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# Bottlenose Dolphins and Seabirds Distribution Analysis for the Identification of a Marine Biodiversity Hotspot in Agrigento Waters

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**Abstract:** The aim of this study is to evaluate the presence of biodiversity hotspots in Agrigento waters (Mediterranean Sea) to define the conservation area for bottlenose dolphins (*Tursiops truncatus*) and seabirds (*Calonectris diomedea*, *Puffinus yelkouan*, and *Hydrobates pelagicus*), according to European directives. With this purpose, the maximum entropy algorithm (MaxEnt) was applied to the sighting points of the focal species. They co-occur in the study area and have been documented to forage behind trawlers. In this study, a fishing rate was designed and used as an explanatory variable of the species distribution, together with physiographic variables. Data were collected during 68 surveys in the waters off Agrigento province. MaxEnt models showed a strong predictive power, with distance from the coast being the greatest predicting variable, followed by slope, depth, and fishing rate. For all the species considered, the probability of presence increased as the fishing rate grew. Cartographic analysis revealed one area shared by the species, which occupies 529 km$^2$, from the shoreline to 100 m depth. This study increases knowledge on the distribution and habitat preferences of the target species in the Sicilian waters. Evaluating the influence of fisheries is a promising method that needs further testing to apply effective management measures.

**Keywords:** bottlenose dolphin; seabirds; distribution; fisheries; management; MaxEnt model

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## 1. Introduction

Marine biodiversity in the Mediterranean Sea is threatened by several anthropogenic impacts, including habitat degradation, overexploitation of marine resources, pollution, and eutrophication, which are mainly concentrated in coastal and shelf areas [1]. Strategies to promote species diversity are effective when the distribution of habitats and species is coherent with the environmental conditions of a given area. Furthermore, these are achieved when the keystone species, important species for the functioning of an ecosystem [2], are recognized [3]. Above all, seabirds [4] and dolphins [5] are amongst these species, since they have a structural role in the ecosystem and in their interconnected trophic webs [6]. As top predators in marine trophic webs, they can regulate the abundance of organisms at lower trophic levels through the reduction of their preys' populations, thus limiting the dominance of species and promoting their coexistence [7–9]. Therefore, dolphins and seabirds are key functional groups according to the Marine Strategy Framework Directive (2008/56/CE) [5]. Their distribution and habitat preference can indicate the influence of environmental and anthropic factors in marine systems [10].

The identification of biodiversity hotspots is pivotal to answer the criteria defined by the Birds [11] and Habitat Directives [12], and to subsequently propose protection measures. Bottlenose dolphins are listed in Annex II of the Habitat Directive (92/43/CEE). The protection of species listed in this Annex requires the institution of Special Conservation

Zones (ZSC). All the seabirds evaluated in this study are included in Annex I of the Bird Directive, which calls for the creation of a coherent network of Special Protection Zones (ZPS) to preserve the species. Therefore, the creation of distribution maps of habitats and species of community interest is fundamental to meet the directives' requirements [13]. Moreover, the description of the natural and effective area of distribution of these species is also needed to reach the "Good Environmental State" proposed by the Marine Strategy Framework Directive (2008/56/CE) [14].

This study aims at obtaining predictive distribution maps of the only coastal cetacean species in Italian waters, bottlenose dolphins (*Tursiops truncatus*), and of protected seabirds species: the Procellariidae (Scopoli's shearwater *Calonectris diomedea*, and Yelkouan shearwater *Puffinus yelkouan*) and Hydrobatidae (European storm petrel, *Hydrobates pelagicus*) families.

The maximum entropy algorithm (MaxEnt) was applied to locate biodiversity hotspots, areas with a stronger presence of the cited species, and to understand their habitat preferences. Species distribution models are statistical tools that relate species distribution data (occurrence or abundance at known locations) with information on the environmental and/or spatial conditions of those locations [15]. They are used to understand how the variables guide the environmental niche of a species and its geographic range [16], in order to extrapolate the different habitats suitable for its presence in the entire study area [17]. This information can then be used to predict the likelihood of habitat suitability in other areas. MaxEnt is very powerful when assessing distribution and habitat use of different species, given its reliance on presence locations only, and has a relatively low sensitivity to spatial errors linked to data on presence [18]. Furthermore, compared with other modelling approaches based on presence-only data, MaxEnt requires less data to build functional models, and it also provides more accurate predictions [18]. MaxEnt was applied in previous studies to obtain predictive results on bottlenose dolphins in the waters of Lampedusa Island [19], in the North-Eastern Atlantic [20], in the waters of the Osa Peninsula, and in Golfo Dulce, Costa Rica [21]. Moreover, there are also studies conducted using MaxEnt on Scopoli's shearwaters along the Tunisian [22] and Iberic [23] coasts, Yelkouan shearwaters [24], and European storm petrels along Spanish coasts [23].

