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Common Bottlenose Dolphin Protection and Sustainable Boating: Species Distribution Modeling for Effective Coastal Planning

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Indicators for preserving marine biodiversity include knowledge of how the spatial distribution and critical habitats of species overlap with human activities and impacts. Such indicators are key tools for marine spatial planning, a process that identifies and resolves conflicts between human uses and the conservation of marine environments. The common bottlenose dolphin in the Mediterranean Sea is considered a vulnerable species by the IUCN Red List and a priority species of the EU Habitat Directive. Here, we estimated spatio-temporal patterns of the species occurrence in the area around one Marine Protected Area (MPA) and two Sites of Community Importance (SCI) of the North western Sardinia, with the aim to predict the species distribution and the main links with the environmental factors and boat traffic. To evaluate whether dolphin groups with calves showed any habitat preference different from groups without calves, separate models for both type of groups were done. The most important contributing variables to the dolphin habitat suitability models were the likelihood of boat presence, habitat type and mean sea surface temperature. Different model outputs were obtained depending on dolphin group composition. The area of high likelihood of dolphin presence ranged between 30 and 60 km^2 and was smaller for groups with calves. Further, the area of highest dolphin habitat suitability overlaps with the area of high boat traffic, suggesting that boating in the study site is a potential relevant anthropogenic threat to dolphins. Particularly, boating is concentrated inside and around the MPA/SCIs, indicating the need for stronger restriction measures. We propose updated SCI boundaries for effective protection of common bottlenose dolphins. These areas and the suggestions of regulation are specifically aimed at reducing the impact of boating on dolphins, especially for groups with calves. *Synthesis and applications.* Management measures should be designed based on the data here provided, and then implemented and enforced to decrease dolphin-boat interactions, especially for mother-calf pairs. The creation of new coastal SCIs should be considered especially where boat traffic overlaps with areas most suitable for dolphins. In these SCIs, boating should be managed to limit disturbance, avoidance or alterations of dolphin vital behavior.

Keywords: marine protected areas, marine spatial planning, overlap analysis, protection effectiveness, species distribution modeling, *Tursiops truncatus*

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INTRODUCTION

Indicators for preserving marine biodiversity include knowledge of how the spatial distribution and critical habitats of target species overlap with human activities, pressure and impacts. Such indicators are key tools for marine spatial planning, a process used around the world to identify and resolve conflicts between human uses and the natural marine environment (UNESCO-Intergovernmental Oceanographic Commission, 2017). In order to achieve the goals of the Maritime Spatial Planning Directive of the EU (2014/89), the development of a full suite of ecological descriptors is needed for assessing the status of ecosystem components under anthropogenic pressures. This has become an ambitious mission for coastal marine systems, an environment highly impacted by human pressure (Micheli et al., 2013). In coastal systems, the main form of protection is the establishment of marine protected areas (MPAs). In EU countries, national MPAs and the protected areas of the Natura 2000 Network (e.g., Site of Community Importance 'SCI' and Special Area of Conservation 'SAC') offer protection for benthic species and habitat. Protected area boundaries often consider species distribution, although these areas may have limited conservation effect on species capable of wide ranging, such as cetaceans (Fortuna et al., 2018). Incorporating regional cetacean presence and distribution information collected over time (seasons, years) is necessary to adequately protect these species.

In general, protected area design should be based on the importance of ecological features of the species to protect. Indeed, the establishment of protected areas for cetaceans must encompass the critical areas necessary for feeding, reproduction and rest (Ashe et al., 2010; Williams et al., 2015), including management purposes (Alessi and Fiori, 2014). As part of the marine spatial plan, decisions should also consider the potential conflict between human demands and biodiversity conservation. Moreover, gathering scientifically sound data to generate accurate predictions of marine spatial assessment of overlapping areas between fauna distribution and human activities reinforces the science-policy interface (Mangano and Sarà, 2017). This would adapt restrictions of protected areas to the species actually included within boundaries and increase effectiveness of wildlife management (Braunisch et al., 2011) to achieve the objectives of the Maritime Spatial Planning Directive.

In biodiverse and/or scenic regions, tourism dominates the economy. For example, in the Mediterranean island of Sardinia tourism has grown quickly in the last three decades due to the wild scenic coasts, white beaches and crystal-clear waters. All these features attract boaters and contribute to make Sardinia one of the Italian regions with the largest concentration of boat berths, tourist ports and marinas (ONN, 2011). However, ocean tourism and recreational boating are still scantly regulated. In fact, recreational boating is still considered not harmful to the environment. However, boat presence and related noise can contribute to morphological, behavioral and physiological trait changes in several marine organisms (Lloret et al., 2008; Juanes et al., 2017; Slabbekoorn et al., 2018).

Bottlenose dolphins are key components of regional marine biodiversity, and populations are declining throughout the Mediterranean Sea (Bearzi et al., 2012) due to overfishing, habitat loss, chemical and acoustic pollution, costal development, human disturbance (e.g., tourism, recreational activities, and shipping), incidental mortality due to marine debris (e.g., fishing gear), and climate change (Bearzi et al., 2012). The bottlenose dolphin is considered vulnerable by the IUCN (International Union for Conservation of Nature) Red List and is in the Annex IV of the priority species of the EU Habitat Directive (92/43/EEC).

According to Article 1 of the Habitats Directive, sites (SCI and than SAC) selected for wide ranging species, "*shall correspond to the places within their natural range*" with "*the physical or biological factors essential to their life and reproduction.*" In the North western Sardinia, even if the presence of the bottlenose dolphins is well documented and the species is among those to be protected, the current boundaries of both MPA and the SCIs have not been drawn to include dolphin presence and distribution; this may impair the efforts to protect the species. Thus identifying the spatio-temporal variability of the preferred coastal habitats of bottlenose dolphins, especially where their distribution widely overlaps with human activities is pivotal for: (i) supporting the decision making to adapt MPA/SCI boundaries to the distribution of the species, (ii) addressing management restrictions.

Here, we measured spatio-temporal patterns of common bottlenose dolphin (*Tursiops truncatus*) occurrence in the area around one MPA and two SCIs of the North western Sardinia. We aimed to predict the species distribution and to verify the relationship with environmental factors and boat traffic. Applying a MaxEnt modeling approach (Maximum Entropy; Braunisch et al., 2011), we used boat presence data to predict the spatial distribution patterns of boating in one of the most popular tourist destinations in Sardinia. We used the likelihood of boat presence and other environmental variables to predict the habitat use of bottlenose dolphins at different temporal scales (Virzi, 2010; Pendleton et al., 2012). We selected environmental variables related to topographic features (slope, depth, and aspect), environmental conditions and proxies of prey availability (sea surface temperature, Chlorophyll-a concentration and habitat type) since they can influence habitat selection. Further, we modeled dolphin presence as a function of the presence of calves, to estimate how group composition influences species distribution. With this information, we propose adjusting existing boundaries to expand SCIs for the purpose of enhancing the protection of common bottlenose dolphin and we suggest regulation specifically aimed at reducing the impact of boating on dolphins.

