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Overlapping distribution of common bottlenose dolphin, recreational boating, and small-scale fishery: Spatial management insight from modelling exercises

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Background. Sustainable management requires spatial mapping of both species distribution and human activities to identify potential risks of conflict. The common bottlenose dolphin (*Tursiops truncatus*) is a priority species of the EU Habitat Directive; thus, to promote its conservation, the understanding of habitat use and distribution, as well as the identification and spatial trend of the human activities which may directly affect population traits, is pivotal.

Methods. A MaxEnt modeling approach was applied to investigate the seasonal (from April to September) distribution of a small *population* of bottlenose dolphins in north-western Sardinia (Mediterranean Sea), using environmental variables and the likelihood of boat and fishing net presence as predictors. Then, the overlapping areas between the dolphins, fishing net and boat presence were identified to provide insights for the marine spatial management of this area.

Results. Three of the main factors influencing the seasonal distribution of bottlenose dolphins in the area are directly (boating and fishing) or indirectly (ocean warming) related to human activities. Furthermore, almost half of the most suitable area for dolphins overlapped with areas used by both fishing and boating. Finally, relyingon fishing distribution models, we also shed light on the potential impact of fishing on the *Posidonia oceanica*beds, a protected habitat, which received higher fishing efforts than other habitat types.

Discussion. Modelling the distribution patterns of anthropogenic activities was fundamental in understanding the ecological impacts both on cetacean habitat use and protected habitats. A greater research effort, especially inside the MPA/SCI, is suggested to detect potential changes in dolphin distribution patterns, also in relation to climate change, to assess dolphin bycatch and the status of target fish species and to evaluate sensitive habitat conditions, such as the *Posidonia oceanica* meadow.

1 **Overlapping distribution of common bottlenose**
2 **dolphin, recreational boating, and small-scale fishery:**
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Abstract

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Introduction

Marine coastal biodiversity in the Mediterranean is severely threatened by different anthropogenic pressures (chemical and acoustic pollution, eutrophication, marine traffic, alien species), which are expected to increase in the next future (Coll et al., 2010, 2012). Moreover, the cumulative and synergistic effects of multiple human-induced alterations on coastal ecosystems may impair the attempt to protect marine biodiversity (Micheli et al., 2013).

Among other species, marine mammals in coastal areas suffer habitat fragmentation and loss, reduced availability of resources and disturbance from human recreational activities (Reeves et al., 2003, 2013; Natoli et al., 2021). One of the most common species distributed along the Mediterranean coasts in the continental shelf (0–200 m) is the common bottlenose dolphin (*Tursiops truncatus*) (Bearzi et al., 2008; Gnone et al., 2023), where local communities, generally small sized, display limited home ranges and may form isolated and even genetically distinct units at small geographic scales (Gnone et al., 2020; Natoli et al., 2021). The species is strictly protected according to the Habitats Directive (Annex IV; 92/43/ECC), the Protocol for Specially Protected Areas, the Biological Diversity in the Mediterranean of the Barcelona Convention (Annex II), and the ACCOBAMS agreement. Prey depletion, incidental catches in fishing activities and habitat loss are currently the primary threats to bottlenose dolphins in the Basin (Bearzi et al., 2012; Natoli et al., 2021). Further, they may be exposed to high levels of human disturbance, such as shipping, recreational boating, collision, and underwater noise (Bearzi, 2002; Reeves et al., 2013).

Sustainable management requires spatial mapping of both species distribution and human activities to identify potential risk of conflict. For example, depredation attempts, bycatch and entanglement in fishing gears, and conflict with fishers are most likely to take place where spatial overlap between marine mammal distribution and fisheries occurs (Di Tullio et al., 2016), while the risk of collisions and disturbance by boating may be most severe in highly attractive tourist areas (O'Connor et al., 2009; La Manna et al., 2020). Thus, according to the EU Habitats Directive and the Maritime Spatial Planning Directive of the EU (2014/89), assessing the overlap between dolphins and human activities

distribution is crucial to identify conservation strategies and strengthen current policies regarding spatial coastal zone management.

The coasts of Sardinia are considered high-biodiversity areas, where the human impacts can be considered less pronounced than other Mediterranean sites (Coll et al., 2012). However, even in the most pristine coasts, two potentially damaging human activities for dolphins, small-scale fishery and boating, are widely spread. Small-scale fishery is currently defined by the European Union as the fishing activities performed by vessels 12 m-and-under in length, which do not use towed fishing gears (Davies et al., 2018). Small-scale fishery is generally considered less impacting on the marine environment than the industrial one, even if it cannot be considered "sustainable" by definition (Davies et al., 2018). In fact, small-scale and artisanal fisheries can have the potential to over-exploit resources and may cause mortality to cetaceans because of by-catch (Read et al., 2006), two of the major causes of cetacean population decline. Further, conflict with fishers due to the depredation on fishing nets can reduce dolphin local abundance and impair conservation status (Read et al., 2006; Read, 2008) owing to retaliatory measures (intentional injury and killing) taken by fishers. The economic crisis faced by small-scale fishery have exacerbated fishers' perceptions of dolphins as competitors (Lauriano et al., 2004; La Manna et al., 2022). This is particularly relevant in Sardinia where a depredation frequency of dolphins on gillnets and trammel nets higher than 50% has been recently estimated (La Manna et al., 2022a). Sardinia is also one of the Italian regions with the largest concentration of boat berths, tourist ports and marinas (ONN, 2011). Recreational boating is still considered less harmful than shipping for the marine environment, thus it is still scantly regulated (La Manna et al., 2020). However, the impact of boating may lead to dolphin behavioral changes, shifts in habitat use, temporary displacement, increase in energy consumption, and, in the long-terms, changes in survival rates or population size (Constantine et al., 2004; Lusseau, 2005; La Manna et al., 2013, 2014). Furthermore, especially in coastal areas, dolphins attract tourists, leading to a significant growth in commercial or accidental dolphin-watching activities, which can represent an additional source of disturbance linked to both the physical presence of boats and the noise they produce (O'Connor et al., 2009; Kassamali-Fox et al., 2020).

106 To promote dolphin conservation, the understanding of their habitat use and distribution,
107 as well as the identification and spatial trend of the human activities which may directly
108 affect populations traits (Carlucci et al., 2016; Lambert et al., 2017; La Manna et al., 2020),
109 is pivotal. Thus, the aim of this study was two folds: i) to investigate the distribution of a
110 small *population* of bottlenose dolphins in the north-western Sardinia and identify the
111 environmental and anthropogenic variables that mostly explain its distribution patterns; ii)
112 to estimate the distribution overlaps between dolphins, boating and small-scale fishing
113 activity. To these aims, a MaxEnt modeling approach (Maximum Entropy; Phillips et al.,
114 2006) was used on fishing gear and boat presence data to predict the spatial distribution
115 patterns of fishing and boating in one of the most popular tourist destinations in Sardinia
116 (Alghero), whose harbor has one of the highest numbers of fishing licenses and boat
117 berths of the island. Then, we used the likelihood of boat and fishing net presence and
118 other environmental variables to predict the distribution of dolphins in two seasons (spring
119 and summer 2022) and in the whole period (spr-sum 2022). Finally, the overlapping areas
120 between dolphin, fishing net and boat presence were identified to provide insights for the
121 marine spatial management of this area.
122
123 **Materials & Methods**
124
125   *Study area*
126 The study area (about 400 km^2) is in northwest Sardinia, Italy (40.5580 N, 8.3193 E, Fig.
127 1) and includes three coastal protection measures (the Capo Caccia - Isola Piana MPA,
128 the SCI 'Capo Caccia e Punta del Giglio' ITB010042 and the SCI 'Entroterra e zona
129 costiera tra Bosa, Capo Marargiu e Porto Tangone' ITB020041) and Alghero, the largest
130 harbor on the western coast of the island (with 2200 berths), which hosts a fishing fleet
131 mainly composed of small-scale fishing vessels (n=75; mean length $\pm$ SD = 7.18 $\pm$ 2.10;
132 La Manna et al., 2022b). The area is characterized by a variety of habitats (Table 2), but
133 the MPA and SCIs were established mainly for the protection of endemic Mediterranean
134 seagrass (*Posidonia oceanica*) and coralligenous. The local economy relies on sea-
135 related tourism activities (La Manna et al., 2016b); fishing is mainly small scaled and
136 based on traditional practice (La Manna et al., 2022b). Common bottlenose dolphin

137   (*Tursiops truncatus*) is the only species of cetacean regularly present in the area. The
138   local population counts 130 photo-identified individuals, with at least 30% of them
139   showing high site fidelity (La Manna et al., 2023b).

140
141   *Field data collection*
142   Data on fishing, boating and the common bottlenose dolphin were collected from April to
143   September 2022. Systematic standardized surveys were conducted from two identical
144   9.7 m motorboats, equipped with 270 hp sterndrive engines. Survey routes followed a
145   haphazard sampling procedure (La Manna et al., 2016a, 2020), with a generally
146   perpendicular direction with respect to the coast and depth contours. In each survey, boat
147   speed was kept between 6 and 10 kn, to ensure dolphin detection, while two experienced
148   observers scanned the sea surface with both necked eyes and with the help of binoculars.
149   Scans occurred from 9 am to 6 pm, only in days with a visibility of over 3 miles and good
150   sea conditions (sea state 2 Douglas; wind force 2 Beaufort). The position of the research
151   boat was automatically recorded every 30 sec using a Garmin GPS chart-plotter. Using
152   binoculars (10 power magnification, 42 mm objective lens), trained observers counted
153   boats, both moored and underway, and fishing buoys encountered within 300 m during
154   the survey, recording their position using GPS. Boats were classified as: recreational
155   inflatable boats, speed boats, cabin cruisers, sail boats, diving boats, fishing boats and
156   tourist ferry boats. Fishing buoys (thus the attached gears) were classified as fishing net
157   or traps, based on their peculiar and distinctive positions (Fig. 2). When the classification
158   was ambiguous the gear was classified as not determined (ND) and excluded from the
159   analysis. During a dolphin sighting, animals were approached cautiously, to avoid
160   disturbance, and data about dolphin group size and geographic position were collected.

