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# Modeling the spatial distribution of the striped dolphin (*Stenella coeruleoalba*) and common bottlenose dolphin (*Tursiops truncatus*) in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea)

Roberto Carlucci[a,*], Carmelo Fanizza[b], Giulia Cipriano[a], Chiara Paoli[c], Tommaso Russo[d], Paolo Vassallo[c]

[a] *Department of Biology, University of Bari Aldo Moro, via Orabona 4, 70125 Bari Italy*
[b] *Jonian Dolphin Conservation, viale Virgilio 102, 74121 Taranto Italy*
[c] *DISTAV, University of Genova, corso Europa 26, 16132 Genova Italy*
[d] *Department of Biology, University of Rome Tor Vergata, via della Ricerca Scientifica snc, 00133 Rome Italy*

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ABSTRACT

Although the EU Marine Strategy Framework Directive (MSFD) is largely based on the establishment of environmental targets and associated proxies to achieve Good Environmental Status (GES), a full suite of ecological indicators for all the ecosystem components is not currently available for ongoing assessment and regular update of GES targets. This is because effective indicators and management actions aimed at preserving/rebuilding marine biodiversity should be found from the knowledge of the spatial distribution of target species and extension of critical habitats as well as their overlapping with human activities, pressure and impacts. In this regard, the spatial distributions of the striped dolphin *Stenella coeruleoalba* and the common bottlenose dolphin *Tursiops truncatus* in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) were investigated by means of a generalized additive model (GAM) and a Random Forest (RF) based on sighting data collected during standardized vessel-based surveys carried out from 2009 to 2015. Eight predictive variables were considered, taking into account both the local physiographic features and human activities existing in the investigated area, suggesting an innovative approach to habitat modeling. In particular, the explanatory variables depth, distance from industrial areas and distance from the coast proved to significantly influence the distribution of both dolphin species. In addition, the distribution of *S. coeruleoalba* and *T. truncatus* were also significantly shaped by the distance from the navy exercise areas and the fishing areas, respectively. On the contrary, the slope and the distance from the main commercial routes never provided any significant influence. The reliability of GAM and RF models in predicting the spatial distribution of both dolphins was tested by applying the Youden Index method to the ROC curves. The RF model allowed the projection of the expected presence/absence pattern of *S. coeruleoalba* and *T. truncatus* to produce the preference habitat versus non habitat map. In particular, the RF model predicted that the striped dolphin is widely present in the central and deeper part of the Gulf of Taranto. In contrast, the common bottlenose dolphin seems to be mainly distributed along the coasts in both the eastern and western sector of the basin. A clear overlapping of the preference habitats estimated for *S. coeruleoalba* and *T. truncatus* is shown north of Punta Alice and in front of Policoro as well as offshore from Ugento in the eastern and western parts of the investigated area, respectively. Finally, the critical habitats of *S. coeruleoalba* and *T. truncatus* are the outcome of both the influence of environmental conditions and anthropogenic pressures presently occurring in the Gulf of Taranto, basically indicating the need for conservation measures, especially considering that the area is expected to be considered for hydrocarbon prospecting. These results contribute to setting up a baseline reference for future assessment of environmental marine disturbances using cetaceans, which are considered a key group in the MSFD, as an ecological indicator.

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* Corresponding author.
*E-mail address:* roberto.carlucci@uniba.it (R. Carlucci).

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## 1. Introduction

The Marine Strategy Framework Directive (MSFD), the Maritime Spatial Planning Directive (MSPD) and the Common Fisheries Policy (CFP) (EU, 2013) are the main EU policies incorporating the ecosystem-based management (EBM) framework to human activities as a significant contribution to achieving the goals of the Biodiversity Strategy for the EU marine environments (EEA – European Environment Agency, 2015). The main issue for EU policy is to deal with the loss of biodiversity in a holistic pathway, maintaining marine habitats as a whole in a healthy, clean, productive and resilient condition. Although the MSFD is largely based on the establishment of environmental descriptors and criteria set to achieve Good Environmental Status (GES) by 2020, a full suite of ecological indicators for all the ecosystem components is not currently available for assessing their status under anthropogenic pressures. Indeed, effective indicators and management actions aimed at preserving/rebuilding marine biodiversity should be found from the knowledge of the spatial distribution of target species and extension of critical habitats as well as their overlapping with human activities, pressure and impacts. Moreover, a key insight of ecosystem-based management is that human activities often affect the marine environment in complex ways. This is highly relevant in the Mediterranean Sea, the largest and deepest enclosed sea on Earth, defined as a sort of ocean in miniature acting as a marine biodiversity hot spot hosting 7% of the world's marine biodiversity (Coll et al., 2012). Mediterranean Sea diversity has been severely altered by different anthropic pressures over time thus making it particularly vulnerable. Anthropogenic pressures include the increasing use of coastal areas, eutrophication, marine traffic, alien species, pollution and dumping, as well as global warming, and they are expected to increase in the future (Bianchi and Morri, 2000; CIESM, 1997; Coll et al., 2010, 2012; Myers et al., 2000). The presence of different environmental and human drivers of change generates cumulative impacts at different spatial and temporal scales (Coll et al., 2012). This condition represents the main obstacle when striving to protect, among others, marine mammals. In Mediterranean coastal areas, dolphins and whales, suffering habitats fragmentation and loss (Simmonds and Nunny, 2002) or the alterations in distribution and availability of resources (Gambaiani et al., 2009; Learmonth et al., 2006; MacLeod, 2009), could also be exposed to high levels of local anthropogenic impact, such as fishing, shipping collision, noise from military sonar or seismic surveys (Bearzi, 2002; Dolman et al., 2010; Fossi and Lauriano, 2008; Hildebrand, 2005) and chemical pollution including marine litter (Aguilar and Borrell, 2005; Fossi et al., 2003; Patterson et al., 2004; Triantafillou, 2008).

Beyond the fact that cetaceans represent totemic species, they respond to most of the criteria defined, within the MSFD, for selecting key species/groups to develop indicators (Azzellino et al., 2014). In fact, the range of cetacean species and their habitat distribution, extent and condition represent fundamental indicator classes providing a common currency for evaluating the impacts of different human activities on ecosystem functioning. However, to date, the knowledge about the presence and the distribution of cetaceans in the Mediterranean Sea, as well as their conservation status, is still rather heterogeneous and defective. In particular, large areas of the central-eastern regions are still scarcely or completely unsurveyed (Notarbartolo di Sciara and Birkun, 2010). Concerning the Ionian Sea (Central-eastern Mediterranean Sea), the available information reports the presence of eight different species of cetaceans (Notarbartolo di Sciara et al., 1993; Notarbartolo di Sciara and Birkun, 2010; Reeves and Notarbartolo di Sciara, 2006). Specifically, more recent observations collected in the framework of a monitoring vessel survey confirmed that the striped dolphin *Stenella coeruleoalba* and the common bottlenose dolphin *Tursiops truncatus* regularly inhabit the Northern Ionian Sea (Dimatteo et al., 2011; Fanizza et al., 2014; Carlucci et al., 2015). Despite the presence of adults, juveniles and calves of *S. coeruleoalba*, no conservation measures to ensure a favorable status and the long-term survival of the species are currently enforced in the area, mostly due to shortcomings in the basic scientific information (Fanizza et al., 2014). Conversely, both species could be exposed to high levels of anthropogenic threats such as strikes from merchant traffic, disturbance from high intensity military sonar and exposure to chemical pollution from the nearby the harbor of Taranto (Cardellicchio et al., 2000; Marsili and Focardi, 1997). In addition, several exploration programs for hydrocarbons have recently been permitted or are under evaluation by the Italian Ministry for the Environment, the Land and the Sea (http://www.va.minambiente.it), in order to detect possible offshore gas/oil deposits within the national Exclusive Economic Zone (EEZ). In particular, these activities have also been allowed in the Northern Ionian Sea, as well as in other Mediterranean areas, representing a potential threat for these species that have both been assessed as vulnerable with evidence of a suspected decline in the subpopulation within the ACCOBAMS regions (Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area) (Reeves and Notarbartolo di Sciara, 2006). Hence the need for identifying the critical habitats for *S. coeruleoalba* and *T. truncatus* in the Northern Ionian Sea becomes even more urgent. In fact, the habitats characterization should be matched with the identification of the distribution of the main anthropogenic threats in order to better support potential alternative management strategies (Ahmadi-Nedushan et al., 2006; Halpern et al., 2008).

In the last thirty years, the advances in regression analysis provided by generalized linear models (GLMs) and generalized additive models (GAMs) has allowed the development of ecological models, increasing our understanding of ecological systems (Guisan et al., 2002). Lastly, the Random Forest technique (Breiman et al., 1984), based on an automatic combination of decision trees has also been applied in comparison with other regression techniques, and has proved to be more reliable and accurate in predicting habitat uses (Cutler et al., 2007; Virkkala et al., 2010). In particular, recent developments in spatial modeling have made it possible to predict the presence/absence or the abundance of a species by means of a set of predictor variables, highlighting the relative importance of habitats (Baumgartner, 1997; Phillips et al., 2006; Pitchford et al., 2015; Redfern et al., 2006; Thorne et al., 2012). These approaches are increasingly becoming essential to identify critical habitats in order to enhance the protection of threatened species, mostly in coastal areas where the potential for conflicts is high (Best et al., 2012; Edren et al., 2010).