MATERIALS AND METHODS

Study Area

The study was done in a 400 km^2 area in northwest Sardinia, Italy (40.5580° N, 8.3193° E, **Figure 1**) near Alghero. The seafloor in this area is covered by a mixture of habitats (**Table 1**). This area includes three coastal protection measures (the Capo Caccia - Isola Piana MPA, the SCI 'Capo Caccia e Punta del Giglio' ITB010042 and the SCI 'Entroterra e zona costiera tra

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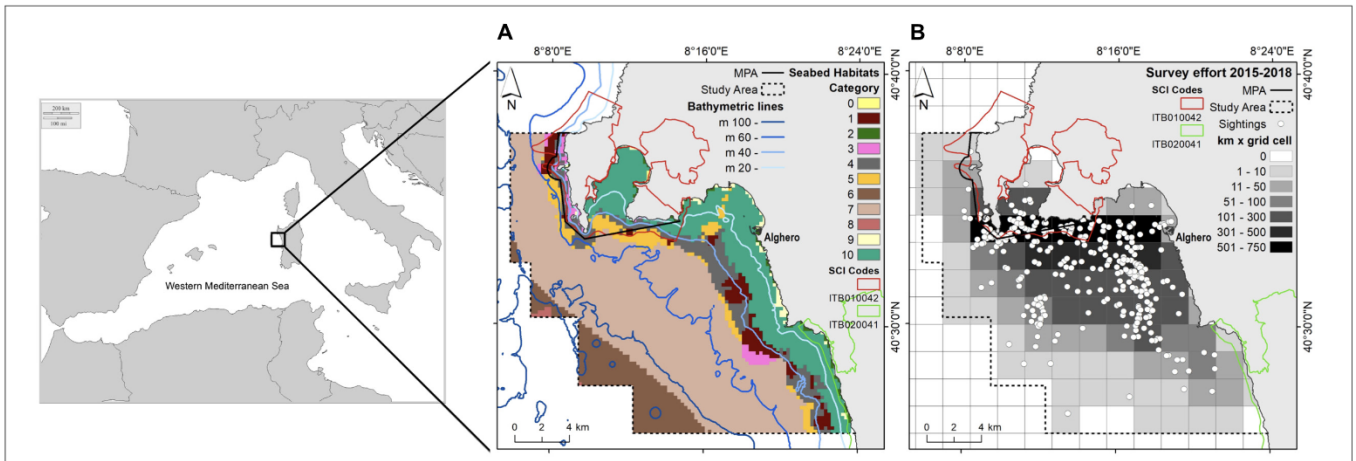


FIGURE 1 | Maps of the study area: **(A)** the habitat types and bathymetric lines; **(B)** the total sampling effort pooled into grid cells (2 km × 2 km) and the dolphin sightings (white dots) for the period 2015–2018.

Bosa, Capo Marargiu e Porto Tangone' ITB020041) and Alghero, the largest port on the western coast of Sardinia (with about 2000 berths). The MPA Capo Caccia - Isola Piana extends for 26.31 km^2. The SCI 'Capo Caccia e Punta del Giglio' is located in the northern part of the Alghero bay and extends for 74 km^2. The SCI 'Entroterra e zona costiera tra Bosa, Capo Marargiu e Porto Tangone' is located in the southern part of the Alghero Bay and it extends for 29.62 km^2. The MPA and SCIs were established mainly for the protection of endemic Mediterranean seagrass (*Posidonia oceanica*), coralligenous habitat, and several protected species, including the common bottlenose dolphin.

TABLE 1 | Description, depth, and relative surface percentage of the habitat types.

Habitat type	Description	Depth (mean ± *SD*)	Depth (range)	Surface (%)
0	Littoral sediment	−3 ± 0.15	−2.6/−2.9	0.1
1	Infralittoral rock and hard substrata	−43 ± 6	−31/−57	3.8
2	Mediterranean communities of infralittoral algae moderately exposed to wave	−4.6 ± 3.1	−1/−19	1.3
3	Mediterranean coralligenous communities moderately exposed to hydrodynamic action	−36 ± 15	−8/−60	1.7
4	Infralittoral coarse sediment	−43 ± 7	−22/−70	7.8
5	Infralittoral fine sand	−50 ± 10	−7/−68	4.5
6	Mediterranean communities of muddy detritic bottoms	−107 ± 5	−91/−120	10.1
7	Mediterranean animal communities of coastal detritic bottoms	−75 ± 17	−41/−131	50.3
8	Mediterranean communities of shelf-edge detritic bottoms	−107 ± 3	−102/−111	0.2
9	Mediterranean communities of well sorted fine sands	−6 ± 5	−2/−28	1.2
10	Posidonia beds	−19 ± 10	−2/−41	19.1

In this area, the local economy relies on summer tourism and ocean tourism activities (La Manna et al., 2016). With respect to boating, the only existing regulation is foreseen by the provisional regulation of the MPA and concerns boat speed limitation, while interactions between boats and dolphins are still not restricted or regulated.

Dolphin and Boat Samplings

From 2015 to 2018, we conducted daily surveys from April to October and we collected data on boat traffic and sightings of the common bottlenose dolphin. We conducted systematic standardized surveys from 9.7 m motor boats. Survey routes followed a random sampling procedure (La Manna et al., 2016), with a generally perpendicular direction with respect to the coast and depth contours. In each survey, two experienced observers scanned the sea surface underway at a boat speed between 10 and 16 km per hour. Scans occurred during daylight (from 9 am to 6 pm), every day with a visibility of over 3 miles and with good sea condition (sea state $\leq$ 2 Douglas; wind force $\leq$ 2 Beaufort). The position of the research boat was automatically recorded every minute using a Garmin GPS chart-plotter. Using binoculars (10× power magnification, 42 mm objective lens), trained observers counted boats, both moored and underway, encountered within 300 m during the survey, recording their position using GPS. Boat classification were: recreational boats (inflatable boats, speed boats, cabin cruisers, and sail boats), tourist boats (excursion/diving boats and tourist ferry boats) and commercial fishing boats. During a dolphin sighting, animals were approached to collect data about dolphin group size and geographic position, and calf presence.