161
162   *Environmental predictors*
163   We incorporated data on environmental variables, dolphin, fishing gear, and boat
164   occurrence into a Geographic Information System (GIS; software ArcMap 10.8) using the
165   World Geodetic System 1984 (WGS84) and the Universal Transverse Mercator (UTM)
166   32 N projection.
167   The following environmental variables were selected to model dolphin distribution, based
168   on previous studies on cetacean (Azzellino et al., 2012; Marini et al., 2014; Bonizzoni et

169   al., 2019; La Manna et al., 2016, 2020): water depth (m), mean sea surface temperature

170   (SSTm), difference between the maximum and the minimum sea surface temperature

171   (SSTr), chlorophyll concentration (Chl-a - mg/m^3), seafloor slope (degree), distance to the

172   coast (m), aspect (downslope direction) and seabed habitat type (Table 1, Suppl. Mat. 1).

173   All data were pooled into grids with a resolution of 250 m and averaged over two periods

174   (spring: from April to June; summer: from July to September) and the whole period (spr-

175   sum). We used 'Raster Correlations and Summary Statistics' tools of the plug-in

176   SDMtoolbox 2.5 for ArcGis to create a correlation matrix of the Pearson correlation

177   coefficients (r) between the environmental predictors (Brown et al., 2017). Since

178   collinearity was found between distance to the coast, chlorophyll concentration and depth,

179   only depth was used in the modelling exercises (Kramer-Schadt et al., 2013).

180

181   *Model generation and validation*

182   We modeled boat, fishing gear, and dolphin occurrence at different temporal scales by

183   Maximum Entropy (MaxEnt version 3.4.1, Phillips et al., 2020), one of the most reliable

184   tools (Elith et al., 2006, 2011) when presence-only data (Guisan and Thuiller, 2005) are

185   available and the number of sightings is low (Elith et al., 2006). MaxEnt estimates a

186   probability distribution (i.e., relative likelihood of presence; McClellan et al., 2014) for a

187   species by contrasting occurrence data with background data, rather than true absence

188   data (Thorne et al., 2012). Thus, MaxEnt does not assume that the absence precludes

189   the likelihood of occurrence and this aspect is particularly relevant in case of highly elusive

190   species, such as cetaceans (La Manna et al., 2016, 2020).

191   Boating and fishing activities were modelled by MaxEnt since they vary temporally and

192   spatially as a function of human behavior (Cummins et al., 2008; La Manna et al., 2020).

193   Thus, we modelled the likelihood of fishing gear and boat presence using the location

194   points of all boats and fishing buoys (distinguished in traps and fishing nets) recorded

195   during the surveys as presence data and the raster surface of depth, slope, aspect, and

196   seabed habitat types as explanatory variables (Table 2). These environmental predictors

197   were chosen since seabed morphology and habitats may affect both fisher and boater

198   behavior. For modeling the likelihood of fishing gear presence, we also considered SSTm

199   and SSTr, since temperature is among the main driver of fish distribution (Azzurro et al.,

200 2019), and distance to harbor, since the distance between the harbor and the fishing site

201 could influence fishers' choice. Other predictors, that have been used in fishing modelling

202 exercises (van der Reijden et al., 2018), such as tidal currents and wave height, were not

203 considered here because of their irrelevance in the local (small scaled) context.

204 For modeling the likelihood of dolphin presence, we considered four continuous

205 environmental variables (SSTm, SSTr, depth and slope), two categorical environmental

206 variables (aspect and seabed habitat type) and two anthropogenic predictors (the

207 likelihood of boat and fishing net presence modeled by MaxEnt). Since collinearity was

208 found between the likelihood of fishing net and trap presence, only the former was used

209 in modelling dolphin presence.

210 For all models, MaxEnt settings were chosen in relation to the specific questions of the

211 study and data limitations (Merow et al., 2013): (i) the cloglog output since it is most

212 appropriate for estimating likelihood of presence (Phillips et al., 2020), (ii) hinge features

213 (Phillips and Dudík, 2008), (iii) default regularization parameters, and (iv) 10-fold cross

214 validation to assess the average behavior of the algorithms randomly partitioning the

215 occurrence data in ten random subsets (Phillips et al., 2006). The geographical extent of

216 the models coincides with the monitored area that includes the typical and known habitat

217 of bottlenose dolphins (Bearzi et al., 2012). Thus, we used all the background sites

218 available (5,358) to increase the predictive performance (Phillips and Dudík, 2008).

219 Furthermore, since background points were generated from the same environmental

220 space as the presence locations, bias files, useful to fine-tune the selection of background

221 points in MaxEnt and to account for sampling bias (Brown et al., 2014), were not used.

222 We ran a jackknife analysis to estimate the contribution of each variable to the MaxEnt

223 run, obtaining alternative estimates of variable importance for our models. The

224 performance of each MaxEnt model was assessed using the AUC (area under the

225 receiver operating characteristic curve; Phillips et al., 2006), a threshold-independent

226 metric of overall accuracy. The AUC provides an adequate evaluation of model

227 performance (Phillips et al., 2006), even if, in the case of presence-only distribution

228 models, AUC will compare presences with background points and cannot be considered

229 a perfect measure of model accuracy (Lobo et al., 2008; Merow et al., 2013). AUC values

230 range between 0 and 1: models with moderate to-good discrimination ability correspond

231   to AUC higher than 0.7 (Swets, 1988). Additionally, we verified the model robustness by

232   computing: (i) the test-AUC standard deviation (SD) and (ii) the difference between the

233   train-AUC values (using all presences) and the mean test-AUC values. Low test-AUC SD

234   and/or small difference between the train-AUC and mean test-AUC values indicate model

235   robustness (Herkt et al., 2016).

236   Using the cloglog output of MaxEnt (Phillips et al., 2020), we produced maps for each

237   season (spring and summer) and the whole period (spr-sum) relative to the likelihood of

238   boat, fishing net and dolphin presence.

239   To visualize the overlapping area between dolphins and boats and between dolphins and

240   fishing nets, the intersections of their representative areas were calculated, for both

241   seasons and the whole period, using as representative areas those with likelihood of

242   presence >0.6. This value corresponds to the threshold which balances sensitivity (the

243   change of correctly identifying suitable areas) and specificity (the change of correctly

244   identifying not suitable areas) (Liu et al., 2013). Finally, two percent area overlap, one

245   between dolphins and boats ($PAO_{d,b}$) and the other between dolphins and fishing nets

246   ($PAO_{d,f}$), were calculated following Atwood & Weeks (2003):

247

$$PAO_{d,b} = (A_{d,b} / A_d) \times (A_{d,b} / A_f)^{0,5}$$

$$PAO_{d,f} = (A_{d,f} / A_d) \times (A_{d,f} / A_f)^{0,5}$$

250

251

252   where $A_{d,b}$ is the overlap area between dolphins and boats, $A_{d,f}$ is the overlap area

253   between dolphins and fishing nets, A_d is the representative area for dolphins, A_b is the

254   representative area for boats, and A_f is the representative areas for fishing nets.

255

256   **Results**

257

258   *Boat and fishing net presence*

259   Between April and September, a total of 2⬛3 boats were counted, 657 in spring and

260   2316 in summer. The accuracy of MaxEnt in predicting the likelihood of boat presence

261   was higher than 0.75 in any investigated period (Table 2). The most important contributor

262   in predicting the likelihood of boat presence was depth, followed by aspect (Table 2). The

263   probability of finding boats was higher between - 60 and - 15 m of depth and similar for

264   all aspect classes, except for the classes 2 (NW) and 7 (W), the orientation most exposed

265   to the dominant local wind (Suppl. Mat. 1 and 2). Overall, the highest likelihood of boat

266   presence was along the north-western part of the Alghero coast and inside the boundaries

267   of the MPA/SCI (Figure 3), especially in summer.

268   A total of 409 fishing nets were counted, 175 in spring and 234 in summer. The accuracy

269   of MaxEnt in predicting the likelihood of fishing net presence was higher than 0.8 in any

270   investigated period (Table 2). The most important contributors in predicting the likelihood

271   of fishing net presence were depth (in summer), SSTm, distance to harbor and seabed

272   habitat type (in spring) (Table 2). In spring, the probability of finding fishing nets was

273   higher in the habitat "Mediterranean communities of muddy detritic bottoms" and

274   "Posidonia bed", and within 4 km to the harbor (Suppl. Mat. 3), while in summer the

275   probability of finding fishing nets was higher between - 60 and - 20 m of depth and

276   between 8 and 12 km from the harbor. In any period, the increase of SSTm decreased

277   the probability of finding fishing nets. Overall, the likelihood of fishing net presence was

278   highest along the coast closest to Alghero, especially in spring, but also in the areas inside

279   and surrounding the MPA/SCI, especially in summer (Figure 3).

280

281   *Dolphin presence*

282   Across all periods, 110 dolphin groups were sighted in about 5650 km of navigation and

283   163 surveys (Fig. 1). All MaxEnt models obtained AUC higher than 0.75, indicating high

284   accuracy in predicting dolphin presence (Table 2). Further, the overall model robustness

285   can be inferred by the small difference between train-AUC and mean test-AUC values

286   (Table 2).