The spatial pattern of *S. coeruleoalba* and *T. truncatus* in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) was modeled, in this study, with the aims of assessing the driving forces influencing the distribution of these top predators and, in turn, suggesting indications and practices for their conservation and management. With these purposes in mind, sighting data collected for both dolphin species from 2009 to 2015 during a standardized vessel-based survey were used and different predictive variables were considered. In particular, physiographic features, reckoned to be important for the distribution of cetaceans both in the Atlantic Ocean (Bailey and Thompson, 2006; Baumgartner, 1997) and more recently in the Mediterranean Sea (Azzellino et al., 2008; Blasi and Boitani, 2012; Marini et al., 2015) were taken into account together with the human activities existing in the basin, suggesting an innovative approach to habitat modeling. Thus, eight predictive variables were tested: depth, slope, distance from coast, canyon, areas of navy exercises, routes of merchant traffic, fishing areas, industrial activities. In particular, these predictive variables were employed to determine the presence/absence probability by means of a generalized additive model (GAM) and a Random Forest (RF).

## 2. Materials and methods

### 2.1. Study area

The Gulf of Taranto in the Northern Ionian Sea (Central Mediterranean Sea) extends about 22000 km$^2$ from Santa Maria di Leuca to Punta Alice (Fig. 1). In particular, the basin is the extension of the Southern-Apenninic orogenic system characterized by very complex bottom topography. In fact, the western sector is characterized by a narrow continental shelf with a steep slope and several channels, while the eastern sector has terraces descending toward the "Taranto Valley", a NW-SE submarine canyon with no clear bathymetric connection to a major river system (Harris and Whiteway, 2011; Pescatore and Senatore, 1986; Rossi and Gabbianelli, 1978). This singular morphology involves a complex distribution of water masses with a mixing of surface and dense bottom waters (Sellschopp and Álvarez, 2003) and the occurrence of upwelling currents with high seasonal variability (Bakun and Agostini, 2001; Milligan and Cattaneo, 2007).

The coastal area in the Gulf of Taranto is characterized by a high level of urbanization (Ladisa et al., 2010). In addition, the coastal zone near the harbor of Taranto is devoted to many different activities among which the intense commercial shipping along the main defined commercial routes (Marine Traffic, 2015) (https://www.marinetraffic.com) stands out together with the presence of heavy industries (Ben Meftah et al., 2008) (Fig. 2). In particular, a mass production steel-works, an oil refinery and a cement plant are sited in the industrial area of Taranto and there is a thermoelectric power station near Corigliano Calabro. Different areas for the execution of navy exercises such as surface and submarine naval maneuvers, and a shooting range are also found in the Gulf of Taranto. Their geographical coordinates and characteristics were gathered by consulting the decrees provided by National Coast Guard and "Notice to Skippers" from 2009 to 2015 (Guardia Costiera, 2015) (http://www.guardiacostiera.gov.it/taranto/Pages/ordinanze.aspx).

Intense fishing activity is also recorded in the basin with trawlers, long-liners, gill-netters, trammel netters and purse seiners distributed in different fishing harbors along the coasts (Carlucci et al., 2016).

### 2.2. Investigated species

The striped dolphin is a cosmopolitan species, preferentially inhabiting highly productive waters off the continental shelf (Forcada et al., 1994; Gannier, 2005; Notarbartolo di Sciara et al., 1993; Perrin et al., 1994). In the Mediterranean Sea, *S. coeruleoalba* is the most abundant cetacean distributed both inshore and offshore (Aguilar, 2000; Gaspari et al., 2007) with a decreasing W-E gradient in abundance, probably reflecting the reduction in the productivity of the easternmost basins (Notarbartolo di Sciara and Birkun, 2010).

The Red List of the IUCN classifies the Mediterranean striped dolphin as vulnerable since it is suspected that a 30% of reduction in subpopulation size has occurred over the last three generations (ca. 60 years) due to the decline in quality of habitat affecting food availability, incidental mortality in fisheries and the effects of pathogens and pollutants (Aguilar and Gaspari, 2012).

The common bottlenose dolphin has coastal and pelagic ecotypes with different morphological and ecological characteristics (Mead and Potter, 1995; Notarbartolo di Sciara and Demma, 2004; Reeves and Notarbartolo di Sciara, 2006). In the Mediterranean Sea, *T. truncatus* forms small groups showing a residential attitude. The species is preferentially distributed within the limits of the continental shelf (Bearzi et al., 2008; Reynolds et al., 2000; Wells and Scott, 2009). However, it can also be found above the shelf-break in the western Mediterranean (Bearzi et al., 1997; Cañadas and Hammond, 2006; Forcada et al., 2004). *T. truncatus* has been included on the Red List of the IUCN, as a vulnerable species being subject to various anthropogenic threats.

### 2.3. Sightings data

Sightings data of both *S. coeruleoalba* and *T. truncatus* were collected from 2009 to 2015 during standardized vessel-based surveys. In particular, until 2012 surveys were carried out using a rib boat, replaced by a 12 m catamaran in the following years. The sampling effort was set to about 5 h/day along 35 nautical miles. Speed was maintained between 7 and 8 knots and trips occurred only in favorable weather conditions (Douglas scale $\leq$3 and Beaufort scale $\leq$4). A line transect sampling was adopted according to Buckland et al. (2001), investigating a survey area of about 640 km$^2$ with an equal coverage probability (Fig. 1). In particular, starting from the harbors of Taranto or Policoro, a random transect was generated each day using the Distance 6.0 software (Thomas et al., 2010).

The observer team on board consisted of at least three people. One was an observer searching for targets around 180° and counting the dolphin specimens during sighting, while the others searched in a sector from the track-line to 90° supporting the activities of the former observer. The observer team rotated roles every 90 min. Once a target had been sighted, 7 × 50 binoculars were used to identify the species and video-photo records were made focusing on body markers. Observers had to maintain a minimum safe distance of 5–10 m from dolphins, lowering speed or interrupting navigation in order to prevent collisions and possible injuries. Date, daytime, sea weather conditions, geographic coordinates, depth (m), group size, perpendicular distance (in nautical miles) of the target from the track-line and the behavior of the dolphins were recorded.

For both species the presence data used to fit the models included all the sightings which occurred along the line transects carried out within the survey area from 2009 to 2015. When no sighting of *S. coeruleoalba* or *T. truncatus* occurred along a transect, the absence data was attributed for both dolphin species.

A validation dataset was employed in order to validate the presence/absence predictions of *S. coeruleoalba* and *T. truncatus* when projected on the whole study area. With that aim, further 60 sightings of both dolphin species were used, being recorded with the catamaran from 2012 to 2015 in the Gulf of Taranto but outside the survey area during different research surveys.

### 2.4. Data processing

The Gulf of Taranto was divided into a regular grid consisting of 109720 square cells (422 horizontal and 260 vertical cells) of about 450 × 450 m. This value of cell size was defined as the best compromise between the will to describe the system in the highest spatial detail and the computational issues associated. A dependent binary (0–1) variable (response) was generated to identify the cells with/without at least one sighting occurrence (respectively reckoned as a presence/absence cell). In addition, a set of 8 explanatory variables (depth, slope, distance from coast, distance from canyons, distance from navy exercise areas, distance from merchant shipping routes, distance from fishing areas, distance from industrial areas) was considered for the analysis (Table 1). Some of these have been applied in other studies on the distribution of dolphins and whales (e.g. Azzellino et al., 2008; Bailey and Thompson, 2006; Fiori et al., 2014; Goetz et al., 2015; Marini et al., 2015; Panigada et al., 2008; Torres et al., 2008). In addition, 4 explanatory variables were