Environmental Predictors

We incorporated data on environmental variables, dolphin presence and boat presence into a Geographic Information System (GIS) using the software ArcMap 10.4.1. The GIS was build using the World Geodetic System 1984 (WGS84) and

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the Universal Transverse Mercator (UTM) 32 N projection. Based on previous cetacean habitat studies (Canadas et al., 2002; Azzellino et al., 2012; Marini et al., 2014; Bohrer do Amaral et al., 2015; La Manna et al., 2016), we selected the following environmental variables: water depth (m), mean sea surface temperature (SST mean), difference between the maximum and the minimum sea surface temperature (SST range), Chlorophyll-a concentration (Chl-a - mg/m^3), seafloor slope (degree), distance to the coast (m), aspect (**Table 2**) and habitat type (**Table 1**). All data were pooled into grids with a resolution of 250 m and averaged for every year (from 2015 to 2018) and for the whole period (2015–2018).

Before running SDMs (Species Distribution Modeling), we used 'Raster Correlations and Summary Statistics' tools of the plug-in SDMtoolbox 2.1 for ArcGis to create a correlation matrix of the Pearson correlation coefficients (r) between the environmental predictors (Brown, 2014; Brown et al., 2017). In case of collinearity (Kumar and Stohlgren, 2009; Kramer-Schadt et al., 2013), only one environmental predictor, between the two, was included in the model (Kumar and Stohlgren, 2009). In the modeling exercise, we interpolated some environmental variables (SST and Chl-a) to fill spatial gaps (about 40 km^2) along the coastline (**Table 2**). These interpolations and the limited number of predictors have constrained interpretation of the results only in terms of the likelihood of presence within the range of these environmental conditions (La Manna et al., 2016).

TABLE 2 | Predictors used for modeling boat traffic and dolphin occurrence.

Predictor	Description, source, and resolution
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 ≤ 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: Radial Basis Function" in the Geostatistical Analyst Toolbar and averaged for each year and for the whole period (2015 to 2018)
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: Radial Basis Function" in the Geostatistical Analyst Toolbar and averaged for each year and for the whole period (2015 to 2018)
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 measures 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 follow: N (1); NW (2); NE (3); S (4); SW (5); SE (6); W (7); E (8).
Distance	The distance to the coast was calculated for each cell centroid from shoreline shapefile using "Near" function in Spatial Analysis Tools in ArcGIS.
Habitat type	Information about the habitat types were derived from the European Marine Observation Data Network (EMODnet) Seabed Habitats project (http://www.emodnet-seabedhabitats.eu/). In the small portions of the study area where data were not available, the benthic biocenotic map produced by the Capo Caccia-Isola Piana MPA was used to fill these data gaps. Habitat type was a categorical variable, with 10 classes.

Model Generation and Validation

The accurate prediction of presences in a modeling processes requires avoiding the use of absences when absence data are not available or not sufficiently reliable, the so-called methodological absences (Lobo et al., 2010). In the case of Cetacean sampling, many locations cannot be surveyed systematically or may receive little survey effort, leading to the lack of true absence data. This lack is higher in areas where environmentally favorable localities are placed nearest to the known presence points (Lobo et al., 2010). Due to the small spatial scale of the present study, the mobility of the studied species and the limited temporal scale of the sampling effort (from April to October), it would be risky to use presence-absence algorithms (Oviedo Correa et al., 2019). Thus, we modeled boat presence and dolphin occurrence at different temporal scales (each year from 2015 to 2018 and the whole period 2015–2018) by MaxEnt (version 3.4.1, Phillips et al., 2020). SDM based on Maximum Entropy (MaxEnt) is one of the most reliable tools (Elith et al., 2006, 2011), especially when presence-only data (Guisan and Thuiller, 2005) are available. In fact, MaxEnt estimates a probability distribution (i.e., relative likelihood of presence; McClellan et al., 2014) for a species by contrasting occurrence data with background data, rather than true absence data (Thorne et al., 2012). Thus, MaxEnt does not assume that the absence precludes the likelihood of occurrence.

Three types of dolphin distribution models were built: models with the occurrence data of (i) all groups sighted, (ii) only groups without calves and (iii) only groups with calves. Calves were defined as dolphins less than or equal to two-thirds the length of an adult and usually associated with an adult female.

For modeling the likelihood of boat presence, we used location points of all boats (recreational, fishing, and tourist boats) recorded during the surveys as presence data and the raster surface of depth, slope, aspect, and distance to the coast as explanatory variables (**Table 2**). Since distance to the coast and depth were collinear, only depth was included in the models. Boat presence data were averaged for each year and for the whole period (2015–2018). For modeling the likelihood of dolphin presence, we considered five continuous variables (SST mean, SST range, Chl-a, depth and slope) and two categorical variables (aspect and habitat type) to be environmental predictors (**Tables 1**, **2**); we considered the likelihood of boat presence (the raster output of 250 m resolution, modeled by MaxEnt) to be an anthropogenic predictor. We preferred calculating the likelihood of boat presence instead of using the presence of boats as predictors since boat movement varies temporally and spatially as a function of human behavior (Cummins et al., 2008; Tallis et al., 2012). For both models, MaxEnt settings were chosen in relation to the specific questions of the study and

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data limitations (Merow et al., 2013): (i) the cloglog output most appropriate for estimating likelihood of presence (Phillips et al., 2017), (ii) hinge features (Phillips and Dudík, 2008), (iii) default regularization parameters, and (iv) 10-fold cross-validation to assess the average behavior of the algorithms randomly partitioning the occurrence data in ten random subsets (Phillips et al., 2006). The geographical extent of the models coincides with the monitored area that includes the typical and known habitat of bottlenose dolphins (Bearzi et al., 2012). Thus, we used all the background sites available (5,358) to increase the predictive performance (Phillips and Dudík, 2008).

We ran a jack-knife analysis to estimate the contribution of each variable to the MaxEnt run, obtaining alternative estimates of variable importance for our models. The performance of each MaxEnt model was assessed using the AUC (area under the receiver operating characteristic curve; Phillips et al., 2006). The AUC provides a threshold-independent metric of overall accuracy and ranges between 0 and 1. Models with moderate-to-good discrimination ability correspond to AUC higher than 0.7 (Swets, 1988). Additionally, we verified the model robustness by computing: (i) the test-AUC standard deviation (SD) and (ii) the difference between the train-AUC values (using all presences) and the mean test-AUC values. Low test-AUC SD and/or small difference between the train-AUC and mean test-AUC values indicate model robustness (Herkt et al., 2016). The AUC provides an adequate evaluation of model performance (Phillips et al., 2006); however, in the case of presence-only distribution models, AUC will compare presences with background points and cannot be considered a perfect measure of model accuracy (Lobo et al., 2008; Merow et al., 2013).

Using MaxEnt from the cloglog output (Phillips et al., 2017), we produced maps of each year (from 2015 to 2018) and of the whole period (2015–2018) for the likelihoods of dolphin and boat presence.