287   The most important contributing variables to the dolphin habitat suitability models were

288   the likelihood of fishing net presence, seabed habitat type, aspect, SSTm and the

289   likelihood of boat presence (Table 2). Particularly, the probability of finding dolphins: i)

290   increased as the likelihood of fishing net presence increased, in all seasons; (ii) changed

291   with the seabed habitat types and aspect classes, depending on the season; (iii)

292   decreased when the SSTm increased in summer; iv) decreased when the likelihood of

293   boat presence was higher than 0.5 in spring (Suppl. Mat. 4). The most suitable areas for

294   dolphins are inside the Alghero Bay, both along its western and southern coasts, and only

295   partially overlap with the boundaries of the MPA/SCI (Figure 3).

296   The area with the likelihood of dolphin presence higher than 0.6 extended for about 58

297   km^2, ranging from 49 km^2 in spring to 61 km^2 in summer (Table 3). This area largely

298   overlapped with both the areas with the highest likelihood of fishing net and boat

299   presence, mainly in Summer (Table 3; Fig. 4).

300

301   **Discussion**

302

303   The study highlighted the distribution patterns of boating and small-scale fishing activity

304   and how they both contribute to defining the distribution of dolphins.

305   Particularly, based on the MaxEnt outputs, boaters tend to navigate inside the Alghero

306   Bay and the MPA/SCI, the areas most protected by the dominant winds and mostly

307   attractive for the scenic coasts and pristine waters. The most important predictor of boat

308   distribution was depth and the area with the likelihood of boat presence higher than 0.6

309   extends for 70 km^2, ranging from 50 km^2 in spring to 62 km^2 in summer. These results

310   were consistent with a previous study conducted between 2015 and 2018 (La Manna et

311   al., 2020), and highlighted the constant use by boaters of the same areas over the years.

312   Further, the study measured the extension of the area with the highest likelihood of fishing

313   net presence (about 60 km^2, ranging between 35 km^2 in spring and 40 km^2 in summer)

314   and found the key environmental factors associated with fishing. In spring, fishers tended

315   to use mainly the coastal shallow waters inside the Alghero Bay, at distance to the harbor

316   shorter than 4 km, coherently with the need for small-sized vessels to remain close to the

317   harbor when the local weather conditions are still variable. Fishers showed a clear

318   preference for specific seabed habitat types (namely, muddy detritic bottom and

319   *Posidonia oceanica* beds), a pattern already observed in other areas (van der Reiijden et

320   al., 2018). In summer, fishers operated at greater distance to the harbor (between 8 and

321   12 km), also using a consistent area within the MPA/SCI. Apart from depth, distance to

322   the harbor and habitat type, SSTm and SSTr were among the most important contributing

323   variables of fishing net distribution in both seasons. The fishing hotspots reflect the

324   fishers' preference for areas with high abundances of the target species, thus the

325 observed decrease of fishnet presence where the SSTm was higher and SSTr lower than
326 4°C, could be related to the effect of warming on fish abundance and distribution. Ocean
327 warming may impact commercially exploited fish stocks, both directly (acting on fish
328 physiology, behavior, reproduction, and distribution) and indirectly (acting on productivity
329 and structure of ecosystems on which fish depend) (Brander, 2007; Cheung, 2018;
330 Holsman et al., 2020). The changes in the quality, timing, and abundance of fish species
331 may alter the transfer of marine secondary production to higher trophic levels, with
332 cascading implications for food webs (Silber et al., 2017), and consequent shift in high-
333 level predator distribution and fishing hotspots. These impacts could be particularly
334 severe in the Mediterranean Sea (Azzurro et al., 2019), one of the fastest warming areas
335 of the planet with temperatures rising at a rate two to three times faster than the open
336 oceans (Cramer et al., 2018).

337 The modelling exercises on boating and fishing were particularly useful for understanding
338 the influence of the anthropogenic factors on dolphin distribution. In fact, the most
339 important contributing variable was the likelihood of fishing net presence, especially in
340 summer, when both fishers and dolphins have used less coastal areas. Consistently, the
341 overlapping area between dolphins and fishing nets in summer reached 47%. The
342 bottlenose dolphin is a species characterized by opportunistic feeding behaviors, known
343 to target a wide range of prey, mostly consisting of demersal fish species (e.g., European
344 hake, red mullet, European conger), benthic fish of soft bottom (e.g., common sole) and
345 cephalopods (e.g., common octopus and common cuttlefish) (Blanco et al., 2001; Bearzi
346 et al., 2008; Milani et al., 2019), which also represent target species for trammel and gill
347 net fishing. Top predators for which the predation risk is generally low, such as the
348 bottlenose dolphin in the Mediterranean Sea, develop strategies of resources and
349 habitats use based on the optimization of their foraging success (Mannocci et al., 2014).
350 Thus, the present result can be explained by both the depredation behavior of the
351 bottlenose dolphins on fishing nets, a widely spread feeding strategy in the Mediterranean
352 Sea (Reeves et al., 2001; Bearzi et al., 2002; Brotons et al., 2008; Lauriano et al., 2004,
353 2009; Revuelta et al., 2018; Pardalou et al., 2020; La Manna et al., 2022), and the likely
354 sharing of the most productive zones within the study area between dolphins and fishers
355 (Pennino et al., 2015; Carlucci et al., 2016).

356 Boat presence was a less important predictors, being relevant only in spring, when an
357 increase in the likelihood of boat presence higher than 0.5 leaded to a decrease in the
358 likelihood of dolphin presence. This result seems to contrast with what was found in a
359 previous study in the same area, where boat presence was the most important
360 contributing variable in the dolphin distribution modelling (La Manna et al., 2020).
361 However, this inconsistency could be explained by the shift in the dolphin distribution
362 towards areas less used by boaters, as confirmed by the reduction from 85% (between
363 2015-2018) to 41% (in 2022) of the overlapping area between dolphins and boats, and
364 by the introduction in the model of a more relevant predictor (the likelihood of fishing net
365 presence), which in turn may be related to prey distribution and dolphin feeding. The latter
366 aspect is also confirmed by the importance of seabed habitat types in modelling dolphin
367 distribution: the preference for certain habitat types, which changes by season, could
368 likely be related to the different prey availability (Hastie et al., 2004; Palacios et al., 2006,
369 2013; Gilles et al., 2016). At the end, SSTm also influenced dolphin distribution, mainly in
370 summer, when higher SSTm reduced the likelihood of dolphin presence. The importance
371 of SST in defining dolphin distribution is coherent with recent studies conducted in other
372 geographical areas (Hartel et al., 2014; La Manna et al., 2016a; Lambert et al., 2017) and
373 with the strong influence of warming and marine heat waves on the occurrence, home
374 range and group sizes recently found in the same dolphin *population* (La Manna et al.,
375 2023a, 2023b).

376   *Study limitations*
377 Some ecologically relevant results were obtained with this study, although not all the
378 potential factors influencing dolphin distribution were included in the models. Thus, the
379 limited number of predictors constrains the interpretation of the results within the range
380 of the investigated environmental conditions (La Manna et al., 2016, 2020). For example,
381 although fishing and SST can be considered good proxies of prey availability, the model
382 predictability would be certainly improved including data on fish abundance and
383 distribution (MacLeod et al., 2014). Further, other aspects remain to be clarified. For
384 example, the distribution of dolphins during the winter months, when sea-based tourist
385 activities cease and fishing reduce due to adverse weather conditions, as well as the
386 influence of different behavioral states (feeding, socializing, resting) on the selection of

387   habitats (Giannoulaki et al., 2017) should be investigated. Finally, considering that marine
388   mammals respond to climate change (Silber et al., 2017), and early indications on the
389   effect of warming on the studied population have already been found (La Manna et al.,
390   2023a, 2023b), further effort should be done to anticipate changes in occurrence,
391   distribution, and relative abundance of this population under climate change scenarios.
392
393   **Conclusions**
394
395   Almost half of the most suitable area for dolphins overlapped with areas used by both
396   fishing and boating. Moreover, three of the main factors influencing the seasonal
397   distribution of bottlenose dolphins in the area are directly (boating and fishing) or indirectly
398   (ocean warming) related to human activities, showing the importance of adding
399   anthropogenic activities in the modelling of cetacean habitat use, especially considering
400   the worldwide increase of human pressure on these species (Tardin et al., 2019).
401   The study confirmed the use by boaters of the same coastal areas over years (La Manna
402   et al., 2020), especially the zones surrounding and inside the MPA/SCI. Therefore,
403   boating represents a constant anthropogenic pressure, which already showed to
404   influence the distribution pattern of dolphin mother-calf pairs (La Manna et al., 2020) and
405   to change whistling as likely adaptation to the noise produced by boats (La Manna et al.,
406   2019). However, the effect of boating on species' fitness and conservation status is far to
407   be disentangled (La Manna et al., 2019). Further, boating, in terms of physical presence
408   of boats, related noise, and anchoring, may have detrimental effects also on other
409   species, such as fish (La Manna et al., 2016b), and habitats, such as the Posidonia
410   meadows (Milazzo et al., 2004; Ceccherelli et al., 2007; Carreño and Lloret, 2021).
411   The study provided also the first evidence on the spatial distribution of small-scale fishing
412   activity, whose vessels (less than 12 m in length) are not legally required to carry
413   automatic identification or vessel monitoring systems, given insights into the areas where
414   the chances for dolphins to encounter setnets is higher, as well as the risk of bycatch and
415   entanglement (Breen et al., 2016). No quantitative data regarding the latter aspects exist.
416   However, several cases of survived or stranded dolphins showing signs of entanglements
417   or violent interactions with fishers and dead dolphins due to bycatch were recorded in

418   Sardinia (La Manna, *pers. comm;* Fig. 5). Another relevant aspect, from a conservation
419   point of view, is the depletion of fish resources due to intense fishing activities, especially
420   when they are exploited in small-sized areas, as in the present study. The population-
421   level consequences of potential prey depletion for species with varied diet, such as the
422   bottlenose dolphin, are difficult to demonstrate (Natoli et al., 2021). However, the
423   identification of 'hot spot areas', namely areas with high probabilities of dolphin presence
424   and fishing activities, can lead to more effective protection and management measures
425   (Sofaer et al., 2019), such as the restrictions of fishing in same areas or seasons
426   (Giannoulaki et al., 2017).

