertl & Leatherwood 1997, Bearzi 2002).

84

85 In the Mediterranean Sea, interactions between dolphins and fishing activity
86 have been reported since more than a century ago (see Barone 1895, for one
87 of the most earliest reports). Recently, in the context of declining fish stocks,
88 the fishing industry has increasingly viewed these interactions as a problem,
89 particularly so for small-scale fisheries (Díaz-López 2006; Lauriano *et al.* 2004,
90 2009; Rocklin *et al.* 2009).

91

92 Dolphins have learned that the catch of gillnet and trammel nets represents a
93 new, easily accessible, food resource (Reeves *et al.* 2001). They remove the
94 fish entangled in nets and damage the fishing gear, by tearing holes in the nets
95 as they attempt to remove fish (Lauriano *et al.* 2004; Cox *et al.* 2003), resulting
96 in reductions in the quantity and/or quality of the catch (Bearzi 2002; Rocklin *et*
97 *al.* 2009), and consequent economic (time, money, or gear) losses by fishers
98 (Gönener & Özdemir 2012). In addition the contact between dolphins and
99 fishing activity increases the likelihood that dolphins will suffer serious injury or
100 death due to entanglement (Wells & Scott 1994; Gorzelany 1998; Wells *et al.*

101 1998, 2008).

102

103 However, some interactions between dolphins and fisheries have been
104 described as cooperative (Busnel 1973; Pryor *et al.* 1990; Neil 2002) and
105 sometimes higher catch have been reported when dolphins were present in the
106 fishing areas (Silva *et al.* 2002; Rocklin *et al.* 2009). Other indirect advantages
107 may also arise from the fact that dolphins make an area more attractive for
108 tourism, thus providing economic benefits (*e.g.*, increased demand for seafood)
109 that may positively influence local fisheries (Bearzi 2002).

110

111 Moreover, most marine mammals, being top predators, are essential
112 components of healthy and sustainable ecosystems and their ecological
113 importance and conservation must be kept in mind (Estes *et al.* 1998), as
114 recognised by the EU Marine Strategy Framework Directive.

115

116 The main types of fishing gear used in coastal Mediterranean waters where
117 conflict with dolphins has been reported are bottom-set trammel nets and
118 gillnets, although dolphins also interact with trawl nets and with small purse
119 seines targeting pelagic schooling fish (Reeves *et al.* 2001). Several studies
120 have been carried out concerning the competitive interactions between marine
121 mammals and fisheries, *e.g.* in Greece (Conides & Papacostantinou 2001),
122 Spain (Brotons *et al.* 2008; Gazo *et al.* 2008), Tunisia (Naceur *et al.* 2004),
123 Corsica (Rocklin *et al.* 2009) and Italy (Reeves *et al.* 2001).

124

125 Despite several reports of the occurrence of depredation by dolphins on

126 trammel net fisheries along Sardinian coasts (Italy), few attempts have been
127 made to evaluate the phenomenon (Lauriano *et al.* 2004; Díaz-Lopez 2006).
128 The lack of information on the frequency and amount of depredation, or on its
129 economic effects, makes any effort to solve or manage the conflict very difficult
130 (Lauriano *et al.* 2009).

131

132 The Archipelago de La Maddalena, located in the northeast of the island of
133 Sardinia, is part of the Pelagos Cetacean Sanctuary, the biggest “Marine
134 Protected Area” (MPA) in the Mediterranean Sea (about 87,500 km²), extending
135 over waters belonging to three European countries (France, Italy and Monaco).
136 For a complete report on the Pelagos Cetacean Sanctuary and its history, see
137 Notarbartolo di Sciara *et al.* 2008.

138

139 Artisanal fisheries around the Archipelago de La Maddalena operate within the
140 coastal waters of the continental shelf, mainly between the coast and the 100
141 *m.* depth contour, coinciding spatially with areas used by dolphins and
142 temporally with the diurnal feeding period of dolphins and thus increasing the
143 probability of the interaction between dolphin and fisheries (Wise *et al.* 2007).

144

145 Local artisanal fishers have expressed concern about reduced catches,
146 increased fishing time and gear damage caused by dolphins, highlighting the
147 importance of this problem for trammel nets that are used to target red mullet
148 (*Mullus surmuletus*, Linnaeus, 1758) and cuttlefish (*Sepia officinalis*, Linnaeus,
149 1758). Resolution of such conflicts requires baseline quantitative information
150 on the impact of dolphin depredation on fisheries (Matthiopoulos *et al.* 2008).

151

152 Here we present a three-step approach to evaluate these interactions in the
153 Archipelago de La Maddalena. Firstly, we evaluate whether the interaction of
154 dolphins with trammel fishing operations in the Archipelago de La Maddalena
155 involves a real negative impact on fishing catches, by modelling the catch per
156 unit effort (CPUE) with respect to occurrence of dolphin interactions,
157 environmental covariates and characteristics of the fishing operations, using
158 Bayesian models. Secondly, we evaluate the hypothesis that the presence of
159 dolphins during fishing operations could alter the composition of the catch at
160 the species level. For this purpose, Partial Correspondence Analysis was used to
161 evaluate how much of the variation in species composition of catches is caused
162 by dolphin interaction, environment or a combination of both. In addition,
163 based on the local commercial value of the target species (per *kg.*), we assess
164 whether there is a real economic loss to fishermen. Finally, we used Bayesian
165 logistic regression to determine the extent to which habitat differences
166 contributed to the occurrence of dolphin interactions.