Overlap Analysis

In order to explore the relationship between the likelihood of dolphin presence and the likelihood of boat presence, we used binary maps using threshold values provided by MaxEnt. Thus, we considered the maximum training sensitivity plus specificity threshold, a method that balances the chance of correctly identifying suitable areas (sensitivity) with the chance of correctly assigning unsuitable areas (specificity - Ramirez-Reyes et al., 2016). Maximizing the sum of sensitivity and specificity (MSSS) is one of the best threshold selection methods with presence-only data (Liu et al., 2013). By these threshold values, we obtained binary maps reclassifying the dolphin and boat model outputs (for the total period 2015–2018) using the 'Reclassify' function of Spatial Analyst Tool (York et al., 2011). For the dolphin models we set: (i) prediction values below the MSSS threshold as 1 (low dolphin habitat suitability) and (ii) prediction values above the MSSS threshold as 2 (high dolphin habitat suitability). Similarly, for the boat models we set: (i) prediction values below the MSSS threshold as 3 (low boat traffic) and (ii) prediction values above the MSSS threshold as 4 (high boat traffic). We multiplied the reclassified dolphin model output with the reclassified boat model output using the 'Raster Calculator' function of Spatial Analyst Tool. This raster calculation resulted in habitat overlap analysis raster layer classes: (i) low dolphin habitat suitability and low boat traffic, (ii) low dolphin habitat suitability and high boat traffic, (iii) high dolphin habitat suitability and low boat traffic and (iv) high dolphin habitat suitability and high level of boat traffic (York et al., 2011). We calculated the surface and relative proportion occupied by each class within the study area for the total period 2015–2018, and for each one of the dolphin models type (all groups, groups with calves and groups without calves).

Finally, based on the overlap analysis we mapped the boundaries of two proposed SCIs: SCI-A in the area of Alghero and SCI-B in the area that connects SCI-A to the closest SCIs in northern and southern Alghero. We identified the SCI-A as the area that contains and connects all the high dolphin suitability cells obtained by superimposing the overlap analysis of each year. As the boundary of this area approximates the isobath of 100 m, the 100 m-contour was used as a limit to define the boundaries of the SCI-B. Thus, in compliance with the request of the Italian Ministry of the Environment and the European Commission, the present study responds to the need of the Sardinia Region to scientifically support the proposal of new coastal SCIs for the protection of bottlenose dolphins by enlarging already existing protected areas.

RESULTS

Likelihood of Boat Presence

During the sampling period we counted a total of 5545 boats. The majority (78%) were recreational boats, while 8% were commercial fishing boats and 14% were tourist boats. Since the likelihood of recreational and tourist boat presence were correlated and the likelihood of fishing boat presence was correlated with the likelihood of recreational boat presence, the models here presented were built considering the likelihood of all boat types presence. Based on AUC, the accuracy of MaxEnt in predicting the likelihood of boat presence was higher than 0.75 in any investigated years (**Table 3**). The most important contributor in predicting the likelihood of boat presence was depth (**Table 3**). The probability of finding boats was higher between −60 and −20 m of depth and decreased deeper than −80 and shallower than −20, regardless of the years. Overall, the highest likelihood of boat presence was inside the boundaries of the MPA/SCI (**Figure 2**).

Likelihood of Dolphin Presence

Across all years, 307 dolphin groups were sighted in about 11,000 km of navigation and 391 surveys (**Supplementary Material 1** and **Figure 1**). All MaxEnt models obtained AUC higher than 0.75, with the only exception of the model referring to groups with calves in 2016; this indicates high accuracy in predicting dolphin presence (**Table 4**). The difference between mean AUC values from test-SDMs and the corresponding training AUC from the SDM was generally low (**Table 4**), indicating overall model robustness.

The most important contributing variables to the dolphin habitat suitability models were the likelihood of boat presence,

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TABLE 3 | Boat presence prediction.

	% contribution			Permutation importance			AUC	AUC difference
	Aspect	Depth	Slope	Aspect	Depth	Slope	Mean ± *SD*	Training – mean test
2015	10.49	**81.57**	7.93	8.02	86.55	5.43	0.76 ± 0.03	0.010
2016	11.38	**80.70**	7.92	11.64	82.55	5.80	0.78 ± 0.03	0.010
2017	10.68	**81.00**	8.31	11.56	80.13	8.31	0.80 ± 0.02	0.007
2018	10.95	**84.62**	4.43	11.20	83.82	4.98	0.81 ± 0.02	0.007
2015–2018	7.53	**91.52**	0.95	11.16	87.18	1.66	0.75 ± 0.02	0.005

Percent contribution and permutation importance of relative contributions of the different variables to the MaxEnt models. Variable importance is presented as the mean of the 10 runs of each single model. Explanatory variables of greatest influence in bold. Output referred to any single year and to the whole period 2015–2018.

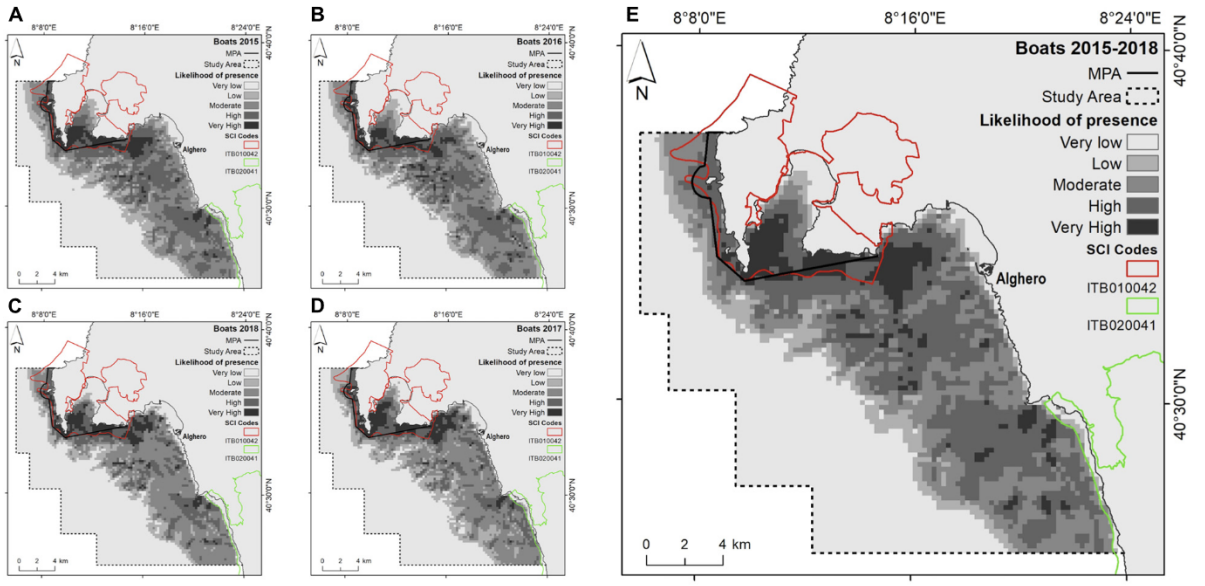


FIGURE 2 | Likelihood of boat presence (cloglog output) as a function of the environmental predictors for yearly: **(A)** 2015; **(B)** 2016; **(C)** 2017; **(D)** 2018; and **(E)** the entire study period (2015–2018).