427   Further, relying on fishing distribution models, we also shed light on the potential impact
428   of fishing on the *Posidonia oceanica* beds, which received higher fishing efforts than the
429   other habitat types. Although this is a protected habitat listed in the Habitats Directive
430   (92/43/ECC), to the best of our knowledge, no studies have investigated the ecological
431   impact of both boating and fishing on seagrass meadow in this area, either inside the
432   MPA/SCI. Since healthy and functional marine ecosystems depends primarily on the
433   minimization of habitat loss and degradation (Klein et al., 2008), knowledge of the
434   location, extent and ongoing condition of this habitat should be implemented, also to
435   protect the numerous varieties of fish and other marine species seeking food and refuge
436   around the seagrass beds (Waycott et al., 2009), with the aim of preserving both
437   biodiversity and fishing socio-economic viability (Vlachopoulou et al., 2013).

438   In conclusion, greater research effort is required to understand the ecological impacts
439   and pressures of boating (Carreño and Lloret, 2021) and fishing, both on dolphins, fish,
440   and protected habitats. Particularly, to draw up management strategies aimed to mitigate
441   the identified impacts, especially inside the MPA/SCI, the following actions should be
442   implemented: i) systematic surveys of the bottlenose dolphin population to detect
443   potential changes in distribution patterns, also in relation to climate change; ii) fishery
444   monitoring to assess dolphin bycatch and the status of target species; iii) assessment of
445   sensitive habitats conditions, especially that of the *Posidonia oceanica* meadow.

446

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References

460 **References**

461 Azzellino, A., Panigada, S., and Lanfredi, C. (2012). Predictive habitat models for
462 managing marine areas: spatial and temporal distribution of marine mammals within the
463 Pelagos Sanctuary (Northwestern Mediterranean Sea). Ocean and Coastal
464 Management, 67, 63–74. doi: 10.1016/j.ocecoaman.2012.05.024.

465 Azzurro, E., Sbragaglia, V., Cerri, J., Bariche, M., Bolognini, L., Ben Souissi, J., et al.
466 (2019). Climate change, biological invasions, and the shifting distribution of
467 Mediterranean fishes: A large-scale survey based on local ecological knowledge. Global
468 Change Biology, 25, 2779–2792. doi.org/10.1111/gcb.14670.

469 Atwood, T.C., Weeks, H.P. (2003). Spatial home-range overlap and temporal interaction
470 in eastern coyotes: the influence of pair types and fragmentation. Canadian Journal of
471 Zoology, 81, 1589–1597.

472 Bearzi, G. (2002). Interactions between cetaceans and fisheries in the Mediterranean
473 Sea. In: Cetaceans of the Mediterranean and black seas: state of knowledge and
474 conservation strategies, Monaco: ACCOBAMS secretariat, Jardins de l'UNESCO,
475 Terrasses de Fontvieille.

476 Bearzi, G., Azzellino, A., Politi, E., Costa, M., and Bastianini, M. (2008). Influence of
477 seasonal forcing on habitat use by bottlenose dolphins *Tursiops truncatus* in the Northern
478 Adriatic Sea. Ocean Science Journal, 43, 175–182. doi: 10.1007/bf03029922.

479 Bearzi, G., Fortuna, C., Reeves, R. (2012). *Tursiops truncatus*. IUCN Red List Threat.
480 Spec. 2012: e.T22563A2782611.

481 Bonizzoni, S., Furey, N.B., Santostasi, N. L., Eddy, L., Valavanis, V.D., and Bearzi, G.
482 (2019). Modelling dolphin distribution within an Important Marine Mammal Area in Greece
483 to support spatial management planning. Aquatic Conservation: Marine and Freshwater
484 Ecosystems, 29, 1665–1680. doi: 10.1002/aqc.3148.

485 Brander, K.M. (2007). Global fish production and climate change. PNAS, 104,19709-
486 19714. doi-org.proxysbauniss.idm.oclc.org/10.1073/pnas.0702059104.

487 Breen, P., Brown, S., Reid. D., Rogan, E. (2016). Modelling cetacean distribution and
488 mapping overlap with fisheries in the northeast Atlantic. Ocean & Coastal Management,
489 134,140-149.

490 Brotons, J.M., Grau, A.M. & Rendell, L. (2008). Estimating the impact of interactions
491 between bottlenose dolphins and artisanal fisheries around the Balearic Islands. Marine
492 Mammal Science, 24(1), 112–127. doi.org/10.1111/j.1748-7692.2007.00164.x.

493 Brown, J.L. (2014). SDMtoolbox: a python-based GIS toolkit for landscape genetic,
494 biogeographic and species distribution model analyses. Methods in Ecology and
495 Evolution 5, 694-700. dx.doi.org/10.1111/2041-210X.12200.

496 Brown, J.L., Bennett, J.R., and French, C.M. (2017). SDMtoolbox 2.0: the next generation
497 Python-based GIS toolkit for landscape genetic, biogeographic and species distribution
498 model analyses. PeerJ, 5: e4095. doi: 10.7717/peerj.4095.

499 Carlucci, R., Fanizza, C., Cipriano, G., Paoli, C., Russo, T., and Vassallo, P. (2016).
500 Modeling the spatial distribution of the striped dolphin (*Stenella coeruleoalba*) and
501 common bottlenose dolphin (*Tursiops truncatus*) in the Gulf of Taranto (Northern Ionian
502 Sea, Central-eastern Mediterranean Sea). Ecological Indicators, 69, 707–721. doi:
503 10.1016/j.ecolind.2016.05.035.

504 Carreño, A., Lloret, J. (2021). Environmental impacts of increasing leisure boating activity
505 in Mediterranean coastal waters. Ocean & Coastal Management, 209, 105693,
506 doi.org/10.1016/j.ocecoaman.2021.105693.

507 Cheung W.W L. (2018). The future of fishes and fisheries in the changing oceans. Journal
508 of Fish Biology, 92, 790–803. doi.org/10.1111/jfb.13558.

509 Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J., Iglesias, A., et al. (2018).
510 Climate change and interconnected risks to sustainable development in the
511 Mediterranean. Nature Climate Change, 8(November). doi.org/10.1038/s41558-018-
512 0299-2.

513 Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F.B.R., et al. (2010). The
514 biodiversity of the Mediterranean Sea: estimates, patterns, and threats. PLoS One,
515 5:e11842.

516 Coll, M., Piroddi, C., Albouy, C., Lasram, F.B.R., Cheung, W.W.L., et al. (2012). The
517 Mediterranean Sea under siege: spatial overlap between marine biodiversity: cumulative
518 threatsand marine reserves. Global Ecology and Biogeography, 21, 465-480.

519 Constantine, R., Brunton, D., Dennis, T. (2004). Dolphin-watching tour boats change
520 bottlenose dolphin (*Tursiops truncatus*) behaviour. Biological Conservation, 117, 299–
521 307.

522 Cummins, V., Gault, J., and O'Mahony, C. (2008). "Establishing information needs for
523 planning and assessment of recreation activity in the coastal environment: a case study
524 from cork harbour, Ireland," in Proceedings of the International Pluridisciplinary
525 Conference "The Littoral: Challenge, Dialogue, Action" - Lille, France.

526 Davies, P., Williams, C., Carpenter, G., Stewart, B.D. (2018). Does size matter?
527 Assessing the use of vessel length to manage fisheries in England, Marine Policy, 97,
528 202-210.

529   Di Tullio, J.C., Fruet, P.F., Secchi, E.R. (2016). Identifying critical areas to reduce bycatch
530   of coastal common bottlenose dolphins *Tursiops truncatus* in artisanal fisheries of the
531   subtropical western South Atlantic. Endangered Species Research, 29, 35-50.

532   Elith, J., Graham, C.H., and Anderson, R.P. (2006). Novel methods improve prediction of
533   species' distributions from occurrence data. Ecography, 29, 129–151.

534   Elith, J., Phillips, S.J., and Hastie, T. (2011). A statistical explanation of MaxEnt for
535   ecologists. Diversity and Distribution, 17, 43–57. doi: 10.1111/j.1472-4642.2010.00725.x.

536   Giannoulaki, M., Markoglou, E., Valavanis, V. D., Alexiadou, P., Cucknell, A., and
537   Frantzis, A. (2017). Linking small pelagic fish and cetacean distribution to model suitable
538   habitat for coastal dolphin species, *Delphinus delphis* and *Tursiops truncatus*, in the
539   Greek Seas (Eastern Mediterranean). Aquatic Conservation: Marine and Freshwater
540   Ecosystems, 27, 436–451. doi.org/10.1002/aqc.2669.

541   Gilles, A., Viquerat, S., and Becker, E.A. (2016). Seasonal habitat-based density models
542   for a marine top predator, the harbor porpoise, in a dynamic environment. Ecosphere,
543   7:e01367.

544   Gnone, G., Bellingeri, M., Airoldi, S., Gonzalvo, J., David, L., et al. (2023). Cetaceans in
545   the Mediterranean Sea: Encounter Rate, Dominant Species, and Diversity Hotspots.
546   Diversity, 15, 321. doi.org/10.3390/d15030321.