167

168 **MATERIALS AND METHODS**

169 **Study area**

170 This study was carried out in waters within 3 miles of the coast of Archipelago
171 de La Maddalena. The entire area is included within a National Park located in
172 the strait of Bonifacio, between the islands of Sardinia and Corsica, and is part
173 of the Pelagos Cetacean Sanctuary, established by Italy, France and Monaco in
174 1999.

175

176 The Maddalena area is characterized by rocky and sandy bottoms extensively
177 covered with Posidonia (*Posidonia oceanica*, Delile, 1813) seagrass beds, with
178 water depth ranging from 0 to 70 *m*. The location of the Archipelago inside the
179 "Bocche of Bonifacio" causes a high hydrodynamism that, associated with
180 shallow depth of the channel and limited tidal range, is responsible for the very
181 clean water which characterizes the area. The general aspect of the coast is
182 indented, characterized by small promontories, bays and narrow channels. The
183 topography of the bottom is variable with large cracks, reefs and small islands
184 (Esposito *et al.* 1992).

185

186 Only 18 fishing boats based in La Maddalena National Park are permitted to
187 undertake artisanal fishing activities in the area. These are small vessels, with
188 length from 6 to 12 *m.*, which employ predominantly bottom-set triple panel gill
189 nets (known as trammel nets) consisting of a small mesh inner and two large
190 mesh outer panels of monofilament net mounted together on the same frame
191 ropes.

192

193 Occasionally, single panel gillnets or different types of gillnets combined in a
194 single gear (e.g. a trammel net combined with a single net) are used. Fishing
195 takes place throughout the year using nets with a stretched mesh size from 20
196 to 62 *mm.* (knot to knot), set at depths ranging from 5 *m.* to 70 *m.*, with soak
197 times from 30 minutes to 7 hours, concentrating fishing effort in the early
198 morning. The net mesh size is chosen based on the main targeted species.
199 Between June and December, red mullet (*Mullus surmuletus*) is targeted using
200 a mesh of between 9 and 12 nodes per 25 *cm.* of rope. Common cuttlefish

201 (*Sepia officinalis*) is targeted between March and June using a mesh of between
202 7 and 9 nodes. Between April and August, European spiny lobster (*Palinurus*
203 *elephas*, Fabricius, 1787) is targeted using mesh with 4-5 nodes. Red mullet
204 lives mainly at depths of 50 to 100 *m.*, common cuttlefish at depth around 200
205 *m.*, and European spiny lobster at depths between 20 to 70 *m.*
206 Although these are the main target species and the most important in terms of
207 abundance, the catches are commonly composed of a very heterogeneous
208 assemblage of species. Finally, in January and February, fishing is not directed
209 at any particular species and the main species caught are usually Scorpaenidae
210 and Serranidae species.

211

212 **Sampling methods**

213 A pilot study (June-September 2006) was performed to explore the local
214 situation as well to design an appropriate sampling regime. Data were then
215 collected between July 2007 and July 2009 by two observers on board
216 commercial trammel fishing boats.

217

218 In order to sample the studied fleet as representatively as possible, we aimed
219 to cover all fishing boats and all seasons. However, this was limited by lack of
220 cooperation by some fishermen (who declined to take observers) and weather
221 conditions and, finally, 10 out of 18 trammel fishing boats were sampled.

222

223 For each fishing operation the observer recorded information on the haul
224 duration, net mesh size, number of 50 *m.* net panels used, geographical
225 location, latitude and longitude, depth of seabed, moon phase, and the

226 presence or the absence of evidence of depredation. Evidence of dolphin
227 attacks and depredation was based on the presence of at least one damaged
228 fish in the nets (Lauriano *et al.* 2004) and/or holes in the nets (Gazo *et al.*
229 2008).

230

231 Based on the nature of the damage, the depredation was identified as due to
232 dolphins or other species, such as sea turtles (*Caretta caretta*, Linnaeus, 1758)
233 or other fish. Fish damage caused by dolphins can be distinguished from
234 damage caused by sea turtles since dolphins bite behind the gills, leaving bite
235 marks with ragged borders and often leaving behind just the head or the body
236 of the fish (*Figure 1*) whereas sea turtles leave different small bites on the fish
237 (Hernandez-Milian *et al.* 2008). The fish species caught in the nets were
238 identified, measured and weighed for each haul.

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257 **Fig. 1.** Photograph of red mullets (*M. surmuletus*) damaged during a trammel fishing
258 operation. In this photo it is possible see that the heads were severed below the gills,
259 and only the body was left. Note the ragged edges left by the dolphin bites.

260

261 In order to identify a more clear definition of the spatial patterns of the fishing
 262 effort, the area of interest was divided into five equally sized sub-areas (*Figure*
 263 2).