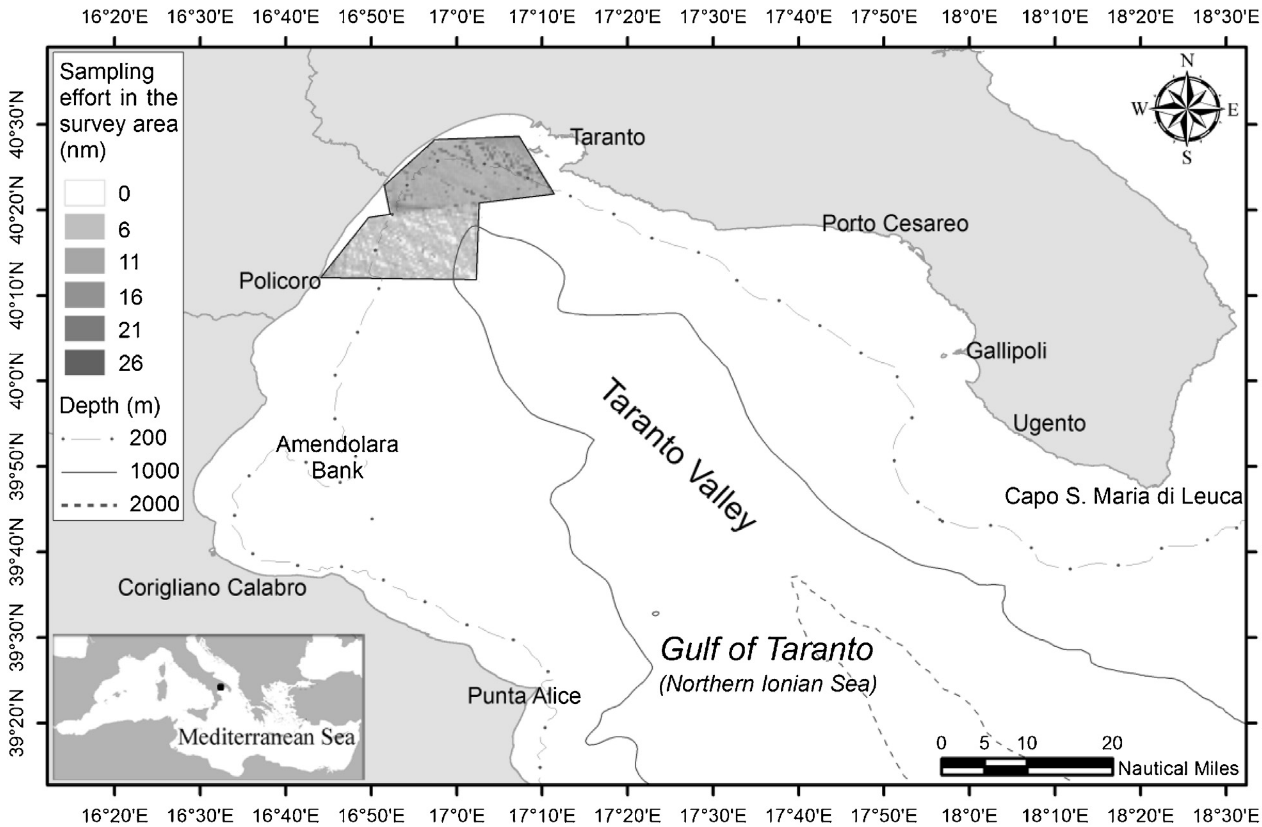


**Fig. 1.** Map of the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) with indication of sampling effort occurred in the survey area from 2009 to 2015. The amount of sampling effort for each cell is represented by a grey scale.

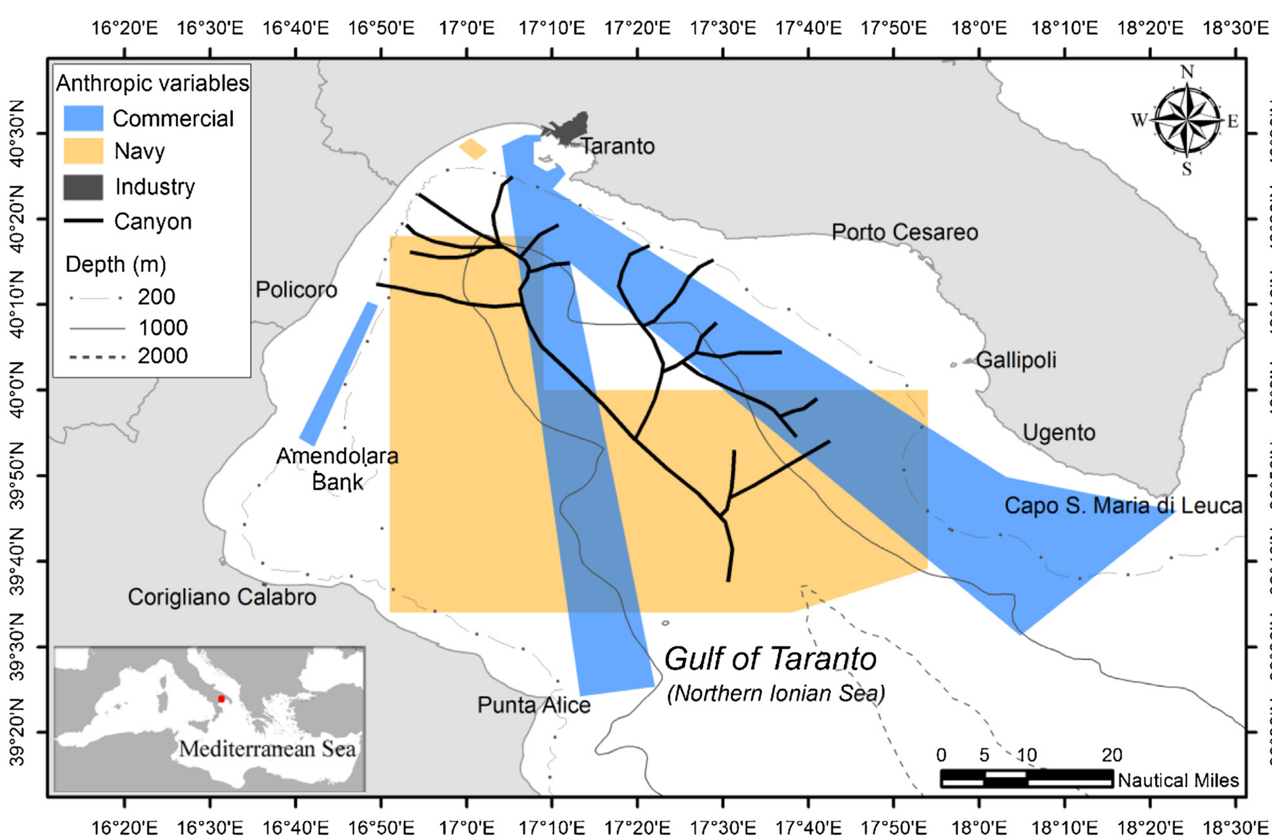


**Fig. 2.** Map of the "Taranto Valley" canyons system with indication of its main axes as identified by Senatore (1987) and anthropic variables identified in the study area.

**Table 1**
List of the explanatory variables selected for modeling the spatial distributions of the striped and common bottlenose dolphins in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea).

| Variable | Calculation method | Acronym |
|---|---|---|
| Depth | Depth values are derived from EMODnet Bathymetry dataset provided by the European Marine Observation and Data Network (http://www.emodnet.eu/bathymetry) | Depth |
| Slope | Maximum rate of depth variation between adjacent cells | Slope |
| Distance from coast | Minimum distance of the cell center from the coastline | Coast |
| Distance from canyon | Minimum distance of the cell center from the main axes of the "Taranto Valley" canyons system (Fig. 2) | Canyon |
| Distance from the navy exercise areas | Minimum distance of the cell center from the areas of navy exercises (Fig. 2) | Navy |
| Distance from the merchant shipping routes | Minimum distance of the cell center from the main merchant routes recorded in/out the Taranto harbor (Fig. 2) | Commercial |
| Distance from the industrial areas | Minimum distance of the cell center from the areas identified as addressed to heavy industrial activities (Fig. 2) | Industry |
| Distance from the areas exploited by fishery | Minimum distance of the cell center from the areas with recorded fishing effort in the 30 days before each sighting | Fishery |

specifically introduced in this study due to the peculiarity of the study area and the strong anthropic features of the Gulf of Taranto (i.e. navy, commercial, industry and fishery). In fact, these latter explanatory variables were considered as proxies for disturbance and impacts that may have an influence on shaping the distribution of both dolphin species. In particular, the distance from the areas of navy exercises, from the main commercial routes and the industrial areas, are employed as measures of the noise disturbance. Lastly, the distance from the areas exploited by fishing is considered as a proxy of the attractive or repulsive influence on dolphins due to the presence of discard thrown into the sea from commercial vessels or to the reduction in prey availability, respectively.

A reconstruction of depth in each cell was modeled for the study area deriving input data at a 1/8 min × 1/8 min resolution from the EMODnet Bathymetry dataset provided by the European Marine Observation and Data Network (EMODnet, 2015) (http://www.emodnet.eu/bathymetry). Finally, the slope was also calculated, considering the maximum rate of depth variation measured between 8 adjacent cells surrounding the target one. In particular, it was calculated as $max|D - D_{\text{near}}|/\text{DI}$ where $D$ is the depth of the target cell, $D_{\text{near}}$ is the depth of the adjacent cells, and DI is the distance in m between the cells compared.

### 2.5. Distribution of fishing activities

The data provided by the Vessel Monitoring System (VMS) (European Commission, 2015a) (http://ec.europa.eu/fisheries/cfp/control/technologies/vms) were used to assess the amount and the distribution of fishing effort concerning fishing vessels larger than 12 m in overall length. Original VMS data were gathered within the EU Data Collection Framework Program. Namely, VMS data for each fishing vessel operating in the area were cleaned, interpolated (Russo et al., 2011a) and linked to external databases (i.e. http://ec.europa.eu/fisheries/fleet/index.cfm (European Commission, 2015b) to assess the fishing gear (Russo et al., 2011b). After the complete reconstruction and classification of the fishing activity for each vessel, the fishing set positions for each vessel/day were finally inferred using speed and depth filters (Russo et al., 2014). The analysis of VMS data revealed that the cumulative contribution of purse seiners, gill-netters, trammel netters and long-liners was negligible in the study area (less than 9% of the total fishing effort per year) and thus only the fishing effort from bottom trawl was considered for training the GAM and RF models. Fishing set positions for trawlers were finally used to compute the spatial distribution of the daily fishing effort on a regular grid covering the entire study area, for each year throughout the time period 2006–2015. Since fishing activity was the only variable considered with temporal variation, it was linked to sightings considering the cumulative fishing effort in the 30 days before each sighting. This is to take into account both the differences in the distribution of fishing effort throughout the year (seasonality) and a reasonable delay between fishing activity and its potential effect on dolphins. Data from 2006 to 2014 were employed for development and training of the models, while 2015 was considered for the prediction.