547   Guisan, A., and Thuiller, W. (2005). Predicting species distribution: offering more than
548   simple habitat models. Ecol. Lett. 8, 993–1009. doi: 10.1111/j.1461-0248. 2005.00792.x.

549   Hastie, G.D., Wilson, B., Wilson, L.J., Parsons, K.M., and Thompson, P.M. (2004).
550   Functional mechanisms underlying cetacean distribution patterns: hotspots for bottlenose
551   dolphins are linked to foraging. Marine Biology, 144, 397–403. doi:10.1007/s00227-003-
552   1195-4.

553   Hartel, E.F., Constantine, R., and Torres, L.G. (2014). Changes in habitat use patterns
554   by bottlenose dolphins over a 10-year period render static management boundaries
555   ineffective. Aquatic Conservation: Marine and Freshwater Ecosystems, 25, 2465. doi:
556   10.1002/aqc.2465.

557   Herkt, K.M.B., Barnikel, G., Skidmore, A.K., and Fahr, J. (2016). A high-resolution model
558   of bat diversity and endemism for continental Africa. Ecological Modelling, 320, 9–28. doi:
559   10.1016/j.ecolmodel.2015.09.009.

560   Holsman, K.K., Haynie, A.C., Hollowed, A.B., Reum, J.C.P., Aydin, K., Hermann, A. J., et
561   al. (2020). Ecosystem-based fisheries management forestalls climate-driven collapse.
562   Nature Communications, 11, 1. doi.org/10.1038/s41467-020-18300-3.

563 Kassamali-Fox, A., Christiansen, F., May-Collado, L.J., Ramos, E.A., Kaplin, B.A. (2020).
564 Tour boats affect the activity patterns of bottlenose dolphins (*Tursiops truncatus*) in Bocas
565 del Toro, Panama. PeerJ., 8: e8804. doi:10.7717/peerj.8804.

566 Klein, C.J., Chan, A., Kircher, L., Cundiff, A.J., Gardner, N., Hrovat, Y., Scholz, A.,Kendall,
567 B.E., Airam, S., (2008). Striking a balance between biodiversity conservation and
568 socioeconomic viability in the design of marine protected areas. Conservation Biology,
569 22, 691–700.

570 Kramer-Schadt, S., Niedballa, J., and Pilgrim, J.D. (2013). The importance of correcting
571 for sampling bias in MaxEnt species distribution models. Diversity and Distribution, 19,
572 1366–1379.

573 La Manna, G., Manghi, M., Pavan, G., Lo Mascolo, F., Sara, G. (2013). Behavioural
574 strategy of common bottlenose dolphins (*Tursiops truncatus*) in response to different
575 kinds of boats in the waters of Lampedusa Island (Italy). Aquatic Conservation: Marine
576 and Freshwater Ecosystems, 23, 745–757.

577 La Manna, G., Manghi, M. and Sarà, G. (2014). Monitoring habitat use by common
578 bottlenose dolphins (*Tursiops truncatus*) using Passive Acoustic Monitoring device in a
579 Marine Protected Area. Marine Mediterranean Science,15, 327-337.

580 La Manna, G., Ronchetti, F., Sarà, G. (2016a). Predicting common bottlenose dolphin
581 habitat preference to dynamically adapt management measures from a Marine Spatial
582 planning perspective. Ocean and Coastal Management, 130, 317–327.

583 La Manna, G., Manghi, M., Perretti, F., Sarà, G. (2016b) Behavioural response of brown
584 meagre (*Sciaena umbra*) to boat noise. Marine Polluttion Bulletin, 110, 324–334.

585 La Manna, G., Ronchetti, F., Sarà, G., Ruiu, A., Ceccherelli, G. (2020). Common
586 bottlenose dolphin protection and sustainable boating: species distribution modeling for
587 effective coastal planning. Frontiers in Marine Science, 7, 542648
588 doi.org/10.3389/fmars.2020.542648.

589 La Manna, G., Arrostuto, N., Campisi, S.S., Manghi, M., Fois, N. & Ceccherelli, G.
590 (2022a). Acoustic detection of bottlenose dolphin depredation on nets and implications
591 for conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 1–12.
592 doi.org/10.1002/aqc.3907.

593 La Manna, G., Moro Merella, M., Ruiu, A., Ceccherelli, G. (2022b). La piccola pesca
594 artigianale nell'Area Marina Protetta Capo Caccia – Isola Piana: risultati del monitoraggio
595 2022 e confronto con le annualità precedenti. Relazione finale, pp. 38.

596 La Manna, G., Ronchetti, F., Perretti, F., Ceccherelli, G. (2023a). Determinants of group
597 size in the common bottlenose dolphins: the role of water temperature and noise.
598 Behavioral Ecology and Sociobiology, 77, 45.

599 La Manna, G., Ronchetti, F., Perretti, F., Ceccherelli, G. (2023b). Not only wide range
600 shifts: Marine warming and heat waves influence spatial traits of a mediterranean
601 common bottlenose dolphin population. Estuarine, Coastal and Shelf Science, 285, 31,
602 108320.

603 Lambert, C., Laran, S., David, L., Dorémus, G., Pettex, E., VanCanneyt, O., et al. (2017).
604 How does ocean seasonality drive habitat preferences of highly mobile top predators?
605 Part I: the north-western Mediterranean Sea. Deep Sea Research, 141,133–154. doi:
606 10.1016/j.dsr2.2016.06.011.

607 Lauriano, G., Fortuna, C.M., Moltedo, G. & Notarbartolo di Sciara, G. (2004). Interactions
608 between bottlenose dolphins (*Tursiops truncatus*) and the artisanal fishery in Asinara
609 Island National Park (Sardinia): assessment of catch damage and economic loss. Journal
610 Cetacean Research Management, 6, 165–173.

611 Lauriano, G., Caramanna, L., Scarno, M. & Andaloro, F. (2009). An overview of dolphin
612 depredation in Italian artisanal fisheries. Journal of the Marine Biological Association of
613 the United Kingdom, 89, 921–929. doi.org/10.1017/s0025315409000393.

614 Lusseau, D. (2005). Residency pattern of bottlenose dolphins Tursiops spp. in Milford
615 Sound, New Zealand, is related to boat traffic. Marine Ecology Progress Series 295, 265–
616 272.

617 Liu, C., White, M., and Newell, G. (2013). Selecting thresholds for the prediction of
618 species occurrence with presence-only data. Journal of Biogeography, 40, 778–789.
619 doi:10.1111/jbi.12058.

620 Lobo, J.M., Jiménez-Valverde, A., and Hortal, J. (2010). The uncertain nature of
621 absences and their importance in species distribution modelling. Ecography 33, 103–114.
622 doi: 10.1111/j.1600-0587.2009.06039.x.

623 Marini, C., Fossa, F., and Paoli, C. (2014). Predicting bottlenose dolphin distribution along
624 Liguria coast (northwestern Mediterranean Sea) through different modelling techniques
625 and indirect predictors. Journal of Environmental Management, 150, 9-20. doi:
626 10.1016/j.jenvman.2014.11.008.

627 McClellan, C.M., Brereton, T., Dell'Amico, F., Johns, D.G., Cucknell, A.C.,Patrick, S.C.,
628 et al. (2014). Understanding the distribution of marine megafauna in the english channel
629 region: identifying key habitats for conservation within the busiest seaway on earth. PLoS
630 One, 9, e89720. doi: 10.1371/journal.pone.0089720.

631 MacLeod, C.D., Santos, M.B., Burns, F., Brownlow, A., Pierce, G.J. (2014). Can habitat
632 modelling for the octopus *Eledone cirrhosa* help identify key areas for Risso's dolphin in
633 Scottish waters? Hydrobiologia, 725, 125−136.

634 Mannocci, L., Laran, S., Monestiez, P., Dorémus, G., Van Canneyt, O., Watremez, P.,
635 Ridoux, V. (2014). Predicting top predator habitats in the Southwest Indian Ocean.
636 Ecography, 37, 261–278.

637 Merow, C., Smith, M.J., and Silander, J.A. (2013). A practical guide to MaxEnt for
638 modeling species' distributions: what it does, and why inputs and settings matter.
639 Ecography 36, 1058–1069. doi: 10.1111/j.1600-0587.2013.07872.x

640 Micheli, F., Halpern, B.S., Walbridge, S., Ciriaco, S., Ferretti, F., Fraschetti, S., et al.
641 (2013). Cumulative human impacts on Mediterranean and Black Sea marine ecosystems:
642 assessing current pressures and opportunities. PLoS One 8:e79889. doi:
643 10.1371/journal.pone.079889.

644 Milani, C.B., Vella, A., Vidoris, P., Christidis, A., Kamidis, N., Leykaditou, E. (2019).
645 Interactions between fisheries and cetaceans in the Thracian Sea (Greece) and
646 management proposals. Fishery Management and Ecology, 26, 374–388.

647 Natoli, A., Genov, T., Kerem, D. et al. (2021). *Tursiops truncatus* (Mediterranean
648 subpopulation). The IUCN Red List of Threatened Species 2021:
649 e.T16369383A50285287. https://www.iucnredlist.org/species/16369383/21524878.

650 Nowacek, S.M., Well, R.S., Solow, A.R. (2001). Short-term effects of boat traffic on
651 bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal
652 Science, 17, 673–688.

653 O'Connor, S., Campbell, R., Cortez, H., Knowles, T. (2009). Whale watching worldwide:
654 tourism numbers, expenditures and expanding economic benefits. International Fund for
655 Animal Welfare; Yarmouth: 2009.

656 ONN (2011). Osservatorio Nautico Nazionale, Rapporto sul Turismo Nautico. Genova:
657 Osservatorio Nautico Nazionale.