280 Statistical analysis

281 We concentrated the statistical analysis on the catch of the 7 main species that
 282 together represent 90% of the total catch value. These species are: red mullet
 283 (*Mullet surmuletus*), red scorpionfish (*Scorpaena scrofa*, Linnaeus, 1758), black
 284 scorpionfish (*Scorpaena porcus*, Linnaeus, 1758), peacock wrasse (*Symphodus*
 285 *tinca*, Linnaeus, 1758), two-banded seabream (*Diplodus vulgaris*, Geoffroy
 286 Saint-Hilaire, 1817), octopus (*Octopus vulgaris*, Cuvier, 1797) and common
 287 cuttlefish (*Sepia officinalis*).

288 Since the catch statistics varied markedly between the boats, we computed the
289 catch per unit effort (CPUE) as the total catch in a fishing operation (in $g.$),
290 standardized per piece of net (of 50 $m.$) and per haul duration (in h), (CPUE in
291 $g. 50 m^{-1} h^{-1}$). These values were then log transformed to downweight extreme
292 values and to ensure a normal distribution and homoscedasticity.

293

294 The modelling strategy proposed involves three steps. First we use a Bayesian
295 General Linear Model (GLM) to evaluate which factors influence the CPUE.
296 Secondly, we applied Partial Correspondence Analysis (PCA) to assess which
297 variables affect the variation in species composition of catches. Finally, we
298 implemented a Bayesian logistic regression to determine the extent to which
299 habitat differences contributed to the presence of dolphin interactions.

300

301 In particular we used a Bayesian approach as it allows both the observed data
302 and model parameters to be considered as random variables, resulting in a
303 more realistic and accurate estimation of uncertainty (Banerjee *et al.* 2004).

304

305 **Step 1: Modelling CPUE**

306 The expected values of CPUE in each haul were related to independent
307 variables, namely mesh size, geographical location, moon phase, season, depth
308 of seabed and dolphin interaction factor, according to the general formulation,

$$309 \quad CPUE_i = \alpha + X\beta + W_i$$

310 where X is the vector of covariates for each survey i , α is the intercept, β is the
311 vector of the model parameters and W_i is the spatial random effect.

312

313 Except for the variable “depth of seabed”, which is continuous, the other
314 explanatory variables are all categorical: mesh size (6”, 7”, 8”, 9”, 11”, 12”),
315 location (northern, central, western, southern, eastern), moon phase (crescent,
316 full moon, waning, new moon), season (winter, spring, summer, autumn) and
317 dolphin interaction (1 = yes, 0 = no). Moreover, a random spatial effect
318 (latitude and longitude of the fishing operation) was introduced in the analysis
319 in order to verify the spatial variability of the data within each sub-area.

320

321 Effects of categorical variables are considered for $k-1$ of the k factor levels, with
322 the remaining one being considered as the base level. Hence the estimated
323 coefficient of each factor level will indicate the deviation with respect to the
324 value of the base level.

325

326 Once the model has been determined, the next step is to estimate its
327 parameters. Following Bayesian reasoning, the parameters are treated as
328 random variables, and prior knowledge has to be incorporated via the
329 corresponding prior distributions of the said parameters. In particular, for the
330 parameters involved in the fixed effects, we use non-informative Gaussian
331 distributions $N(0, 100)$.

332

333 A model selection with both backwards and forwards approaches was used to
334 select relevant variables. Specifically, we used the Deviance Information
335 Criterion (DIC), a well-known Bayesian model-choice criterion for comparing
336 complex hierarchical models (Spiegelhalter *et al.* 2002). Lower values of DIC
337 represent the best compromise between fit and parsimony.

338

339 **Step 2: Modelling species composition catches**

340 In order to test the hypothesis that the species assemblage in the catches
341 differs with dolphin depredation, we computed the proportion of each species
342 for both, depredated and non-depredated, fishing operations. Then, we assess
343 whether there was (or not) a real economic loss to fishermen by computing
344 three new categories of economic loss. The species were classified, according
345 to local commercial value per kg., into three different categories: high, medium
346 and low price (*Table 1*).

347

348 **Table 1.** *The seven species that together represent 90% of the total catches were*
349 *classified according to their local economic value per kg (Maddalena fish market) into*
350 *three different categories: high, medium and low price category.*

351

Species	Category
<i>M.surmuletus</i>	High Price (15.00-18.00 €)
<i>S.scrofa</i>	High Price (14.00-15.00 €)
<i>O.vulgaris</i>	High Price (13.00-15.00 €)
<i>S.tinca</i>	Medium Price (8.00-9.00 €)
<i>D.vulgaris</i>	Medium Price (8.00-9.00 €)
<i>S.officinalis</i>	Low Price (5.00-7.00 €)
<i>S.porcus</i>	Low Price (5.00 €)

352

353 As data meet normality conditions (Shapiro-Wilk normality test, $p = 0.08$), we
354 used Z-test in order to assess if the differences in the proportions, between
355 depredated and non-depredated fishing operations, were statistically
356 significant.