### 2.6. Spatial analyses

Techniques applied for modeling the spatial distribution of dolphins and whales are usually based on the collection of presence-absence data. As the presence/absence data set was zero-inflated, the number of absence cells was balanced to the number of presence cells. This was done by maintaining all the presences and extracting at random the corresponding number of absences (Azzellino et al., 2012; Fiori et al., 2014; Marini et al., 2015). This approach was proposed to avoid the application of more sophisticated methods such as the hurdle-Negative Binomial and zero-inflated mixture-Negative Binomial models (Hall, 2000). In fact, the adopted procedure has the advantage of bringing a unique zero inflated correction into the analysis that could be applied to both GAM and RF modeling, so limiting the introduction of further differentiations between methodologies. Finally, explanatory variables were tested to check normality and avoid collinearity.

#### 2.6.1. Generalized additive model

The greatest benefit of using additive modeling (GAM) resides in its flexibility in capturing non-linear species-habitat relationships. In fact, when data are related to certain variables but the relationships fail to be simply linear, GAM uses a link function to establish a relationship between the mean of response variable and the smooth function of the explanatory variables. As a consequence, the association between response and explanatory variables derives from the data itself and not from the model, because no kind of parametric assumption is made (Hastie and Tibshirani, 1990; Yee and Mitchell, 1991).

In this study, the GAM approach was applied to determine whether the selected variables affect the distribution of *S. coeruleoalba* and *T. truncatus* in the study area, as recently employed for cetaceans in the Pacific and Atlantic oceans (Forney et al., 2012; Tardin et al., 2013) and Mediterranean Sea (Marini et al., 2015; Tepsich et al., 2014). In particular, the GAM regression and smoother terms were derived using penalized regression splines using the MGCV library for freeware R (Wood, 2006) with a binomial distribution (family = binomial, link function = logit) of the dependent variable (presence/absence of dolphins in each spatial cell). Smoothness selection was based on an Un-Biased Risk Estimator (UBRE).Thus, for each species, the spatial distribution of dolphins in each cell $Y_i = B\ (1, P_i)$ was investigated as a binomial variable with $P_i$ (probability of presence/absence) equal to $e^{g(x_i)}/(1 - e^{g(x_i)})$, with $P_i$ being between 0 and 1 according to a Bernoulli distribution. In particular, $g(x_i) = \alpha + f_j(x_j) + \ldots + f_n(x_n)$ is a combination of smoothing functions (splines) $f_j(x_j)$ of explanatory variables (smoothers), $x_j$ are the explanatory variables (depth, slope and distances from the coast, canyon, industry, fishery, commercial routes and navy exercise areas) and $f_j$ are the best smoothing functions estimated by maximum likelihood and fitting data better than a straight line. The numerical output of the model showed significant variables, selected by means of a chi-squared test with a significance level for the selection of the explanatory variable fixed at 5%. Significant explanatory variables were selected by means of a Backward Elimination method (Zuur et al., 2007). In particular, a model of size *p* (with *p* being the total number of variables) was developed and non-significant variables were eliminated one at time in a step by step procedure. Thus, when a variable is selected a significant non-linear relationship exists between this variable and the presence/absence of dolphins.

A graphic representation of the influence predicted by GAM on presence/absence of dolphins in function of each smoother is shown. The higher is the value in the smoothing curve, the more probable is the presence of dolphins in the corresponding value of the selected explanatory variable.

#### 2.6.2. Random forest

Random Forest (RF) is a classification technique of neural networks (Breiman, 2001). It is based on regression tree methodology and is able to model a response variable from a number of explanatory variables by subdividing a dataset into subgroups. This can be represented as a binary tree, a hierarchical structure formed by nodes and edges, the latter representing some sort of information flow between adjacent nodes. In particular, subgroups originate from recursive partitions based on decision rules that allow each part to be divided successively into smaller data portions.

This is achieved by two means: (1) a random selection of explanatory variables is chosen to grow each tree (3 predictors at each node) and (2) each tree is based on a different random data subset, created by bootstrapping (Efron, 1979). Finally, the optimal "splitting" in comparison with real data is identified and selected as a predictor. The data portion used as a training subset is known as the "in-bag" data, whereas the rest is called the "out-of-bag" data. The latter are not used to build the tree, but provide estimates of generalization error, which always converges as the forest size increases (Breiman, 2001). The number of trees needs to be sufficiently high (800 in this case) since the mean square error is calculated from prediction with the test dataset averaged over all trees (out-of-bag error).

The rank importance of each explanatory variable is accounted for as the changes in mean square error estimated by leaving a variable out of the model. After the most relevant variables were identified, the following step consisted of studying the nature of the dependence between the response variable and each explanatory variable. Partial dependence plots were used to characterize relationships graphically between individual explanatory variables and predicted probabilities of presence obtained from RF (Hastie et al., 2001).

All the 8 explanatory variables have been employed for the RF regression but, for the sake of brevity, only the four most relevant explanatory variables for each prediction are discussed while the remaining partial plots are reported as supplementary material.

#### 2.6.3. Verification of model performance

Model performance was evaluated for the verification of reliability of predictions. In particular, predictions within the survey area were compared to observed values allowing the compilation of an error matrix reporting the true (a) and false presences (b) as well as the true (c) and false absences (d) (Allouche et al., 2006).

In addition, a set of metrics of model accuracy was calculated, including sensitivity and specificity. Sensitivity is calculated as the ratio between true presences and total presences a/(a + c), counting for the probability that the model will correctly classify a presence. Specificity is computed as the ratio between true absences and total absences b/(b + d), measuring the probability that the model will correctly classify an absence. Finally, the true skill statistics (TSS = sensitivity + specificity-1) have been proposed as a new measure for the performance of the presence–absence distribution model in order to correct the dependency of sensitivity and specificity upon prevalence (the overall proportion of presences).

The optimal cut-off probability value was selected by applying the Youden Index method (Fluss et al., 2005) to the receiver operating characteristic (ROC) curve (Fielding and Bell, 1997). The ROC curve is obtained by plotting the true-positive rate (sensitivity) against the false-positive rate (1-specificity) for various cut-off values. In particular, the Youden Index method allows the determination of the optimal cut-off point using the maximum vertical distance of the ROC curve from the chance line (where false positive rate = true positive rate) (Hajian-Tilaki, 2013). Once the optimal cut-off was identified, the model was projected to the entire study area and the suitable habitat areas (cells with probability prediction higher than cut-off) were plotted and validated with an independent set of data collected outside the survey area borders (validation dataset).

## 3. Results

Within the survey area, a total of 438 daily surveys were carried out from 2009 to 2015. An effort of about 2190 h of observations and 15330 nautical miles was applied searching for *S. coeruleoalba* and *T. truncatus*, obtaining 405 and 46 sightings of striped dolphin and bottlenose dolphin, respectively (Table 2). With the exclusion of 15 sightings during which both dolphin species were observed along the same transect, the rest of the sightings occurred with a single dolphin species observation of *S. coeruleoalba* or *T. truncatus*.

*S. coeruleoalba* was observed in 89.8% of the total sightings recorded from 2009 to 2015. The frequency of occurrence calculated as the number of sightings per daily survey ranged from 0.78 (2014) to 1.13 (2010) (Table 3). Sightings occurred in a depth range between 15 and 1000 m with a mean depth of 421 ± 160 m. The encounter rate, calculated as the number of sightings per effort in nautical miles, varied between 0.022 (2014) and 0.032 (2010). A mean aggregation number of 43 ± 36 dolphins was estimated for the species in the basin. *T. truncatus* was observed in 10.2% of total sightings recorded during the investigated period showing a frequency of occurrence ranging between 0.07 (2013) to 0.15 (2011) (Table 3). Sightings occurred in a depth range between 2 m and 586 m with a mean depth recorded of 143 ± 151 m. A mean aggregation number of 11 ± 9 specimens was estimated for the area and the encounter rate varied from 0.002 (2013) to 0.004 (2011).

The resulting presence cells totaled 323 and 43 for *S. coeruleoalba* and *T. truncatus* respectively; as a consequence the model training procedures were based on 646 cells for *S. coeruleoalba* and 86 cells for *T. truncatus*.