658 Palacios, D.M., Baumgartner, M.F., Laidre, K.L., and Gregr, E.J. (2013). Beyond
659 correlation: integrating environmentally and behaviourally mediated processes in models
660 of marine mammal distributions. Endangered Species Research, 22, 191–203. doi:
661 10.3354/esr00558.

662 Palacios, D.M., Bograd, S.J., Foley, D.G., and Schwing, F.B. (2006). Oceanographic
663 characteristics of biological hot spots in the North Pacific: a remote sensing perspective.
664 Deep Sea Reearch II Top. Stud. Oceanogr. 53, 250–269. doi:
665 10.1016/j.dsr2.2006.03.004.

666 Pardalou, A. & Tsikliras, A.C. (2020). Factors influencing dolphin depredation in coastal
667 fisheries of the northern Aegean Sea: implications on defining mitigation measures.
668 Marine Mammal Science, 36, 1126–1149. doi.org/10.1111/mms.12702.

669 Phillips, S.J., Anderson, R.P., and Schapire, R E. (2006). Maximum entropy modeling of
670 species geographic distributions. Ecological Modellling, 190, 231–259.
671 doi:10.1016/j.ecolmodel.2005.03.026.

672 Phillips, S. J., and Dudík, M. (2008). Modeling of species distributions with Maxent: new
673 extensions and a comprehensive evaluation. Ecography 31, 161–175.
674 doi:10.1111/j.0906-7590.2008.5203.x.

675 Phillips, S.J., Dudík, M., and Schapire, R.E. (2020). Maxent Software for Modeling
676 Species Niches and Distributions (Version 3.4.1). Available online at:
677 http://biodiversityinformatics.amnh.org/open_source/maxent/.

678 Pennino, M.G., Rotta, A., Pierce, G.J. & Bellido, J.M. (2015). Interaction between
679 bottlenose dolphin (*Tursiops truncatus*) and trammel nets in the archipelago de La
680 Maddalena. Hydrobiologia, 747, 69–82. doi.org/10.1007/s10750-014-2127-7.

681 Read, A.J., Drinker, P. & Northridge, S. (2006). Bycatch of marine mammals in U.S. and
682 global fisheries. Conservation Biology, 20, 163–169. doi.org/10.1111/j.1523-
683 1739.2006.00338.x.

684 Read, A.J. (2008). The looming crisis: interactions between marine mammals and
685 fisheries. Journal of Mammalogy, 89, 541–548. doi.org/10.1644/07-mamm-s-315r1.1.

686 Reeves, R.R., Read, A.J. & Notarbartolo di Sciara, G.N. (Eds.) (2001). Report of the
687 workshop on interactions between dolphins and fisheries in the Mediterranean, evaluation
688 of mitigation alternatives, Roma: ICRAM.

689 Reeves, R.R., Smith, B.D., Crespo, E., Notarbartolo di Sciara, G. (2003). Dolphins,
690 whales, and porpoises: 2002−2010 conservation action plan for the world's cetaceans.
691 IUCN/SSB Cetacean Specialist Group, Cambridge.

692 Reeves, R.R., McClellan, K., Werner, T.B. (2013). Marine mammal bycatch in gillnet and
693 other entangling net fisheries, 1990 to 2011. Endangered Species Research, 20, 71−97.

694 Revuelta, O., Domenech, F., Fraija-Fernandez, N., Gozalbes, P., Novillo, O., Penades-
695 Suay, J. et al. (2018). Interaction between bottlenose dolphins (*Tursiops truncatus*) and
696 artisanal fisheries in the Valencia region (Spanish Mediterranean Sea). Ocean and
697 Coastal Management, 165, 117–125. doi.org/10.1016/j.ocecoaman.2018.08.001.

698 Silber, G.K., Lettrich, M.D., Thomas, P.O., Baker, J.D., Baumgartner, et al. (2017).
699 Projecting Marine Mammal Distribution in a Changing Climate. Frontiers in Marine
700 Science, 4. doi.org/10.3389/fmars.2017.00413.

701 Sofaer, H.R., Jarnevich, C.S., Pearse, I.S., Smyth, R.L., Auer, S., Cook, G.L., Edwards,
702 T.C., Guala, G.F., Howard, T.G., Morisette, J.T., and Hamilton, H. (2019). Development

703   and Delivery of Species Distribution Models to Inform Decision-Making. BioScience, 69,
704   544–557. doi.org/10.1093/biosci/biz045.

705   Swets, J.A. (1988). Measuring the accuracy of diagnostic systems. Science 240, 1285–
706   1293. doi: 10.1126/science.3287615.

707   Tardin, R.H., Chun, Y., Jenkins, C.N., Maciel, I. S., Simão, S.M., & Alves, M.A.S. (2019).
708   Environment and anthropogenic activities influence cetacean habitat use in southeastern
709   Brazil. Marine Ecology Progress Series, 616, 197-210.

710   Thorne, L.H., Johnston, D.W., Urban, D.L., Tyne, J., Bejder, L., Baird, R.W., et al. (2012).
711   Predictive modeling of spinner dolphin (*Stenella longirostris*) resting habitat in the main
712   Hawaiian Islands. PLoS One 7:e43167. doi: 10.1371/journal.pone.0043167.

713   Vlachopoulou, E.I., Meriwether Wilson, A., Miliou, A. (2013). Disconnects in EU and
714   Greek fishery policies and practices in the eastern Aegean Sea and impacts on Posidonia
715   oceanica meadows. Ocean & Coastal Management, 76,105-113.

716   van der Reijden, K.J., Hintzen, N.T., Govers, L.L., Rijnsdorp, A.D., Olff, H. (2018) North
717   Sea demersal fisheries prefer specific benthic habitats. PLoS ONE 13, e0208338.
718   doi.org/10.1371/journal.pone.0208338.

719   Waycott, M., Duarte, C.M., Carruthers, T.J.B., et al. (2009). Accelerating loss of
720   seagrasses across the globe threatens coastal ecosystems Proceedings of the National
721   Academy of Sciences of the United States of America, 106, 12377-12381.

723 **FIGURE CAPTIONS**
724
725 Fig. 1. Map of the study area showing the total sampling effort (shades of blue) pooled
726 into grid cells (2 x 2 km). Red points: dolphin sightings between April and September
727 2022.
728
729 Fig. 2. Peculiar and distinctive positions of the fishing buoys used to classify the gear as
730 fishing net or traps.
731
732 Fig. 3. Likelihood of boat, fishing net and dolphin presence (cloglog output of MaxEnt
733 models) for spring (upper row), summer (middle row), and the whole period (spr-sum,
734 lower row).
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737 fishing net representative areas (B) in the two seasons (spring and summer) and for the
738 whole period (spr-sum). PAO: percent area overlap.
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740 Fig. 5. Effects of interactions between dolphins and fishery in Sardinia: dolphins showing
741 clear signs of entanglement (A and C) and violent interaction with fishers (who use dive
742 spearguns to get away the animals from the nets, B and D).
743

Table 1(on next page)

Description and sources of the predictors used for modelling fishing net, boat and bottlenose dolphin presence.

1 Table 1. Description and sources of the predictors used for modelling fishing net, boat and bottlenose
2 dolphin presence.
3

Predictors	Description and sources
Water depth	Water depth was mapped using the points recorded every 30 s by the GPS during surveys with very good sea conditions (sea state $\leq$1). These points were used to create a raster bathymetry surface using "Topo to raster" function of Spatial Analyst tools (resolution 250 m).
SST (mean and range)	SST source satellite data were downloaded from GOS Project 2010 (https://doi.org/10.5067/GHOUH-4GM20). Monthly climatological raster of GHRSST L4 SST images with 1 km of resolution were created using the plug-in Marine Geospatial Ecology Tools 0.8a68 for ArcGIS. SST raster surfaces were downscaled to the spatial resolution of 250 m using the interpolation tool "Geostatistical Wizard: kernel smoothing" in the Geostatistical Analyst Toolbar and averaged for each season (spring and summer) and for the whole period (spr-sum)
Chl-a	Chl-a GlobColour monthly L3 products with a resolution of 1 km were downloaded from GlobColour Project (http://globcolour.info). Chl-a raster surfaces were downscaled to the spatial resolution of 250 m using the interpolation tool "Geostatistical Wizard: kernel smoothing" in the Geostatistical Analyst Toolbar and averaged for each season (spring and summer) and for the whole period (spr-sum)
Slope	Slope defined the bathymetric gradient along the study area and was measured in degrees. A continuous raster surface (250 m resolution) of seabed gradient was derived from water depth using "Slope" function in Spatial Analyst Tools in ArcGIS.
Aspect	Aspect corresponds to the heterogeneity of the downslope direction and was calculated by deriving the maximum rate of change in water depth values from each cell to its neighbors, using "Aspect" function in Spatial Analyst Tools in ArcGIS. Aspect was a categorical variable, with 8 classes, coded as follows: flat (0); N (1); NW (2); E (3); SE (4); S (5); SW (6); W (7); NE (8).
Distance to the coast	The distance to the coast was calculated for each cell centroid from shoreline shapefile using "Near" function in Spatial Analysis Tools in ArcGIS.
Distance to the harbor	The distance to harbor was calculated for each raster cell using "Euclidean distance" function of the Spatial Analyst tool. The source to calculate the distance was the closest raster cell to the entrance of the harbor, while the coastline was defined as a barrier. The resulting raster was reclassified using the "Reclassify" function of the Spatial Analyst tool to create a categorical variable with 5 classes of distance coded as follows: 4 (from 0 to 4 km), 8 (from 4 to 8 km), 12 (from 8 to 12 km), 16 (from 12 to 16 km) and 20 (from 16 to 20 km).
Seabed Habitats	Information about the habitat types were derived from the European Marine Observation Data Network (EMODnet) Seabed Habitats project (http://www.emodnet-seabedhabitats.eu). Habitat type was a categorical variable, with 9 classes, coded as follows: 1 = Mediterranean infralittoral rock (MB15); 2 = Coralligenous biocenosis (MC151); 3 = Mediterranean infralittoral coarse sediment (MB35); 4 = Mediterranean infralittoral sand (MB55); 5 = Biocenosis of Mediterranean muddy detritic bottoms (MC451); 6 = Mediterranean circalittoral coarse sediment (MC35); 7 = Biocenosis of Mediterranean open-sea detritic bottoms on shelf-edge (MD451); 8 = Biocenosis of *Posidonia oceanica* (MB252); 9= Facies of dead "mattes" of *Posidonia oceanica* without much epiflora (MB2523).