357

358 In addition we applied the PCA to assess how much of the variation of the
359 species composition of catches is uniquely explained by dolphin interactions,
360 how much is uniquely explained by environment or how much is explained by

361 some joint effect of the two components. To partition the total variance of the
362 CPUE of the 7 main species, we ran three different models: a full model with all
363 environmental variables and the dolphin interaction as explanatory variables, a
364 partial model in which environment explains species composition data
365 conditioned on dolphin predation, and a partial model where dolphin interaction
366 explains species composition data conditioned on environment. The
367 significance of each PCA model was tested by Monte Carlo permutations tests,
368 to retain the 10 ones that best explain the variation in the species composition
369 catches. We used as environment variables the depth of the seabed, the
370 season, the moon phase and the geographical location of each fishing
371 operation. For this purpose we used the *vegan* package of the R software (R
372 Development Core Team 2014).

373

374 **Step 3: Modelling dolphin depredation**

375 In addition, in order to assess whether dolphins depredation was related to
376 habitat features, we modelled the occurrence of dolphin depredation using
377 Bayesian logistic regression.

378

379 The 354 surveys were modelled as a binary process, $Z_i \sim \text{Binomial}(\pi_i)$, where 1
380 indicates records in which the depredation was recorded, and 0 the opposite.
381 The probability of occurrence of depredation by dolphins is indicated by π_i . The
382 model can be expressed as:

$$383 \quad Z_i \sim \text{Bin}(\pi_i),$$

$$384 \quad \text{logit}(\pi_i) = \alpha + X_i\beta + W_i$$

385 where X_i is the vector of covariates for each survey i , α is the intercept, β is

386 the vector of regression parameters, W_i is the spatial random effect and the
387 relationship between π_i and the covariates of interest includes the usual logit
388 link. We used as covariates the location, the depth of the seabed, the season,
389 mesh size, the moon phase and a random spatial effect (latitude and
390 longitude). Vague Gaussian distributions for the parameters involved in the
391 fixed effects were used, in order to allow empirically derived distributions. As
392 for the Bayesian GLMs, this model was fitted using both backwards and
393 forwards stepwise procedures and the goodness-of-fit of each model was also
394 assessed using the DIC.

395

396 To fit Bayesian models we used the integrated nested Laplace approximation
397 (INLA) methodology and software (<http://www.r-inla.org>). INLA provides
398 accurate approximations to posterior distributions of the parameters and is
399 computationally fast (Rue *et al.* 2009). In addition, INLA can be used with R
400 software, thus providing a familiar interface for the programming of the model.

401

402 **RESULTS**

403 Between July 2007 and July 2009 a total of 354 fishery operations was
404 observed and evidence of dolphin predation was recorded in 84 of these cases.
405 In particular, 54 out 354 fishing operations were sampled in the Western area,
406 84 in the Central, 78 in the Northern, 74 in the Eastern and 64 in the Southern
407 area.

408

409 **Relationship between dolphin interactions and total CPUE**

410 The Bayesian model of CPUE selected for its best fit (based on the lowest DIC)

includes season, moon phase, mesh size, depth of seabed and dolphin interaction as covariates.

413

Table 2 presents a numerical summary of the posterior distributions of the fixed effects for this final model.

416

Table 2. Numerical summary of the posterior distributions of the fixed effects for the best CPUE model. This summary contains the posterior mean of the estimated parameters, the standard deviation, the median and a 95% credible interval, which is a central interval containing 95% of the probability under the posterior distribution. Effects of categorical variables are considered for $k-1$ of the k factor levels, with the remaining one being considered as the base level. Hence the estimated posterior mean of each factor level will indicate the deviation with respect to the value of the base level.

425

Variable	Mean	Sd	Q _{0.25}	Q _{0.95}
Intercept	-1.07	0.90	-2.85	0.71
Season(Summer)	1.49	0.36	0.78	2.21
Season(Winter)	1.80	0.46	0.89	2.72
Season(Spring)	0.93	0.26	0.42	1.44
Moon(Crescent)	1.07	0.26	0.55	1.58
Moon(New)	0.32	0.32	-0.31	0.94
Moon(Waning)	0.47	0.25	-0.03	0.96
Dolphin interaction(Yes)	-0.43	0.26	-0.94	0.07
Mesh size(7")	4.71	0.73	3.27	6.16
Mesh size(8")	4.64	0.81	3.05	6.24
Mesh size(9")	4.27	0.72	2.85	5.68
Mesh size(11")	5.45	0.78	3.91	6.99
Mesh size(12")	6.19	0.75	4.72	7.66
Depth of seabed	-0.03	0.01	-0.04	0.01

426

427

Results showed that winter is the season with the highest estimated CPUE (posterior mean = 1.80; 95% CI = [0.89, 2.72]) with respect to the reference level (autumn season). Summer and spring seasons also showed higher estimated CPUE than the reference level (respectively, posterior mean = 1.49; 95% CI = [0.78, 2.21] and posterior mean = 0.93; 95% CI = [0.42, 1.44]),

432

433 leaving autumn as the season with the lowest estimated CPUE.

434

435 The crescent moon is the phase that shows the highest estimated CPUE
436 (posterior mean = 1.07; 95% CI = [0.55, 1.58]) with respect to the reference
437 level (full moon), which is the phase that presents the lowest estimated CPUE.