habitat type and mean SST (**Figure 3**). Particularly, the probability of finding dolphins: (i) remained low as the probability of boat occurrence increased; (ii) was high for all habitat types with the sole exception of the habitat "Mediterranean animal community of coastal detritic bottoms" (number 7); (iii) decreased when the mean SST increased (**Supplementary Material 2**). The most suitable areas for dolphins are inside Alghero Bay, both along its southern coast and inside/around the boundaries of the MPA and the *SIC* ITB010042 (**Figure 4**); these areas extend for about 51 km^2, ranging from 59 km^2 in 2015 to 37 km^2 in 2017 (**Table 5**).

Influence of Dolphin Group Composition

Different model outputs were obtained depending on the type of dolphin group composition (**Figures 5**, **6**). The overall likelihood of finding groups without calves did not change as the likelihood of boat presence increased; the likelihood of finding groups with calves was lower at higher likelihood of boat presence (**Supplementary Material 2**). Furthermore, while the likelihood of finding groups without calves was high for almost all habitat types, for groups with calves it was high exclusively in three habitat types: (i) "infralittoral rock and hard substrata" (number 1), (ii) "infralittoral coarse sediment" (number 4) and (iii) "infralittoral fine sand" (number 5). For both types of dolphin groups, the likelihood of presence decreased with mean SST increase in all years (**Supplementary Material 2**).

Considering all dolphin groups, across all years, 15.1% of the study area was characterized by high (between 0.6 and 0.8) and very high (between 0.8 and 1) likelihood of dolphin presence. In groups with calves, this area was smaller than in groups without calves (**Table 5**). The areas inside and around the boundaries of the MPA/SCI correspond to a lower likelihood of dolphin presence for groups with calves (**Figure 6**).

Overlap Analysis

Based on the overlap analysis, considering all dolphin groups, 24% of the study area (79.6 km^2) was characterized by high dolphin habitat suitability, across all years. The area of high dolphin habitat suitability for groups with calves was smaller

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TABLE 4 | Mean test AUC and standard deviation and AUC difference (training – mean test) for the dolphin presence predictions, distinguished by dolphin social group type.

All groups	AUC	AUC difference	Groups w/o calves	AUC	AUC difference	Groups with calves	AUC	AUC difference
	Mean ± SD	Training – mean test		Mean ± *SD*	Training – mean test		Mean ± *SD*	Training – mean test
2015	0.75 ± 0.07	0.09	2015	0.74 ± 0.09	0.11	2015	0.77 ± 0.90	0.17
2016	0.74 ± 0.09	0.13	2016	0.76 ± 0.08	0.12	2016	0.63 ± 0.08	0.26
2017	0.80 ± 0.06	0.06	2017	0.81 ± 0.07	0.06	2017	0.75 ± 0.11	0.13
2018	0.84 ± 0.05	0.04	2018	0.83 ± 0.06	0.05	2018	0.87 ± 0.06	0.01
2015–2018	0.81 ± 0.03	0.03	2015 2018	0.81 ± 0.03	0.03	2015 2018	0.81 ± 0.06	0.06

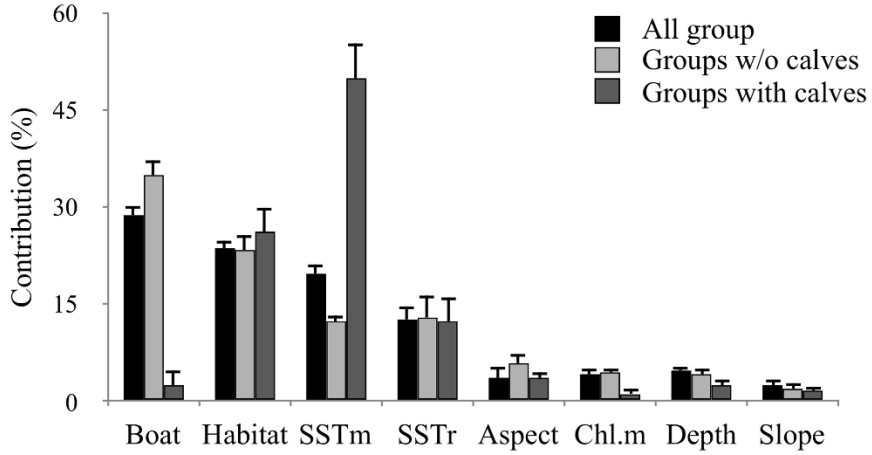


FIGURE 3 | Percent contribution (±SD) of the different variables to the MaxEnt models run with (i) all groups (black bars); (ii) groups without calves (light gray bars); (iii) groups with calves (dark gray bars). Period: 2015–2018.