### 3.1. GAM results

GAMs developed for *S. coeruleoalba* and *T. truncatus* reached 34.70 and 23.04% of explained deviance, respectively. The spatial

**Table 2**
Sampling period, number of daily surveys, effort (hours and nautical miles), range of investigated depth (m) and number of sightings of *S. coeruleoalba* and *T. truncatus* occurred in the Gulf of Taranto from 2009 to 2015.

| Sampling period | Daily surveys (n.) | Effort | | Depth range (m) | Number of sightings | |
|---|---|---|---|---|---|---|
| | | hours | nautical miles | | *Stenella coeruleoalba* | *Tursiops truncatus* |
| April-August 2009 | 13 | 65 | 455 | 93–500 | 11 | 1 |
| April-August 2010 | 24 | 120 | 840 | 180–636 | 27 | 3 |
| January-November 2011 | 61 | 305 | 2135 | 15–665 | 54 | 9 |
| January-August 2012 | 50 | 250 | 1750 | 20–694 | 42 | 6 |
| June-December 2013 | 73 | 365 | 2555 | 20–882 | 64 | 5 |
| May-December 2014 | 105 | 525 | 3675 | 2–1000 | 82 | 11 |
| April-October 2015 | 112 | 560 | 3920 | 30–950 | 125 | 11 |
| Total | 438 | 2190 | 15330 | 2–1000 | 405 | 46 |

**Table 3**
Sampling period, encounter rate (sightings per survey effort in nm), frequency of occurrence (number of sightings per daily survey), mean aggregation number with standard deviation and depth range for the sightings of *S. coeruleoalba* and *T. truncatus*.

| Sampling period | Encounter rate | | Frequency of occurrence | | Mean aggregation number | | Depth range (m) | |
|---|---|---|---|---|---|---|---|---|
| | *Stenella coeruleoalba* | *Tursiops truncatus* | *Stenella coeruleoalba* | *Tursiops truncatus* | *Stenella coeruleoalba* | *Tursiops truncatus* | *Stenella coeruleoalba* | *Tursiops truncatus* |
| April–August 2009 | 0.024 | 0.002 | 0.85 | 0.08 | 46 ± 29 | 10 | 200–500 | 93 |
| April–August 2010 | 0.032 | 0.004 | 1.13 | 0.13 | 49 ± 35 | 11 ± 7 | 200–636 | 180–419 |
| January–November 2011 | 0.025 | 0.004 | 0.89 | 0.15 | 43 ± 29 | 16 ± 11 | 15–665 | 36–586 |
| January–August 2012 | 0.024 | 0.003 | 0.84 | 0.12 | 46 ± 34 | 21 ± 11 | 22–694 | 20–500 |
| June–December 2013 | 0.025 | 0.002 | 0.88 | 0.07 | 62 ± 40 | 6 ± 5 | 117–882 | 20–421 |
| May–December 2014 | 0.022 | 0.003 | 0.78 | 0.10 | 39 ± 48 | 9 ± 7 | 144–1000 | 2–401 |
| April–October 2015 | 0.032 | 0.003 | 1.12 | 0.10 | 33 ± 22 | 7 ± 5 | 150–950 | 30–500 |

**Table 4**
GAM statistics applied to the explanatory variables with indication of the estimated degrees of freedom (edf), chi squared and p values obtained from the test based on model deviance for *S. coeruleoalba* and *T. truncatus* in the Gulf of Taranto.

| *Stenella coeruleoalba* | | | | *Tursiops truncatus* | | | |
|---|---|---|---|---|---|---|---|
| | Estimate | Std. err. | p-val | | Estimate | Std. err. | p-val |
| (Intercept) | −2.130 | 0.129 | <0.001 | (Intercept) | −2.213 | 0.399 | <0.001 |
| Approximate significance of smooth terms | | | | | | | |
| Variable | edf | Chi.sq | p-val | Variable | edf | Chi.sq | p-val |
| f(fishery) | 0.621 | 2.735 | 0.033 | f(fishery) | 0.887 | 7.501 | 0.036 |
| f(depth) | 2.716 | 70.252 | <0.001 | f(depth) | 0.705 | 2.926 | 0.004 |
| f(navy) | 1.169 | 68.747 | <0.001 | f(industry) | 2.658 | 10.839 | 0.001 |
| f(industry) | 2.329 | 15.178 | <0.001 | | | | |

distribution of *S. coeruleoalba* was mainly affected by depth, navy and industry (Table 4). A lower influence but still significant was shown by fishery. Slope, coast, canyon and commercial were not significant explanatory variables and so not considered in GAM regression for *S. coeruleoalba*. The habitat identified by the GAM for *S. coeruleoalba* was characterized by a depth greater than 250 m, distance from the areas of navy exercises greater than 6 km, distance from industrial areas ranging from 5 to 25 km and distance from fishing areas exceeding 32 km (Fig. 3). Depth is commonly applied in distribution analyses and the range identified by GAM is in good agreement with previous studies (e.g. Panigada et al., 2008). On the contrary, the other explanatory variables significantly affecting the *S. coeruleoalba* distribution are not commonly applied but identify the preferred habitat as affected by human activity and the presence of *S. coeruleoalba* moved away from these disturbance sources.

The spatial distribution of *T. truncatus* was mainly affected by industry, depth and fishery (Table 4). Slope, coast, canyon, commercial and navy were not significant variables and so not considered in GAM regression for *T. truncatus*. The GAM identified the *T. truncatus* habitat as characterized by waters less than 300 m in depth, distances from fishery areas less than 10 km and distance from industrial areas greater than 40 km (even if a lower peak was detected from 15 to 25 km) (Fig. 4).

Depth is the morphological factor able to shape the spatial distribution of both dolphin species. In particular, it is well known that the main habitat of *T. truncatus* is limited to shallower water (Connor et al., 2000). Great influence is due to anthropic factors with the repulsive effect of industrial areas on *S. coeruleoalba* and the interaction between fisheries and *T. truncatus*.

### 3.2. RF results

Random forest identified that the spatial distribution of *S. coeruleoalba* was mostly driven by depth, distance from industrial areas, distance from the coast and distance from navy exercise areas (Fig. 5). On the contrary, slope and distance from the fishery were less important. For each adopted variable the univariate partial dependence plots identified the range of optimal values expected to increase the probability of presence (signature) in the RF model. A threshold level is clearly detectable with a very low probability of presence of striped dolphins in waters less than 200 m deep (Fig. 6). The influence of depth values on the spatial distribution of *S. coeruleoalba* showed an increasing with depth trend, reaching higher values starting from 300 m. The second explicative variable influencing the striped dolphin spatial distribution in the basin was the distance from the industrial areas. In fact, a single peak between 10 and 25 km was observed with a reduction of presence probability at distances from the industrial areas greater than 28 km. Distance

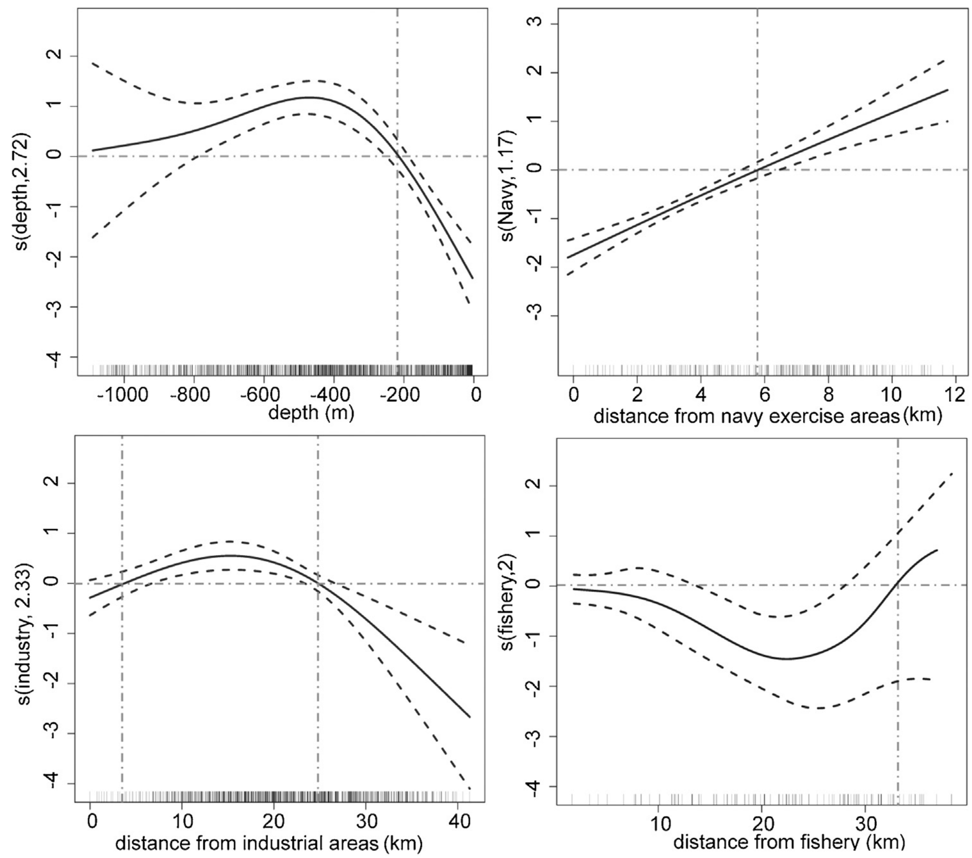


**Fig. 3.** Predicted smooth splines of the response variable presence/absence of *S. coeruleoalba* as a function of the validated explanatory variables. The degrees of freedom for non-linear fits are in parentheses on the y-axis. Tick marks above the x-axis indicate the distribution of sightings. Dotted lines represent the 95% confidence intervals of the smooth spline functions.

from the coastline had little influence on the striped dolphin distribution with a steep increase in probability starting from 10 km and very low probabilities at distances less than 5 km. This result should be correlated with increasing depth observed going away from coasts. Finally, distance from the areas of navy exercise showed a relevant effect on the spatial distribution of *S. coeruleoalba*. A continuous increasing trend was detected with higher values at distances exceeding 18 km.

The spatial distribution of *T. truncatus* was mainly shaped by depth, distance from the industrial areas, coast and fishery (Fig. 5). The slope was also a not very important explanatory variable for this species in the RF model. The depth variable showed the highest influence around 100 m with a steep reduction in probability down to 300 m (Fig. 7). An abrupt increase in probability was observed with increasing distance from the industrial areas with a clear threshold detected at 40 km. Distance from the coast showed a relevant effect on the spatial distribution of the common bottlenose dolphin. A clear influence was detected within 5 km where the shallower grounds were observed. Finally, the common bottlenose dolphin was shown to stay within 5 km of the fishing areas.