438

439 Dolphin interaction was associated with a lower estimated CPUE than the
440 reference level (No dolphin interaction) (posterior mean -0.43; 95% CI = [-0.94,
441 0.07]).

442

443 Using 6" mesh size as the reference level, all other mesh sizes show higher
444 CPUEs. *Table 2* shows a trend for greater mesh size to correspond to higher
445 estimated CPUE.

446

447 Finally, the seabed depth shows a negative relationship with estimated CPUE
448 (posterior mean of slope coefficient -0.03; 95% CI = [-0.04, 0.01]), i.e. catch
449 rates were high in shallower water.

450

451 **The species composition of catches**

452 In nets not attacked by dolphins the most common species caught was the red
453 mullet (31% of total CPUE), followed by octopus (18%), cuttlefish and red
454 scorpionfish (14% each), black scorpionfish (7%), peacock wrasse (4%) and
455 two-banded seabream (2%). The remaining 10% of the total CPUE was
456 composed of various species belonging for the most part to the Serranidae
457 family (*Figure 3*).

Fig. 3. Percentages of the seven main species fished in relation to total CPUE, with and without depredation by dolphins. The class "Miscellaneous" includes several species belonging to the Serranidae family. Error bars represent the standard deviation.

When dolphin interaction was recorded, the species composition of catch was different from when dolphins were absent. The species that showed the greatest reduction in catch were the cuttlefish (-10%; $z = 3.33$; $p < 0.05$) followed by red mullet (-7%; $z = 1.11$; $p > 0.05$), while the greatest increases were seen for the two species of scorpionfish, with catch of the red scorpionfish up by 18% ($z = -3.06$; $p < 0.05$), and the black scorpionfish by 7% ($z = -0.166$; $p < 0.05$).

In the presence of dolphin interactions, red scorpionfish became the most important species, comprising around 32% ($z = -3.06$; $p < 0.05$) of the total CPUE, and black scorpionfish rose to 14% ($z = -0.166$; $p < 0.05$) of the CPUE. Red mullet was reduced to 24% ($z = 1.11$; $p > 0.05$) of total CPUE and the

476 catches of octopus and two-banded seabream fell to 15% ($z = 0.6$; $p > 0.05$)
 477 and 1% ($z = 0.08$; $p > 0.05$), respectively. Catches of cuttlefish and peacock
 478 wrasse also declined, to 4% ($z = 3.33$; $p < 0.05$) and 2% ($z = 5$; $p < 0.05$),
 479 respectively (*Figure 3*). Miscellaneous species fell to 8% ($z = 0.51$; $p > 0.05$) of
 480 total CPUE.

481

482 High price category (red mullet, red scorpionfish and octopus) species were 8%
 483 more abundant in catches associated with dolphin depredation ($z = -1.21$; $p <$
 484 0.05 , *Figure 4*).

485

487 **Fig. 4.** Percentages of the CPUE (in $g. 50 m^{-1} h^{-1}$) in three price categories, by species,
 488 in nets unattacked and attacked by bottlenose dolphins. Error bars represent the
 489 standard deviation.

490

491 The lower amounts of red mullet and octopus in catches attacked by dolphins
 492 were offset in terms of economic value by the higher amount of red

493 scorpionfish. The yields of both the medium (two-banded seabream and
494 peacock wrasse) and low (cuttlefish and black scorpionfish) price categories
495 were about 3% for low price) lower in catches that suffered dolphin attacks,
496 differences which were not statistically significant ($z = 1.07$; $p > 0.05$ and $z =$
497 0.6 ; $p > 0.05$. respectively).

498

499 The analysis of the species composition of catches through the PCA shows that
500 the total percentage of variance explained by the environmental variables and
501 dolphin interactions is equal 25.52%. In particular, for the “environmental” PCA
502 of the species assemblages, controlling for the dolphin interaction, the
503 percentage of variance explained is equal to 17.75%. For this PCA , the Monte
504 Carlo tests of the relationships found ($F = 1.88$, $P < 0.05$) were significant,
505 indicating that environment variables explain a significant proportion of
506 variation in species assemblage compositions after excluding effects of dolphin
507 interaction. On the contrary, for the “dolphin interaction” PCA, the variance
508 explained is about 4.25% and the Monte Carlo tests of the relationships found
509 ($F = 4.06$, $P < 0.05$) were significant, indicating that dolphin interaction also
510 explained a significant part of the variation in the composition of species
511 assemblages after taking account of effects of environmental variables.

512

513 **Logistic regression for dolphin depredation**

514 The selected model for the depredation probability included as final relevant
515 predictors the location, season and depth of seabed (*Table 3*).

516

517

518 **Table 3.** Numerical summary of the posterior distributions of the fixed effects for the
519 best binomial model (dolphin depredation). This summary contains the posterior mean
520 of the estimated parameters, the standard deviation, the median and a 95% credible
521 interval, which is a central interval containing 95% of the probability under the
522 posterior distribution. Effects of categorical variables are considered for $k-1$ of the k
523 factor levels, with the remaining one being considered as the base level. Hence the
524 estimated posterior mean of each factor level will indicate the deviation with respect
525 to the value of the base level.