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Table 2(on next page)

Percent contribution of the different variables to the MaxEnt models predicting the likelihood of a) boat b) fishing net and c) bottlenose dolphin presence.

Variable importance is presented as the mean of the 10 runs of each single model. Output referred to spring, summer and the whole period (spr-sum).

1 Table 2. Percent contribution of the different variables to the MaxEnt models predicting the likelihood of a)
2 boat b) fishing net and c) bottlenose dolphin presence. Variable importance is presented as the mean of
3 the 10 runs of each single model. Output referred to spring, summer and the whole period (spr-sum).
4

MaxEnt Model	% Contribution								AUC	AUC difference
Boat	Depth	Aspect	Slope	Seabed habitat					Mean ± SD	Training - mean test
Spring	65.3	16.6	16.2	1.9					0.80 ± 0.03	0.017
Summer	65.7	25.4	5.3	3.7					0.79 ± 0.03	0.007
Spr-Sum	70.2	21.8	4.4	3.5					0.78 ± 0.02	0.007
Fishing net	Depth	Aspect	Slope	Seabed habitat	Dist. to harbor	SSTm	SSTr		Mean ± SD	Training - mean test
Spring	7.9	4.3	4.8	25.2	28.4	28.8	0.5		0.84 ± 0.05	0.020
Summer	35.7	3.2	1.9	7.4	13.5	14.2	24.1		0.84 ± 0.02	0.021
Spr-Sum	21.5	2.8	2.3	6.4	17.1	33.9	15.9		0.81 ± 0.02	0.023
Bottlenose dolphin	Depth	Aspect	Slope	Seabed habitat	SSTm	SSTr	Boat	Fishnet	Mean ± SD	Training - mean test
Spring	6.1	7.6	4.4	30.3	3.6	2.0	9.9	36.2	0.80 ± 0.08	0.102
Summer	0.7	16.4	7.9	18.9	11.0	3.6	0.7	40.8	0.78 ± 0.08	0.076
Spr-Sum	2.8	11.8	9.6	22.9	7.8	1.9	2.5	40.6	0.79 ± 0.05	0.005

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6

Table 3(on next page)

Measurement of the overlapping areas between dolphins and fishing nets and between dolphins and boats, in the two seasons (spring and summer) and for the whole period (spr-sum).

A_d: representative area for dolphins; A_b: representative areas for boats; A_f: representative areas for fishing nets. PAO_{db}: percent area overlap between dolphins and boats; PAO_{df}: percent area overlap between dolphins and fishing nets.

1 Table 3. Measurement of the overlapping areas between dolphins and fishing nets and between dolphins
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4 percent area overlap between dolphins and boats; PAO_{df}: percent area overlap between dolphins and
5 fishing nets.
6

	Spring	Summer	Spr - Sum
A_d (km)	48.8	60.6	58.0
A_b (km)	50.7	62.3	70.0
A_f (km)	35.1	39.7	59.7
PAO_{db}	17%	43%	41%
PAO_{df}	6%	47%	42%

7

Figure 1

Map of the study area showing the total sampling effort (shades of blue) pooled into grid cells (2 x 2 km). Red points: dolphin sightings between April and September 2022.
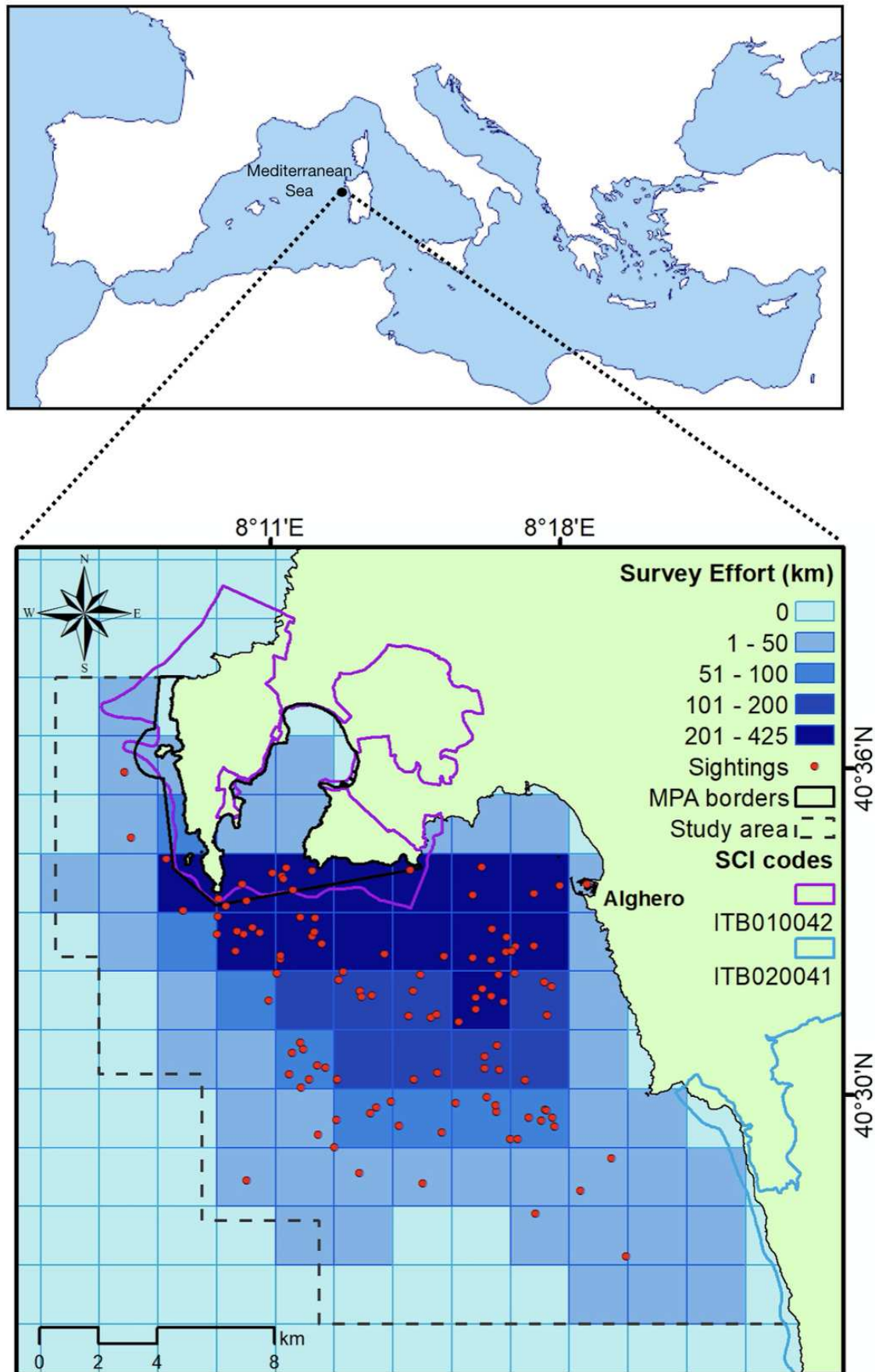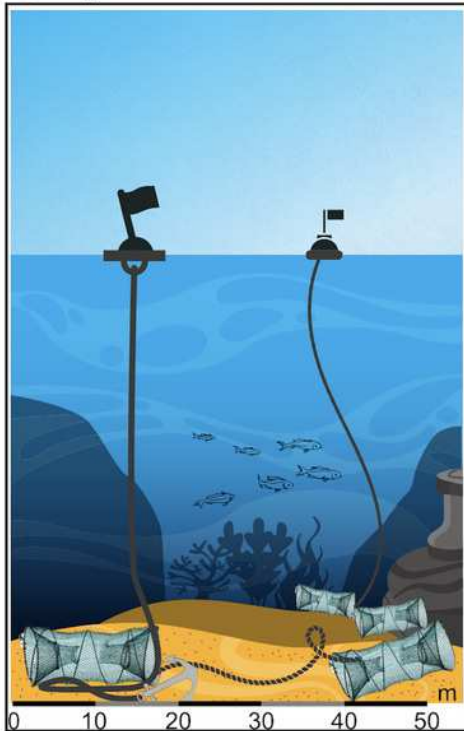
Figure 2

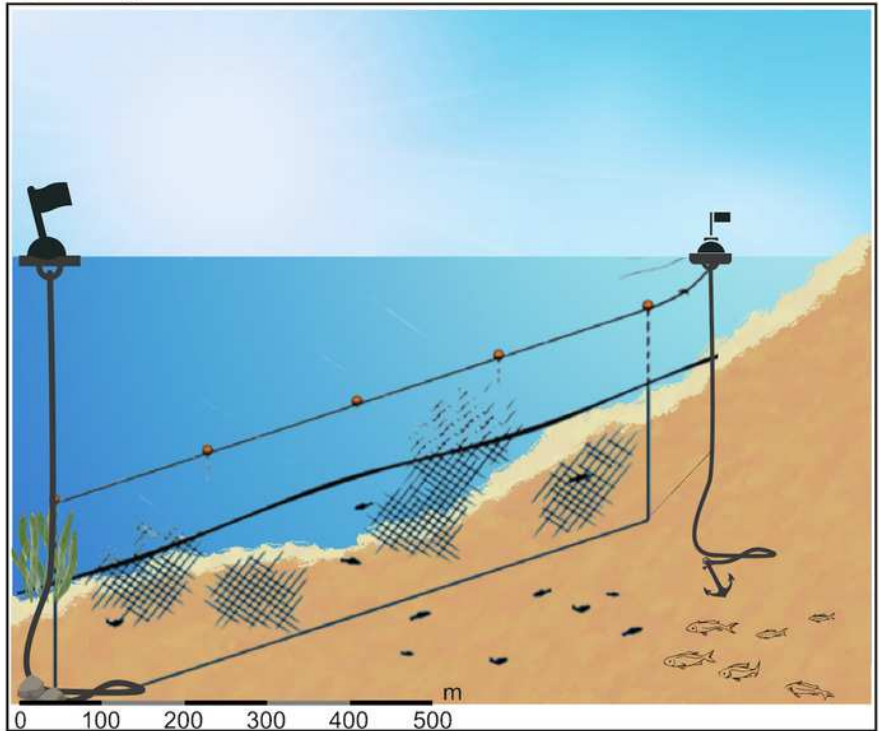Peculiar and distinctive positions of the fishing buoys used to classify the gear as fishing net or traps.