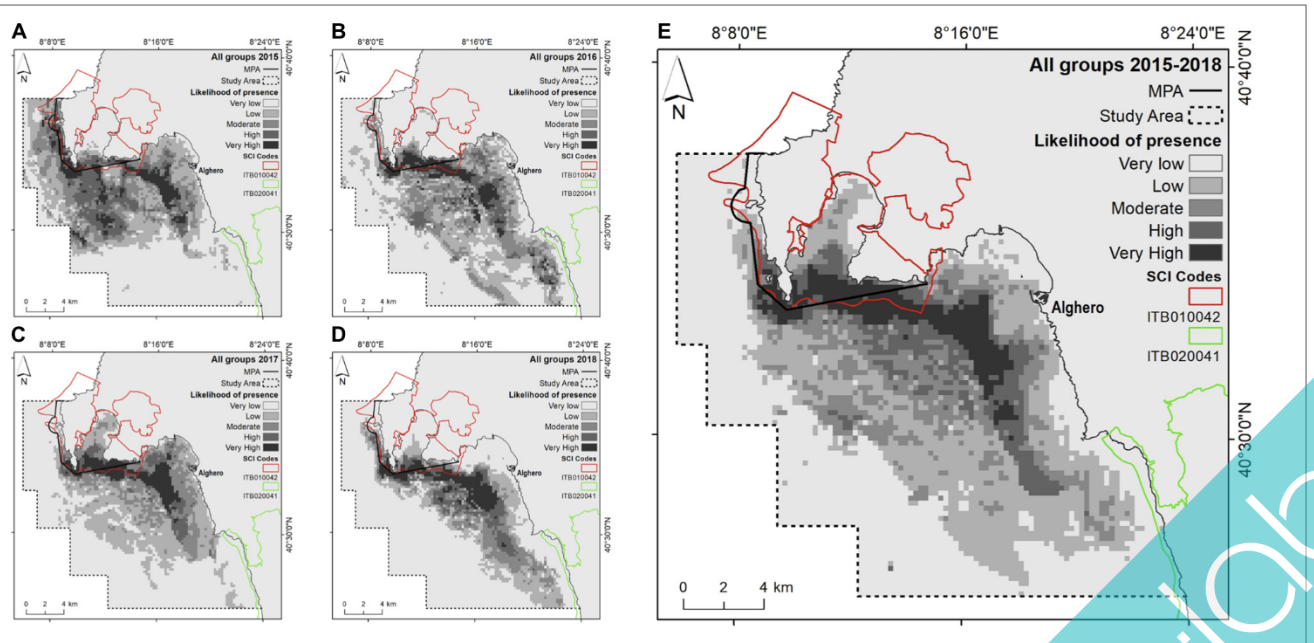


FIGURE 4 | Likelihood of dolphin presence (cloglog output) as a function of the environmental predictors for all groups. **(A)** 2015; **(B)** 2016; **(C)** 2017; **(D)** 2018; **(E)** the entire study period (2015–2018).

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TABLE 5 | Area (km and %) associated with classes of high (0.6–0.8) and very high (0.8–1.0) likelihood of dolphin presence as a function of year, distinguished by dolphin group composition.

Year	All groups				Groups w/o calves				Groups with calves			
	High		Very high		High		Very high		High		Very high	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
2015	34.9	10.4	24.4	7.3	33.7	10.1	19.1	5.7	21.4	6.4	16.2	4.8
2016	23.6	7.1	19.2	5.7	21.6	6.4	18.9	5.6	31.8	9.5	15.0	4.5
2017	16.3	4.9	20.9	6.2	16.5	4.9	18.5	5.5	12.8	3.8	14.4	4.3
2018	23.9	7.1	20.2	6.0	28.9	8.6	16.8	5.0	14.0	4.2	14.1	4.2
2015–2018	28.3	8.4	22.6	6.7	24.1	7.2	23.5	7.0	21.7	6.5	16.9	5.1

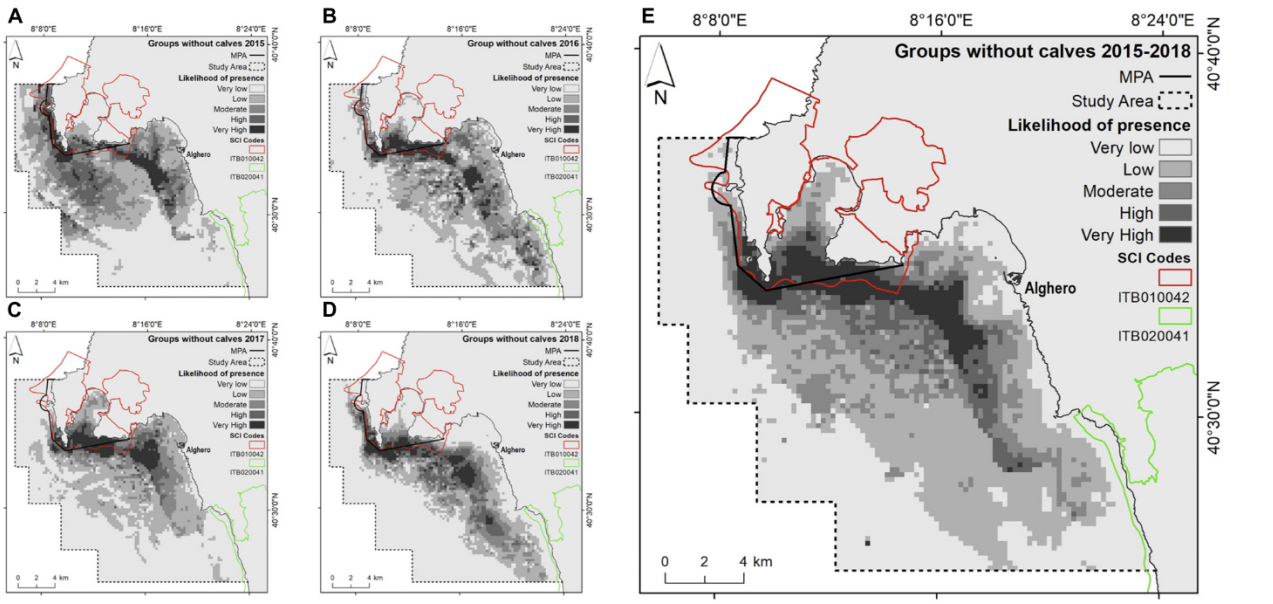


FIGURE 5 | Likelihood of dolphin presence (cloglog output) as a function of the environmental predictors for groups without calves. **(A)** 2015; **(B)** 2016; **(C)** 2017; **(D)** 2018; **(E)** the entire study period (2015–2018).

(60.3 km^2). More than 85% of the high dolphin habitat suitability areas overlapped with the high boat traffic area (**Table 6** and **Figure 7**).

In order to comprise and connect all cells with high dolphin habitat suitability, we obtained SCI area of 290 km^2 (SCI-A; **Figure 8**), representing about 72% of the study area. Extending the boundaries of the proposed SCI-A to the closest SCIs in northern and southern Alghero, following approximately the bathymetric limit of the SCI-A area (100 m), we obtained an enlarged area of 1,120 km^2 (SCI-B; **Figure 8**).

DISCUSSION

In the present study, more than 85% of the area with high dolphin habitat suitability overlaps with the high boat traffic area. Further, a distinct use of core areas of different size between dolphin groups with and without calves was found. Although the groups with calves preferred certain habitat types (infralittoral rock and hard substrata, infralittoral coarse sediment, and infralittoral fine sand), they avoided those within and around the boundaries of the existing MPA/SCI; these areas are characterized by the highest likelihood of boat presence. Indeed, boating is concentrated within the MPA/SCI, which represents the only management tool available for bottlenose dolphin protection. Nevertheless, the only existing restriction to boat traffic concerns the limitation of boat speed in some MPA's zones. These findings may suggest that boating in Alghero is a potentially relevant anthropogenic threat to dolphins. This could be the result of a compromise between the need of finding resources in the most productive habitats and the need to reducing the disturbance of boating activities (Frid and Dill, 2002), in terms of noise and risk of physical injuries (Pirotta et al., 2015). Moreover, human disturbance may be perceived by dolphins as a predation risk (Frid and Dill, 2002) and may alter the access to food resources (Allen et al., 2001), effectively reducing habitat availability (Carlucci et al., 2016; Coppes et al., 2017). Another possible scenario is that mothers avoid the busiest areas because these imply a high energy expenditure due to vigilance (Frid and Dill, 2002) or interruption of natural behavior, such as suckling (Elwen and Best, 2004).