### 3.3. Models comparison and performances verification

Both GAM and RF identified depth, industry and navy as important variables for *S. coeruleoalba*. On the contrary RF resulted affected by distance from coast while GAM is significantly affected by fishery (lastly important for RF). For *T. truncatus*, both regression techniques identified the same explanatory variables (except coast which again is revealed as important only by RF).

Regarding the common identified explanatory variables, the dependencies of response variable revealed for RF more abrupt trends with clear thresholds for most of the variables while for GAM identified linear or smoother trends (Figs. 3, 4, 6 and 7). This may be due to the greater ability of RF to cope with the intrinsic variability of natural data and to relate in highly non-linear ways with the response (Parravicini et al., 2012; Siroky, 2009) and it is expected to influence the reliability of the predicted distributions.

The reliability of the GAM and RF models in predicting the spatial distribution of both *S. coeruleoalba* and *T. truncatus* was tested by applying the Youden Index method to the ROC curves. The optimal cut-off values and the set of predictive accuracy metrics were estimated for each model and species within the survey area (Table 5). The most reliable model is expected to show the highest values of sensitivity, specificity and TSS, being able to correctly identify both presences and absences of the target species. In particular, the RF model was the most reliable for modeling the spatial distribution of both the striped and bottlenose dolphins. Thus, the information provided by RF prediction together with the selection of the cut-off values allowed the projection of the expected presence/absence pattern of *S. coeruleoalba* and *T. truncatus* over the entire study area providing the preference habitat versus non habitat map (Fig. 8). The reliability of the projection on the Gulf of Taranto was tested, considering the spatial distribution of sightings of both dolphins in the validation dataset. The true presence rates of 0.73 and 0.77 for the striped dolphin and bottlenose dolphin were estimated, respectively.

The RF model predicted that the striped dolphin is widely present in the central and deeper part of the Gulf of Taranto. In contrast, the bottlenose dolphin seems to be mainly distributed along

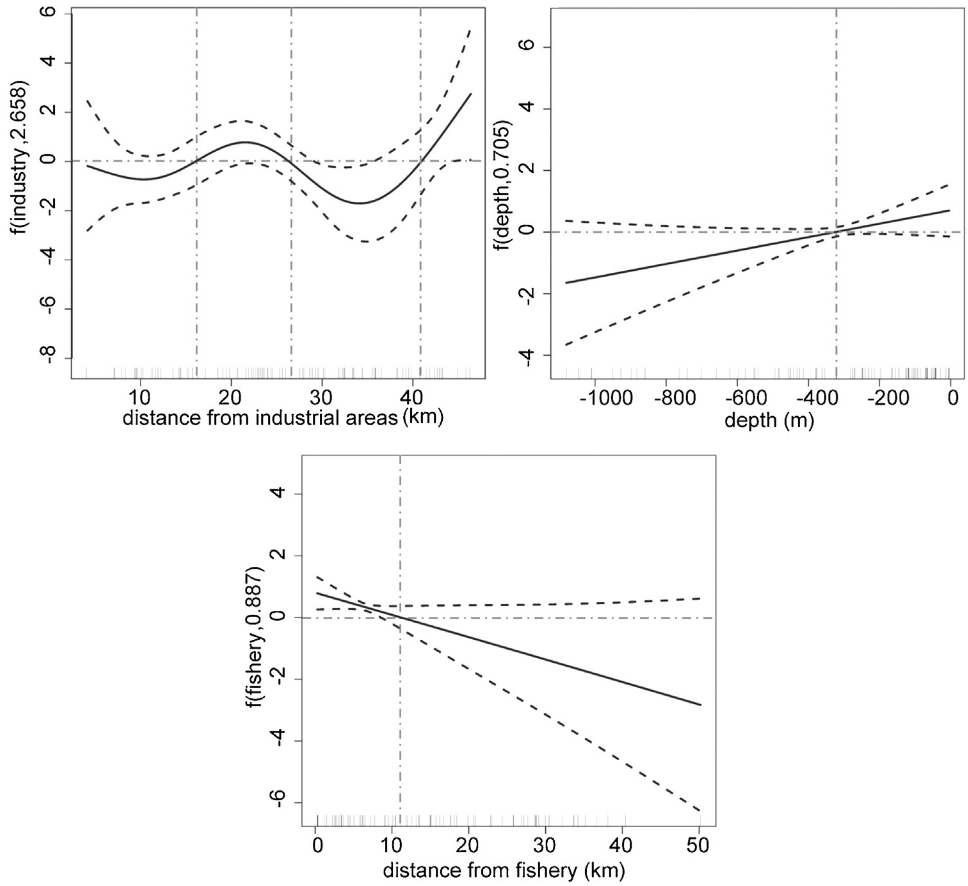


**Fig. 4.** Predicted smooth splines of the response variable presence/absence of *T. truncatus* as a function of the validated explanatory variables. The degrees of freedom for non-linear fits are in parentheses on the y-axis. Tick marks above the x-axis indicate the distribution of sightings. Dotted lines represent the 95% confidence intervals of the smooth spline functions.

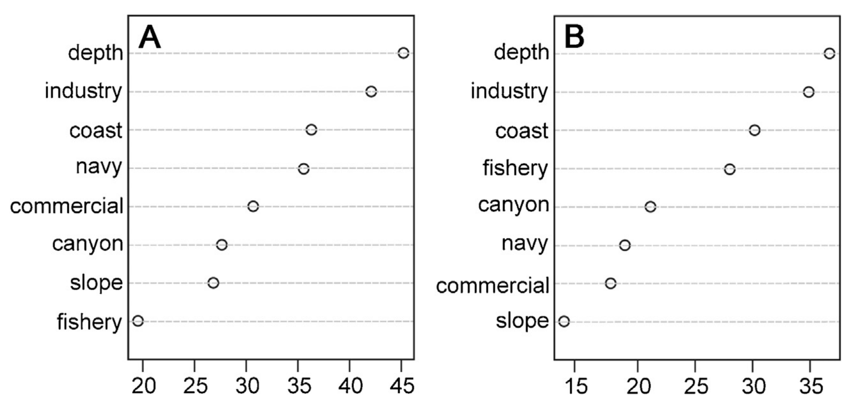


**Fig. 5.** Ranking importance scores of the explanatory variables used in the RF models for *S. coeruleoalba* (A) and *T. truncatus* (B). Importance is quantified as the percentage of increase in mean square error when that explanatory variable is removed from the RF model.

**Table 5**
Measures of predictive accuracy of GAM and RF models outputs.

| | Model | Cut-off | Sensitivity | Specificity | TSS |
|---|---|---|---|---|---|
| *S. coeruleoalba* | GAM | 0.30 | 0.74 | 0.78 | 0.52 |
| | RF | 0.51 | 0.97 | 0.95 | 0.92 |
| *T. truncatus* | GAM | 0.26 | 0.72 | 0.77 | 0.49 |
| | RF | 0.52 | 0.95 | 0.94 | 0.89 |

the coasts in both the eastern and western sector of the Gulf of Taranto. Clear hot spots were also observed for *T. truncatus* slightly offshore in the eastern sector due to favorable hydrographic and trophic conditions (i.e. presence of the Amendolara Bank) and in the western sector due to the wider platform.