Figure 3

Likelihood of boat, fishing net and dolphin presence (cloglog output of MaxEnt models) for spring (upper row), summer (middle row), and the whole period (spr-sum, lower row).
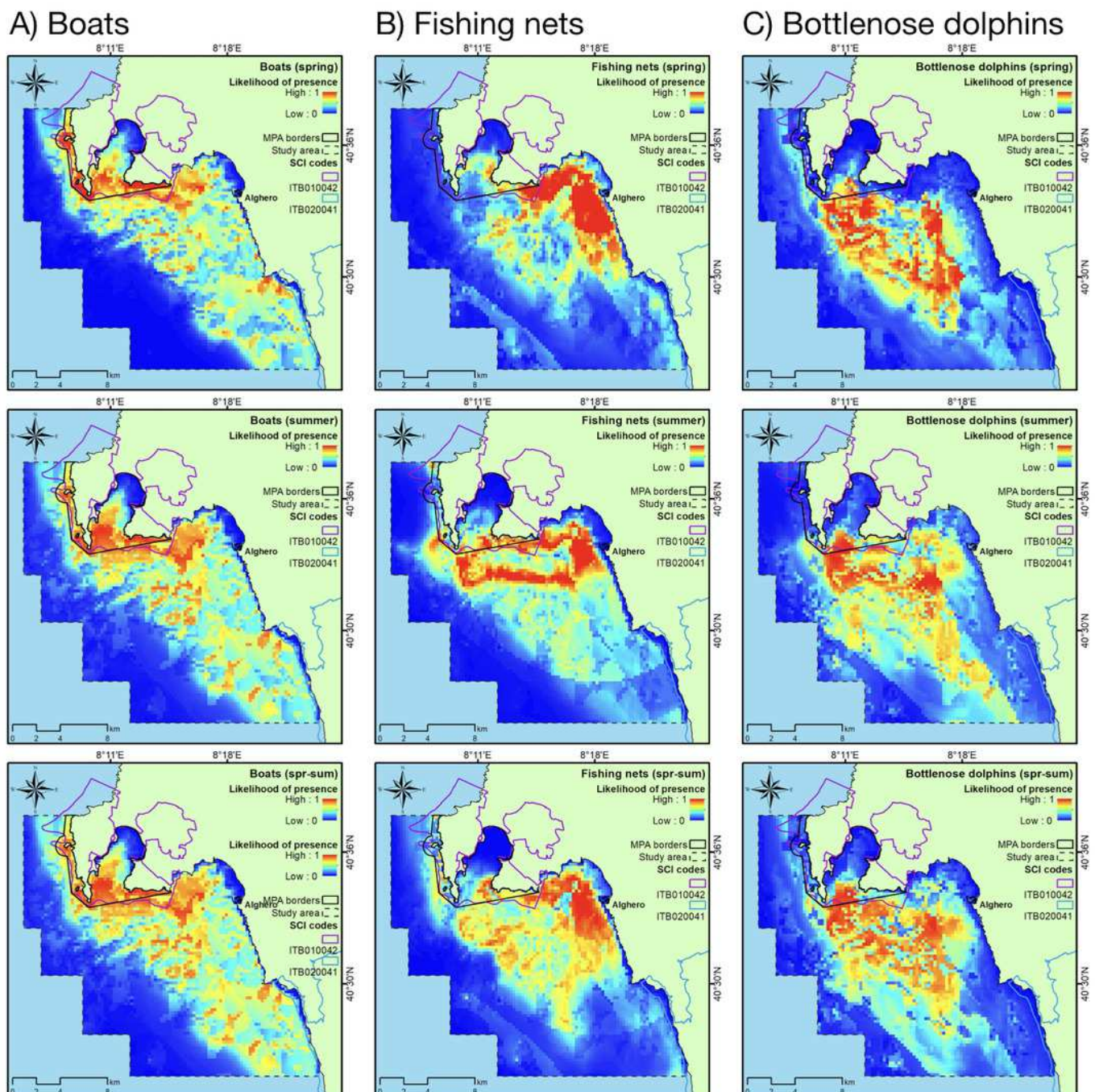
Figure 4

Overlapping between dolphin and boat representative areas (A) and dolphin and fishing net representative areas (B) in the two seasons (spring and summer) and for the whole period (spr-sum). PAO: percent area overlap.
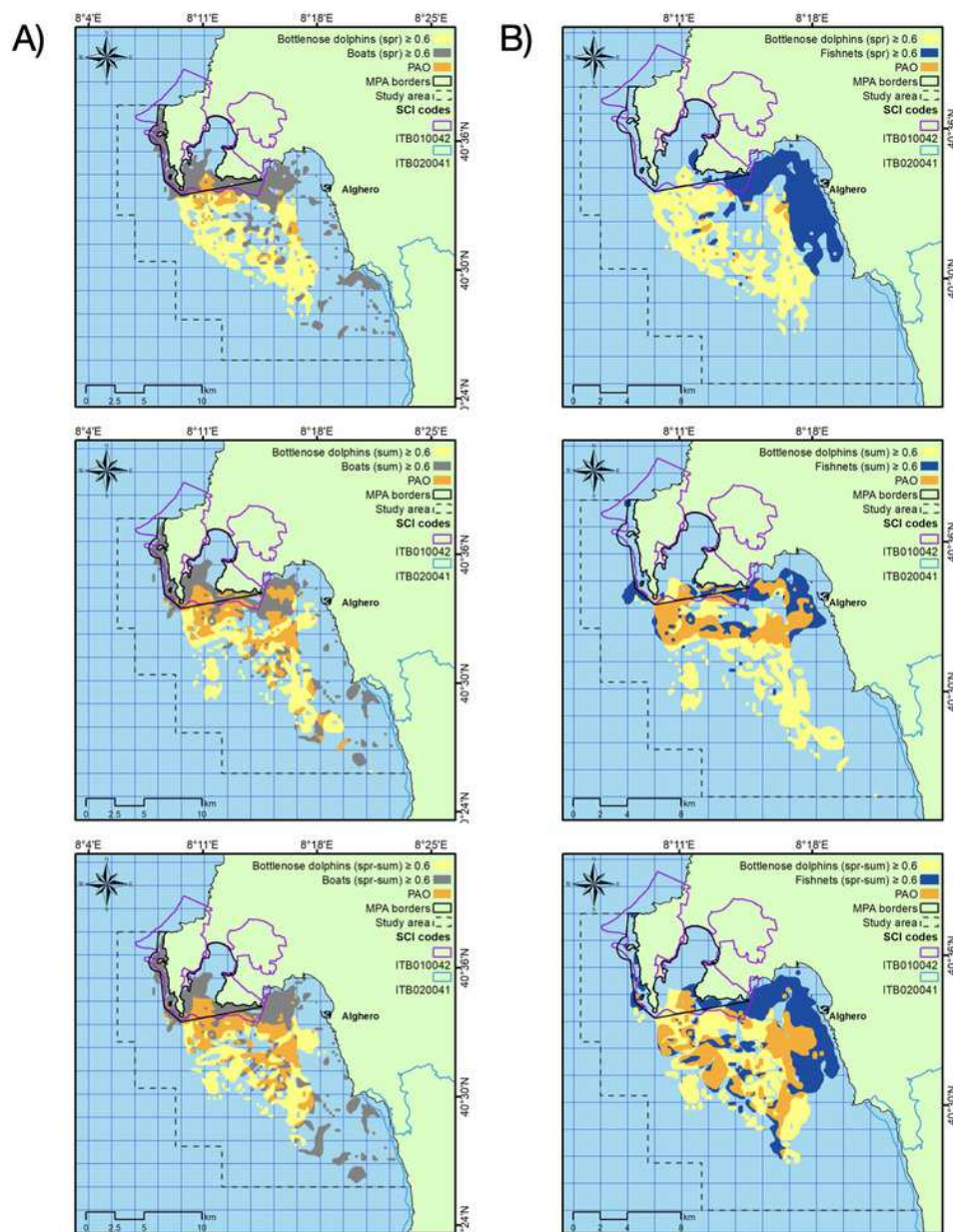
Figure 5

Effects of interactions between dolphins and fishery in Sardinia: dolphins showing clear signs of entanglement (A and C) and violent interaction with fishers (who use dive spearguns to get away the animals from the nets, B and D).