526

Variable	Mean	Sd	Q _{0.25}	Q _{0.95}
Intercept	0.45	0.98	-1.46	2.42
Season(Summer)	-3.20	0.66	-3.88	1.21
Season(Winter)	2.41	0.24	-0.89	2.72
Season(Spring)	-2.71	0.46	-1.42	3.44
Area(Southern)	-1.62	0.72	-3.09	0.25
Area(Eastern)	-0.32	0.88	-2.20	1.28
Area(Central)	2.16	0.64	0.93	3.48
Area(Western)	-0.22	0.58	-1.20	1.48
Depth of seabed	-0.05	0.02	-0.11	-0.00

527

528

529 There was an apparent seasonal effect, with depredation more frequent in the
530 winter season. Indeed, the winter shows the highest estimated probability of
531 depredation (posterior mean = 2.41; 95% CI = [-0.89, 2.72]) with respect to the
532 reference level (autumn season). Conversely, the summer showed the lowest
533 estimated probability of depredation compared the reference level (posterior
534 mean = -3.20; 95% CI = [-3.88, 1.21]).

535

536 The central area is the zone that shows the highest dolphin interaction
537 (posterior mean = 2.16; 95% CI = [0.93, 3.48]) with respect to the reference
538 level (northern area), while the southern is the area with the lowest estimated
539 probability of depredation (posterior mean = 1.62; 95% CI = [-3.09, 0.25]).

540

541 Depth of the seabed shows a negative relationship with the occurrence of

dolphin interaction (posterior mean slope coefficient -0.05; 95% CI = [-0.11, -0.00]); i.e. there were more dolphin interactions in shallower water.

DISCUSSION

In the Archipelago de La Maddalena, fishing operations during which no interactions with dolphins were recorded showed both quantitative and qualitative differences in catch composition compared with those for which attacks were reported. Dolphin attacks were also associated with lower values of CPUE. Lauriano *et al.* (2004) found a similar trend in Asinara (NW Sardinia) and the authors suggested that this could be due either to dolphins eating fish from the nets, reducing the CPUE, or dolphins scaring fish away from the nets so fewer are caught. However, it is also possible (albeit less plausible) that dolphin prefer the areas where the fish abundance is lower or that they are associated with other predators which eat the catches (Torres 2007).

It is worth mentioning that, in the waters of the Archipelago de La Maddalena, large fish (>3 m), sharks and sea turtles are extremely rare in inshore waters where fishing is concentrated. An incidence of predation by sea turtles of only 1% was recorded during the 354 fishing operations examined. However, in addition to the presence or absence of dolphin interactions, there are other factors that contributed significantly to the variability of CPUE, such as depth of seabed, location, season and moon phase. Moreover, the presence of dolphin interactions could also be predicted from environmental conditions, suggesting that the link between dolphin interactions and catch is not simply one of cause and effect. Equally, however, the dolphin-environmental relationship may be

564 indirect. For example, fish catches may depend on environmental conditions,
565 dolphin depredation depends on fish catch and therefore dolphin depredation
566 will appear to depend on the environment.

567

568 Some other studies have found a positive association between dolphin
569 predation and high CPUE. Silva *et al.* (2002), in the Azores, and Rocklin *et al.*
570 (2009), in Corsica, reported that catches were higher in the presence of
571 dolphins. This could be explained by the fact that dolphins only attack the nets
572 in which the catches are high, or that they drive the fish into nets, thus
573 increasing the catches of fish and CPUE, or simply that dolphins tend to be
574 found where fish abundance is higher.

575

576 In the present study, the spatial component appears to be an important factor
577 only for the probability of occurrence of dolphin interaction. Indeed, Bayesian
578 logistic regression showed that the central area is the one with highest
579 probability of occurrence of dolphin interaction. Geographical variation in the
580 effect of dolphin interactions probably depends on the extent to which dolphins
581 and fisheries overlap in space and time when exploiting their shared resource
582 (Brotons *et al.* 2008; Matthiopoulos *et al.* 2008). A possible counter-argument is
583 that dolphins and fishers both target the best habitat so that, based on fish
584 abundance, CPUE should be higher in dolphin areas than in non-dolphin areas
585 and the loss due to dolphins could thus be bigger than it seems.

586

587 There was also seasonal variation in quantitative catch composition. Our
588 results are consistent with those obtained by Brotons *et al.* (2008) in the

589 Balearic Islands. The winter season is the period with the highest CPUE and the
590 highest occurrence of dolphin interaction. There are different possible reasons
591 for the observed seasonal variation in depredation frequency, including
592 seasonal movement by dolphins (ongoing studies of the dolphin population in
593 the area suggest that dolphins have an inshore distribution during winter, (see
594 <http://www.lamaddalenapark.it> for more details)). The increased nautical traffic
595 in summer that characterizes this area could prompt displacement of these
596 animals to areas where there are fewer recreational boats, to avoid noise and
597 the risk of collisions. Gonzalvo *et al.* (2008) found a similar migration trend
598 around Balearic Islands. In the Archipelago de La Maddalena, as in the Balearic
599 Islands, tourism is the main industry, with around 8.5 million visitors each year
600 and around 15,000 registered leisure boats (Rotta 2009). Seasonal movements
601 by dolphins may reduce the probability that dolphins encounter trammel nets
602 during summer and can therefore lead to higher rates of depredation in winter.