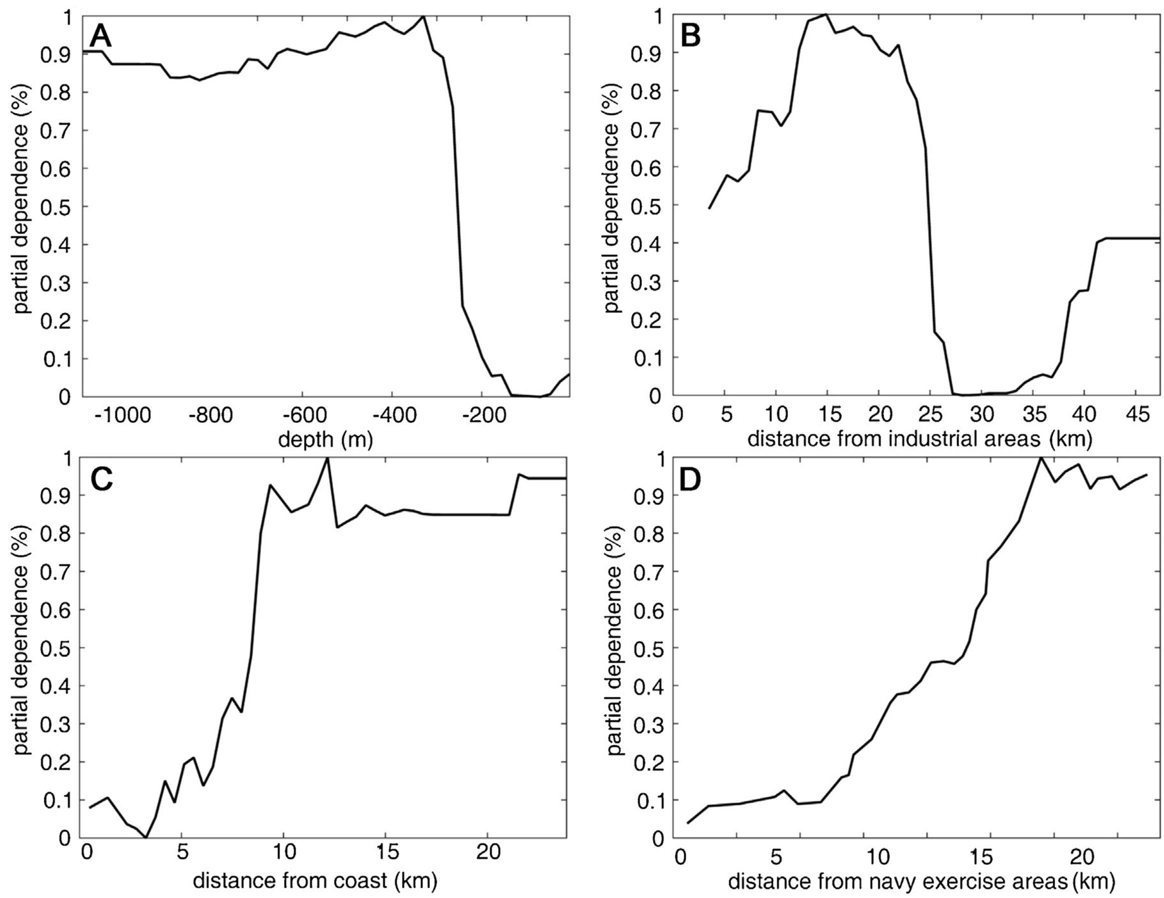


**Fig. 6.** Univariate partial dependence plots of the explanatory variables depth (A), distance from the industrial areas (B), distance from coast (C) and distance from areas of navy exercise (D), estimated by the RF model for *S. coeruleoalba*.

A clear overlapping of the preference habitats estimated for *S. coeruleoalba* and *T. truncatus* is shown north of Punta Alice and in front of Policoro as well as offshore from Ugento in the eastern and western parts of the Gulf of Taranto, respectively.

## 4. Discussion and conclusions

The maintenance of healthy and functional marine ecosystems mostly depends on the implementation of comprehensive governance, striking a balance between conservation and socioeconomic viability and minimizing the risk of habitat fragmentation and biodiversity loss (Klein et al., 2008). In fact, species diversity affects multiple ecosystem functions, from local to global scales, including the maintenance of productivity, resistance to and recovery from perturbation as well as the stability of food webs. On the contrary, the loss of biodiversity, due to the increasing human use of ocean and coastal waters, has the potential to reduce multi-trophic interactions and cause trophic cascade repercussions, in turn limiting the delivery of ecosystem goods and services (Costanza et al., 1997; Österblom et al., 2007).

In that regard, the main EU environmental policies dealing with the loss of biodiversity indicate the need for a more robust and comprehensive knowledge base to support policies and actions, which could result in more effective management. In particular, the Marine Strategy Directive Framework requires a biodiversity assessment of species and habitats at ecologically relevant scales in order to assess whether pressure/state changes are within safe biological limits (Berg et al., 2015) and the definitions of indicators and reference points designed to show whether the "Good Environmental Status" (GES) can be achieved in the EU waters by 2020 (Laurila-Pant et al., 2015).

Human activities and their impacts are able to influence the distribution of cetaceans both directly and indirectly. In this regard, among the considered variables some are able to directly influence the distribution of both dolphins (e.g. commercial shipping routes with potential collision risks). Others may indirectly act upon other biotic (e.g. fishing exploitation with competition for food resources) or abiotic factors (e.g. naval exercises, commercial merchant routes and industry generating noise and pollution). Nonetheless, in this study the explanatory variables depth, distance from industrial areas and distance from the coast, turned out to significantly affect the distribution of both striped dolphin and common bottlenose dolphin in the Northern Ionian Sea. On the contrary, slope, which is widely applied in other studies on modeling the spatial distribution of cetaceans (Azzellino et al., 2012; Cañadas et al., 2002, 2005; Pirotta et al., 2011), never brought significant improvement to the predicted distribution of either dolphin species. The same occurred with the distance from the main commercial routes into and out of the Taranto shipping harbor, which does not provide any significant influence.

Two out of four among the most significant explanatory variables for modeling the spatial distribution of both species proved to be dependent on human presence and activities. This finding highlights how heavy anthropic pressure negatively acts as a driving force in shaping the habitat use of marine species outstripping natural and geomorphological parameters that would normally shape the critical habitat of an undisturbed species. In fact, in this study both *S. coeruleoalba* and *T. truncatus* never showed a peak in probability values close to the industrial areas, confirming the effect

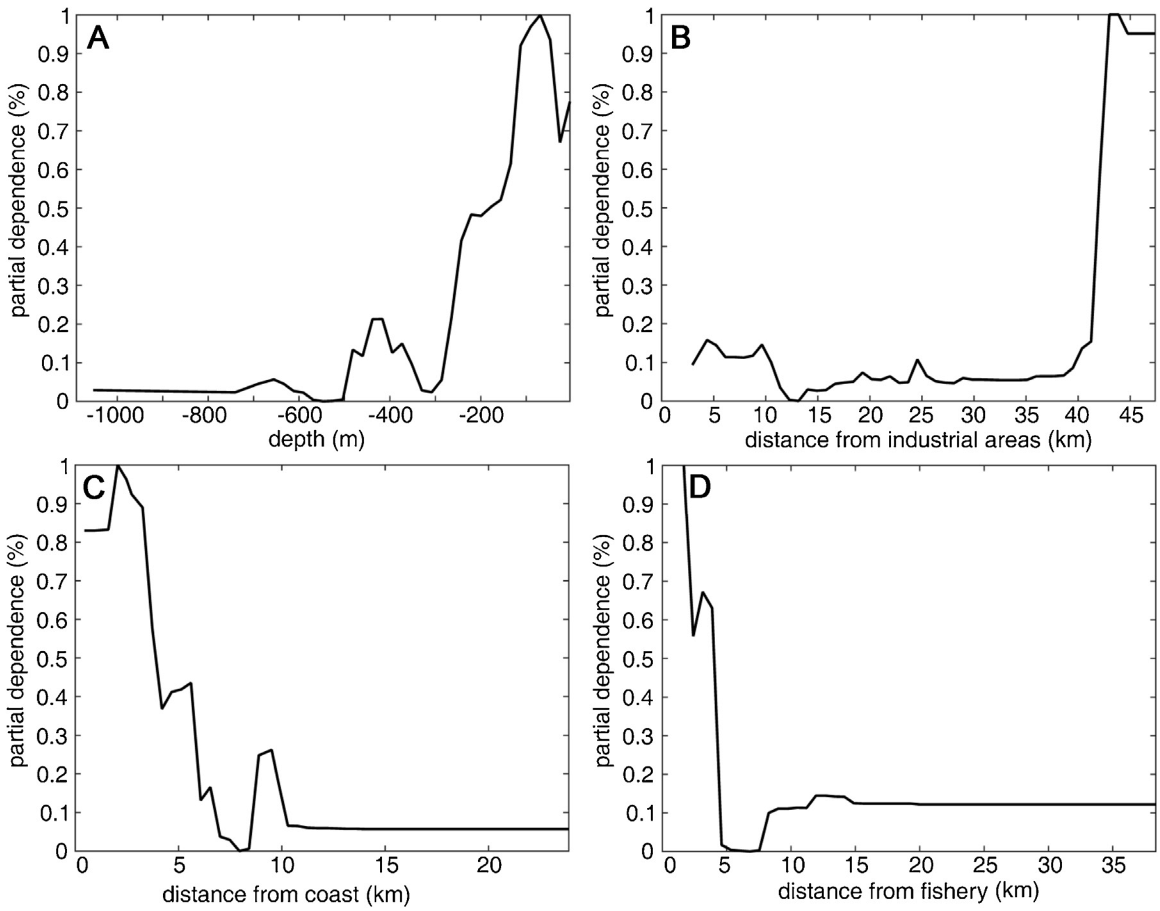


**Fig. 7.** Univariate partial dependence plots of the explanatory variables depth (A), distance from the industrial areas (B), distance from coast (C) and distance from fishery (D), estimated by the RF model for *T. truncatus*.

of this explanatory variable in reducing habitat suitability for both dolphins.

The distribution of common bottlenose dolphin is significantly affected by the distance from fishing areas, while the striped dolphin was unaffected by this variable. In particular, the presence of *T. truncatus* was particularly probable closer to fishing areas with a sudden increase within 5 km. This result was in some way expected since common bottlenose dolphins have been reported to be attracted by fishing vessels being able to deliberately and opportunistically use fishing nets as an integral part of its feeding strategies (Brotons et al., 2008; Chilvers and Corkeron, 2001; Corkeron et al., 1990; Diaz Lopez, 2006; Fertl and Leatherwood 1997; Lauriano et al., 2004; Pace et al., 2003; Pulcini et al., 2002; Wells and Scott, 2009). However, this interaction could also be due to the sharing of productive areas, sustained by a significant upwelling phenomenon (Manca et al., 2006; Matarrese et al., 2011; Carlucci et al., 2014), exploited by fishing and also used for feeding by *T. truncatus*.

The striped dolphin shows a significant dependency on the distance from navy exercise areas displaying the tendency to be more present at increasing distance from such areas, thus avoiding this disturbance (Dolman et al., 2010, 2011).