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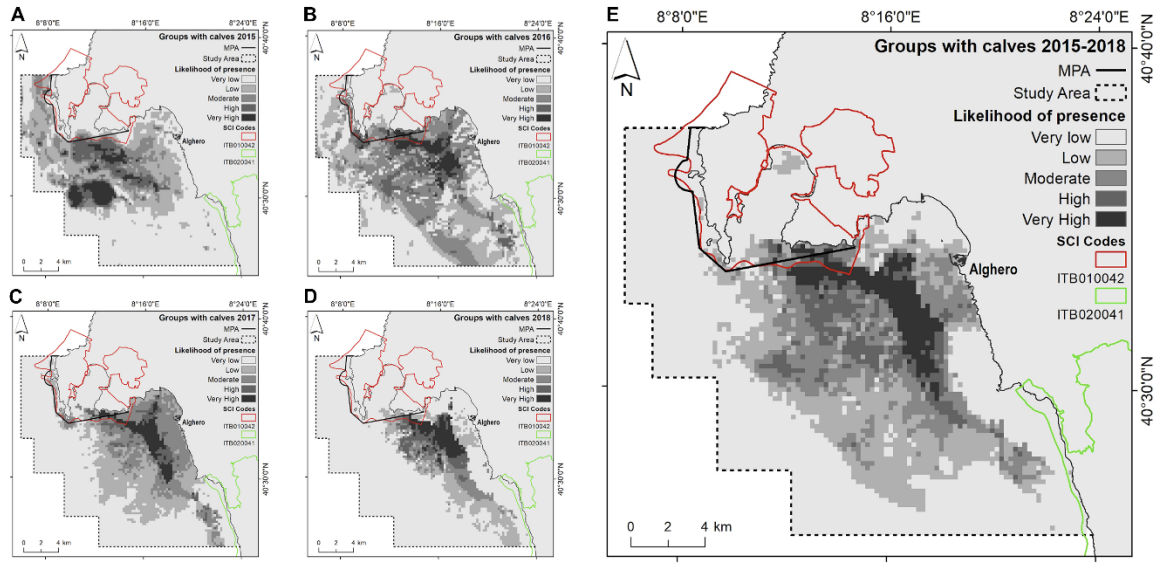


FIGURE 6 | Likelihood of dolphin presence (cloglog output) as a function of the environmental predictors for groups with calves. **(A)** 2015; **(B)** 2016; **(C)** 2017; **(D)** 2018; **(E)** the entire study period (2015–2018).

Disturbance from boating seems to be better tolerated by groups without calves; model output and overlap analysis indicated an overlap between the areas that are most suitable for the species and those areas that are most used by boaters. Nevertheless, chronic exposure to human disturbance, especially during feeding, may elicit an alteration of the energy budget of the individuals; this could have consequences at the individual and population levels that should be carefully investigated (New et al., 2013).

Dolphin Habitat Preference

Over the entire study period (2015–2018), the most important predictors of dolphin distribution were the habitat type, the likelihood of boat presence and SST. In other Mediterranean studies, the most common predictors of bottlenose dolphin distribution were depth and distance from the coast, two variables often correlated. Namely, bottlenose dolphins prefer areas close to the 100 m isobath (Blasi and Boitani, 2012; Marini et al., 2014; La Manna et al., 2016), but they can be distributed in coastal areas with seafloor no deeper than 400 m (Azzellino et al., 2012; Carlucci et al., 2016; Bonizzoni et al., 2019). Conversely, in this study, the model suggests that dolphins prefer habitat type rather than variables related to the geophysical properties of the seabed (depth, aspect, and slope). A habitat preference could be due to different prey availability (Heithaus and Laurence, 2002; Lambert et al., 2017; Zanardo et al., 2017) and/or physical conditions of physiological importance (Guisan and Zimmermann, 2000). In fact, cetacean distribution is mainly influenced by attempts to optimize foraging efficiency in areas where prey availability is high (Hastie et al., 2004; Palacios et al., 2006, 2013; Redfern et al., 2006; Gilles et al., 2016). Prey availability can also be linked to water temperature, which is among the environmental variables that influence dolphin distribution (Bearzi et al., 2008; Hartel et al., 2014; Lambert et al., 2017). Sea surface temperature is the most important driver of trophic dynamics in marine food webs, which are essentially based on ectotherms (La Manna et al., 2016). To date, no information is available concerning the abundance and distribution of fish communities in the study area. A study conducted on the Spanish Mediterranean coast (Blanco et al., 2001) found that demersal and benthic fish of soft bottom were the most abundant dolphin preys, followed by octopodids of hard rocky bottom and of soft sand/coarse substrata.

Furthermore, dolphin distribution varied depending on calf presence. The difference in habitat suitability as a function of the presence and age of calves has been noted for other cetaceans (Weir et al., 2008; Cartwright et al., 2012; Hartman et al., 2014; Rayment et al., 2014; Pace et al., 2018). Consistently, different studies found that the diet of bottlenose dolphin can change in terms of species and size of prey as a function of individual sex and age; for females, it can also depend on their association with calves and juveniles (Blanco et al., 2001). This supports the

TABLE 6 | Output of the overlap analysis.

	All groups		Groups w/o calves		Groups with calves	
	km²	%	km²	%	km²	%
A	162.2	48.5	161.2	48.1	162.4	48.5
B	93.1	27.8	87.5	26.1	112.3	33.5
C	8.8	2.6	9.8	2.9	8.6	2.6
D	70.8	21.1	76.4	22.8	51.7	15.7

Surface (km² and% of the study area) of the four classes: A, low dolphin habitat suitability/low boat traffic; B, low dolphin habitat suitability/high boat traffic; C, high dolphin habitat suitability/low boat traffic; D, high dolphin habitat suitability/high boat traffic.