603

604 CPUE was also influenced by the moon phase. The highest estimated CPUE
605 values were recorded during the crescent moon phase. Although it is known
606 that the lunar cycle affects the catchability of many species, few studies have
607 been carried out to test this hypothesis in the Mediterranean Sea. Yousif &
608 Sabrah (2004) showed significantly higher CPUE for mullet species (*Upeneus*
609 spp.) at full moon in the Red Sea. More information is known about the
610 influence of moon phase on the migration of top predators (Neves Dos Santos
611 & Garcia 2005; Damalas *et al.* 2007). Hernandez-Milian *et al.* (2008) showed
612 significant positive relationships between moon phase and sightings of short-
613 beaked common dolphin (*Delphinus delphis*, Linnaeus, 1758) and Atlantic

614 spotted dolphin (*Stenella frontalis*, Cuvier, 1829) in the Azores. Although
615 previous studies suggest that moon phase is likely to be important in
616 determining behavior of the many delphinid species that forage on vertically
617 migrating prey (Hernandez-Milian *et al.* 2008; Benoit-Bird *et al.* 2009), our
618 results show that the lunar phase is not correlated with dolphin interaction in
619 these waters.

620

621 Trammel nets of 12 nodes mesh size showed the highest CPUEs among gears
622 used by fishermen in this study. This type of net is used for targeting red
623 mullet, which is one the most frequently caught species in the area. The mesh
624 size seems to have no effect on the occurrence of the dolphin interaction.

625

626 Several studies have shown that the bathymetry of an area can be a significant
627 factor in determining the distribution of dolphins, depth being one of the
628 variables with the strongest influence (e.g. Cañadas *et al.* 2002; Yen *et al.*
629 2004). Results of this study show a clear negative correlation between
630 occurrence of dolphin interaction and depth of seabed. In addition Bayesian
631 analysis show that CPUE was negatively correlated with the depth of seabed,
632 which is probably related to the habitat of the target species of the fisheries,
633 which usually inhabit shallow waters (Blanco *et al.* 2001). It is well known that
634 recruitment for most of the fish species in the Mediterranean Sea, takes place
635 in shallow water near the coast (depth<60m), where the trammel nets are
636 sited (Lleonart & Maynou 2003). A likely explanation is that fish distribution is
637 strongly affected by depth and consequently the predator distribution is also
638 related to depth (Massutí & Reñones 2005).

639

640 The results of our study concerning species depredated by bottlenose dolphins
641 show similarity to those obtained by Lauriano & Di Muccio (2002) in Sardinia
642 and Rocklin *et al.* (2009) in Corsica (close to Archipelago de La Maddalena),
643 both studies on trammel nets. In these cases, red mullet was the most
644 depredated species, followed by comber (*Serranus cabrilla*, Linnaeus, 1758)
645 and forkbeard (*Phycis phycis*, Linnaeus, 1766) and no evidence of depredation
646 on cephalopods was recorded.

647

648 In the Balearic Islands, Brotons *et al.* (2008) observed high CPUE of octopus
649 when dolphins were present. The authors suggest that octopuses are attracted
650 to depredated nets by odours released from damaged fish after depredation. In
651 our study cuttlefish is the species most depredated by dolphins, followed by
652 red mullet and octopus. It is known that cephalopods are part of the bottlenose
653 dolphin diet, and similar patterns have been found in different Mediterranean
654 Sea areas (Blanco *et al.*, 2001).

655

656 Scorpionfish species catches were higher in the presence of dolphins in the
657 fishing area. Similar results have been demonstrated in Corsican waters
658 (Rocklin *et al.* 2009), where the occurrence of benthic-pelagic fish was higher in
659 the presence of dolphins, balanced by a correspondingly lower occurrence of
660 the reef associated fish group. The authors suggested that fish located in the
661 water column, such as benthic-pelagic fish, may try to escape from dolphins,
662 increasing their risk of being caught in the nets, whereas reef-associated fish
663 remained hidden in rocks. Little is known about the general behaviour of fish

664 facing a predator, but it seems reasonable to propose that demersal species,
665 such as the scorpionfish species, show similar behaviour to benthopelagic
666 species in the Corsica waters. Obviously another explanation could be that
667 dolphins are present in the areas where the occurrence of the red scorpionfish
668 is higher, independently of their foraging behaviour.

669

670 In this study, we cannot argue that dolphins deliberately drive fish into the nets
671 to facilitate their depredation, or say whether dolphin attacks generate panic
672 movements among fish schools. Camera and acoustic detection-based studies
673 of nets would be needed to discover how the interaction works. However, the
674 PCA results suggest that it is more likely that these differences in species
675 composition are due to habitat effects or a mixture of difference of habitats and
676 dolphin-induced effects.