Depth and distance from the coast proved to be the verified geomorphologic variables most significantly affecting the distribution pattern of both dolphin species. In fact, the striped dolphin is mainly predicted in waters deeper than 350 m and at distances from coast greater than 10 km. On the contrary, the bottlenose dolphin is mainly distributed within 5 km of the coast and in waters around 100 m in depth, rarely being found in waters deeper than 200 m. In both cases, the results are in agreement with other estimations carried out on habitat preference for *S. coeruleoalba* and *T. truncatus* in the Mediterranean Sea (Marini et al., 2015; Panigada et al., 2008; Tepsich et al., 2014). In fact, it has been reported that *T. truncatus* prefers coastal areas within 400 m, while *S. coeruleoalba* is expected to increase around 1600–2000 m beyond the continental shelf (Azzellino et al., 2012; Cañadas et al., 2002).

Regarding the application of modeling techniques, the reliability of the different regression techniques was tested, providing indication for further studies at a different spatial scale. However, in this study RF displayed better ability to cope with the observed distribution of both *S. coeruleoalba* and *T. truncatus* in the Northern Ionian Sea, confirming findings reported in other areas (Cutler et al., 2007; Virkkala et al., 2010). In particular, RF has been successfully used for environmental mapping and management (Parravicini et al., 2012; Pesch et al., 2011) and for the characterization of the spatial distribution of bottlenose dolphin (Marini et al., 2015), also because it is particularly appropriate for identifying and modeling complex interactions between multiple variables (Loh, 2008).

Finally, the critical habitats of *S. coeruleoalba* and *T. truncatus* as estimated in this study are the outcome of both the influence of environmental conditions and anthropogenic pressures presently occurring in the Gulf of Taranto, basically indicating the need for conservation measures (Ingram and Rogan, 2002; Pérez-Jorge et al., 2015). Unfortunately, these habitats widely overlap the areas requested for hydrocarbon exploration by means of seismic airgun surveys recently permitted or under evaluation by the Italian Ministry for the Environment, the Land and the Sea (2015) (Fig. 9). These latter and new threats could increase the level of anthro-

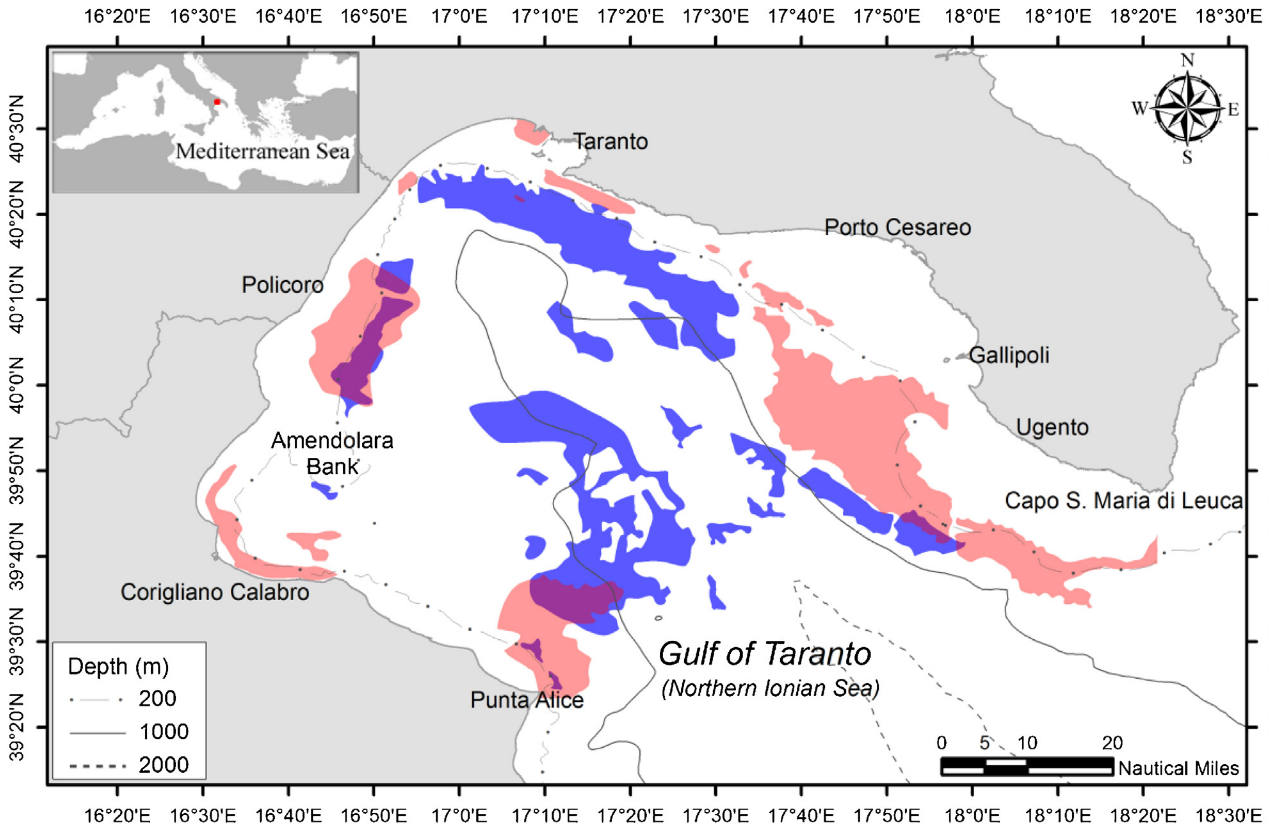


**Fig. 8.** Identification of habitat areas for the striped dolphin (blue) and common bottlenose dolphin (red) in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea).

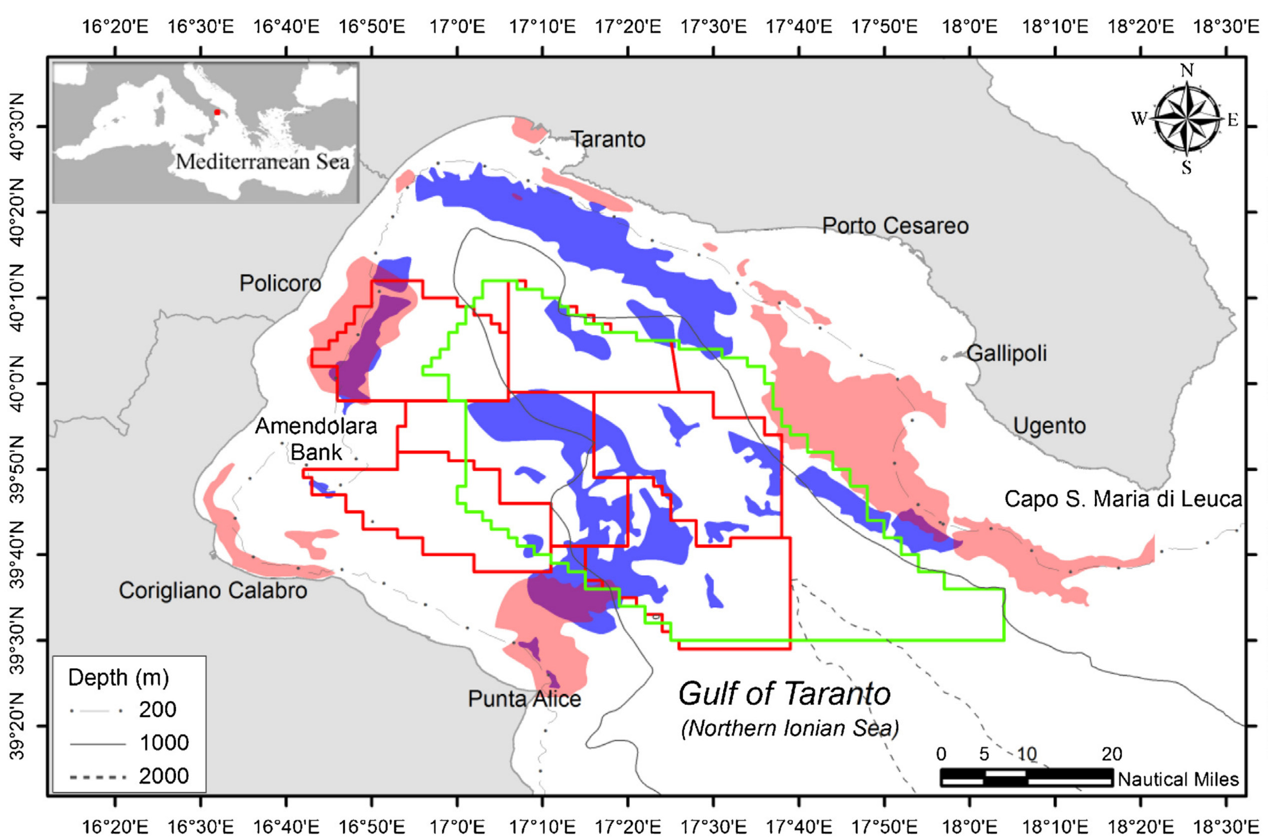


**Fig. 9.** Overlapping between critical habitats of *S. coeruleoalba* and *T. truncatus* and areas requested for hydrocarbons explorations (in red hydrocarbons explorations, in green hydrocarbons prospections).

pogenic influence in the Northern Ionian Sea, potentially affecting the health of dolphin populations (i.e. alteration in feeding, orientation, hazard avoidance and social behaviour) and determining a deterioration in habitat quality (prey distribution and abundance) (Bain and Williams, 2006; Fewtrell and McCauley, 2012; Finneran et al., 2015; Gordon et al., 2004).

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2016.05.035.

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