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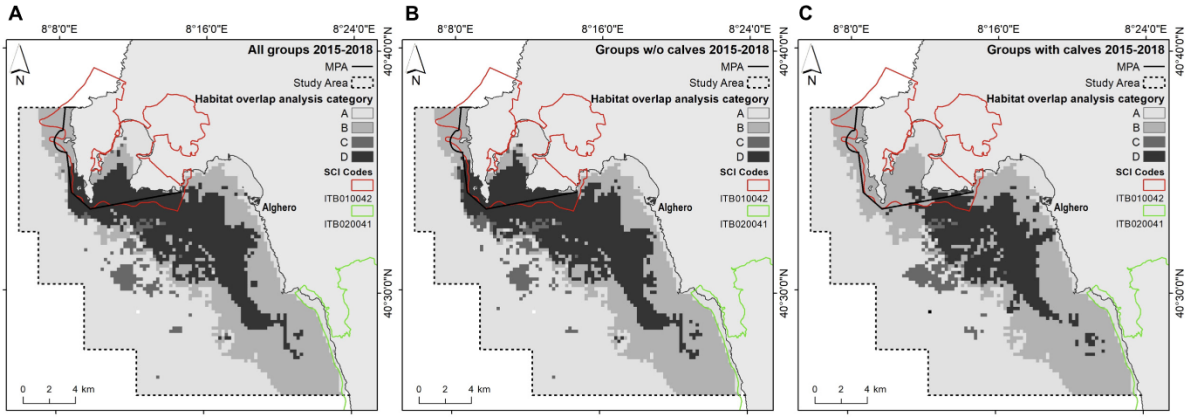


FIGURE 7 | Output of the overlap analysis. The maps show the areas of low and high dolphin habitat suitability and areas of low and high boat traffic, for **(A)** all groups, **(B)** groups without calves, and **(C)** groups with calves. (A) Low dolphin habitat suitability and low boat traffic; (B) low dolphin habitat suitability and high boat traffic; (C) high dolphin habitat suitability and low boat traffic; (D) high dolphin habitat suitability and high level of boat traffic.

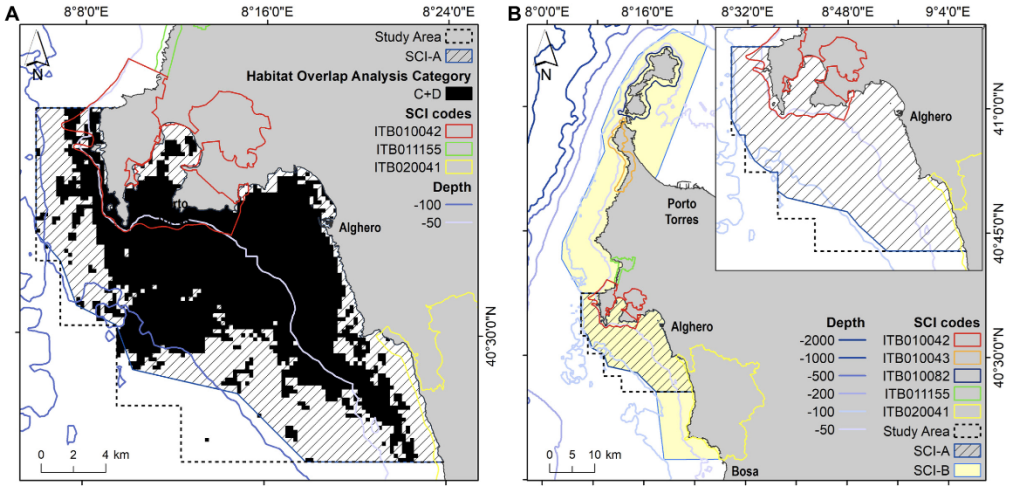


FIGURE 8 | Boundaries of the proposed SCIs **(A,B)** for the protection of bottlenose dolphin, in comparison with the existent SCIs inside and outside the study area. **(A)** SCI-A is the area that contains and connects all the high dolphin suitability cells obtained by superimposing the overlap analysis of each year (black area in the map **A**). **(B)** SCI-B includes the area that connect the SCI-A to the closest SCIs in the North and South of Alghero; as the boundary of SCI-A approximates the isobath of 100 m, the 100 m-contour was used as a limit to define the boundaries of the SCI-B.

differences in dolphin distribution as a function of habitat type depending on calf presence.

In the present study, we were only able to model the annual distribution of the bottlenose dolphin and could not consider seasonal trends in environmental variables or boating activity. Thus, we cannot infer whether the habitat preferences of bottlenose dolphins can change as a consequence of the seasonality of human presence and the environment. We also do not yet fully understand how the requirements of different reproductive stages or calf age affect habitat preference. Furthermore, even if we produced ecologically plausible results, we cannot exclude that the presented models could be improved through the inclusion of information related to the differential use of the several habitat types (Hastie et al., 2004; Forney et al., 2012). We also acknowledge that proximal predictors such as prey availability would improve model predictability, rather than the derived proxies of prey distribution considered in this study, such as SST and Chl-a.

Management Implications

The development of efficient conservation strategies for the bottlenose dolphin should encompass an accurate description of its distribution (Lambert et al., 2017). Species distribution model predictions should include human activities that can overlap with the habitat use of the species. Coastal tourism is exerting an increasing pressure on coastal ecosystems (Douvere and Ehler, 2007) and knowing the spatial distribution of tourism related boat traffic, especially within and around MPAs/SCIs, should become prerequisite for effective human activities management

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in tourist areas. In particular, the potential biological cost of boat impacts on female dolphins and calves should be a main concern for MPA/SCI management as stressors caused by boating can influence pregnancy success, calf survival, and population stability (Moberg, 2000).

This study posits that the boundaries of the existing SCIs in the Alghero region should be tailored to include high dolphin suitability areas and should connect with the other contiguous SCIs along the north western Sardinian coast. Implementing and enforcing a spatial plan in the Alghero area that includes bottlenose dolphin protection would be possible by considering the results of modeling exercise. The overlap analysis presented here is the result of the spatial interaction between humans and dolphins, and identifies the need to balance human use and species conservation needs in the Alghero region. Therefore, adjusting the MPA and/or SCI boundaries could help reduce anthropogenic impacts to dolphins (Cartwright et al., 2012).

Furthermore, the MPA/SCIs management plans should be accurately implemented and enforced to decrease dolphin-boat interactions, especially for mother-calf pairs. Particularly, the maximum number of boats, the maximum distance of boats to dolphin groups and boat speed in presence of dolphins should be restricted in MPA/SCI, as already be done in other Italian MPAs. Additional investigations should address dolphin reactions to boats, in terms of distribution, habitat use and behavioral alterations.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because the study is observational and was approved by the Marine Protected Area Capo Caccia Isola Piana.

AUTHOR CONTRIBUTIONS

GLM, FR, GS, and GC conceived the ideas and designed methodology. GLM, FR, and AR collected the data. GLM and FR analyzed the data. GLM, GS, and GC led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.542648/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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