677

678 In economic terms, the difference in species composition in the event of
679 dolphin depredation (regardless of whether it is directly caused by the dolphin
680 depredation) does not significantly alter the profitability of catches for
681 fishermen. Indeed, high price category (red mullet, red scorpionfish and
682 octopus) species were 8% more abundant in catches associated with dolphin
683 interaction. The lower amounts of red mullet and octopus in the total catch
684 were offset in terms of economic value by the higher amount of red
685 scorpionfish.

686

687 It should be noted that other economic losses have not been evaluated in this
688 study. As mentioned in the introduction, interaction of dolphins often causes

689 damage to the nets, e.g. holes (Fertl & Leatherwood 1997; Brotons *et al.* 2008),
690 reducing catching efficiency and capacity (Bearzi 2002), and resulting in lost
691 time and direct financial losses by fishermen (Zahri *et al.* 2004). Unfortunately,
692 we don't have any additional information about these others factors that could
693 help to assess these economic losses in the area.

694

695 Potentially the most worrying finding was the high probability of interactions
696 with dolphins observed around the Archipelago de La Maddalena waters, which
697 reached 24% per fishing operations. This value is much higher than that
698 observed by Lauriano *et al.* (2004) in Asinara (10%) and the 12.5% recorded by
699 Rocklin *et al.* (2009) in Corsica, both on trammel net fisheries. Possible
700 explanations for this localized effect include locally depleted fish stocks or an
701 increase in the number of animals specializing on depredating nets in this area.
702 Indeed, Pennino *et al.* (2013) provides evidence for socially learned tradition in
703 foraging tactics within a community of resident wild bottlenose dolphins in
704 these waters.

705

706 This study allows better understanding of how coastal bottlenose dolphins
707 interfere with the trammel fishery in the Archipelago de La Maddalena. The
708 nature and level of interactions will be dependent on several factors. For
709 example, in this study different environmental factors were found to be
710 correlated with low fish catches (e.g. season, depth of seabed, area).
711 Nevertheless, fishermen perceived that only dolphins were detrimental to their
712 activities.

713

714 Considerable flexibility of approach in mitigating and managing this issue will
715 be required in this area. Based on our analyses of factors affecting CPUE and
716 the incidence of depredation, it is possible that changes in fishing practices, in
717 relation to the fishing grounds or fishing patterns could result in both increased
718 CPUE and decreased depredation. Possible tools for an efficient fisheries
719 management could be spatial and temporal closures of high-intensity dolphin
720 interaction areas. However, in order to identify and locate these potential
721 spatio-temporal closures, a more solid knowledge of species-environment
722 relationships is needed, as well as more detailed information about the fishing
723 effort in this area.

724

725 Alternatively, an agreed mechanism to estimate economic costs could be
726 established between fishermen and National Park Authority, which could
727 support a compensation scheme for predator damage, in exchange for greater
728 collaboration in research by fishermen. This approach has been tested by the
729 Swedish Environmental Protection Agency
730 (<http://www.internat.naturvardsverket.se/>), which provides a reimbursement for
731 damage caused by dolphins. Reimbursement requires that fishermen give the
732 net to the coastguard who must verify the extent of the damage. This practice
733 interrupts fishing activities, and is inconvenient for fishermen who wish to
734 apply (Lauriano *et al.* 2004). However it is necessary that these
735 reimbursements are targeted and actively controlled, otherwise adverse effects
736 may be obtained as in the Archipelago of Madeira, where damage to gear
737 caused by monk seals (*Monachus monachus*, Hermann, 1779) is reported to be
738 overestimated by fishermen seeking for economic compensation (Hale *et al.*

739 2011).

740

741 Despite strong evidence that dolphin depredation occurs, it appears to lead to
742 minimal loss of revenue obtained from the catch and, if other economic
743 impacts (e.g. net damage) prove not to be a major issue, management action
744 could therefore include educating fishers to accept the interactions.

745 Another possibility is the use of acoustic deterrents to discourage dolphins from
746 approaching nets, although raises a range of other issues, including the
747 possibility of fish being deterred from entering the nets, the possibility of
748 causing hearing damage in the dolphins, and the cost of purchasing and
749 maintaining such devices.

750

751 Future studies are needed in order to fill knowledge gaps regarding this historic
752 conflict and to understand what might be the best option to mitigate this
753 problem. Further and more specific research should be conducted to determine
754 the economic losses suffered by fishermen, taking into account damaged gear
755 and lost fishing time. In addition, will be useful to collect information about
756 dolphins by-catch in this area, as by-catch also damages fishing gear so is part
757 of the economic evaluation. Furthermore, knowledge about dolphins by-catch is
758 essential for conservation programs because it provides a clear picture of the
759 relationship between fisheries and dolphins.

760 More detailed studies are needed on the spatio-temporal distribution of fishing
761 activity, on distribution, habitat use and movements of bottlenose dolphins, as
762 well as *in situ* data on the nature of the interaction between dolphins, fish and
763 net. For example, are dolphins usually present in the area at the time the net is

764 set, does their presence affect fish behavior and how often are fish completely
765 removed by dolphins? A combination of underwater cameras adjacent to nets,
766 coupled with acoustic detection of dolphins could help answer these questions.

767

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776

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