Food availability is often of the utmost importance to determine distribution patterns of top predators such as bottlenose dolphins and seabirds [25–27]. Commercial fisheries represent an anthropogenic concentration of food [28]. Consequently, seabirds and bottlenose dolphins consume less energy searching for food when fishing boats are in the area [28,29]. Several dolphin populations have modified their behavioral responses to take advantage of these foraging opportunities, which has led to forms of commensalism, mutualism, or depredation [30]. In particular, bottlenose dolphins showed strong associations with active trawlers, which affect their behavior and habitat use [31]. Bottom trawl fishing can also impact on the life-history traits, population dynamics, and community structure of seabirds [32–34]. The species considered in this study have been observed in different parts of the world while following trawlers and pair trawlers (hereafter fishing boats) to capture prey directly from the nets, or to feed on waste thrown overboard [28,31,33,35–38].

Realizing the co-occurrence of commercial fisheries and our focal species, the presence of commercial fisheries is tested in this study to understand the distribution of bottlenose dolphins and protected seabirds through the MaxEnt model. Taking into account that the presence and number of fishing boats vary over time, a fishing rate metric was designed to be used as a predictive variable in the model. This rate gives an indication on how much a given area is utilized by fishing activities. Evaluating the influence that human activities have on determining species distribution is an approach that needs to be developed in order to obtain useful information for the implementation of management measures effective in protecting the species.

A central issue in conservation is to identify the areas where conservation resources should be directed [39]. In the last decades, the identification of biodiversity hotspots has become a tool for setting conservation priorities to preserve species and their ecosystems [39].

In this study, species' distribution is used with the aim of identifying biodiversity hotspots relevant to the conservation of marine ecosystems. Bottlenose dolphins and protected seabirds were chosen as focal species considering the regulative framework protecting them, their ecological role, and their shared habit of exploiting fishing vessels to forage. This method could provide environmental managers with a new perspective on habitat preferences. In addition, it will increase knowledge on the distribution of protected species in an area where information is currently inadequate.

## 2. Materials and Methods

### 2.1. Study Area

The study area (37.0867 N, 13.0329 E–37.5034 N, 13.8662 E) is located in the coastal waters off the Agrigento province, in the Strait of Sicily, and it covers approximately 1066 km$^2$. The Strait of Sicily was identified as an Ecologically or Biologically Significant Area (EBSA) by the Contracting Parties of the Convention on Biological Diversity (2014) [40]. In the Mediterranean Sea, the Strait of Sicily is one of the most important areas for demersal fishery resources mainly caught with trawl nets. Furthermore, it is a feeding area for 30% of the global population of Scopoli's shearwater (*Calonectris diomedea*), 10% of the global population of the Yelkouan shearwater (*Puffinus yelkouan*) colony, and the colony of the endemic Mediterranean subspecies of storm-petrel (*Hydrobates pelagicus melitensis*) [41–43].

The waters off the Agrigento province host three fishing fleets, mainly composed of trawlers and pair trawlers; both activities show strong interactions with bottlenose dolphins [44]. Trawlers represent approximately 30% of the fishing fleet in Porto Empedocle (54 boats), 45% of the fleet in Sciacca (137 boats), and 40% of the one in Licata (97 boats), while the remaining percentages are attributed to artisanal fishery. Trawling results in overfished demersal stocks [45] and in fragmented habitats and associated biocenoses [46]. The province of Agrigento is a well-stocked area, with several rivers flowing through it, which increases the nutrient intake in the investigated area. The San Leone, Naro, and Salso rivers all contribute to create large sand bars that interfere with the circulation of seawaters [47]. In fact, sand bars work as a physical barrier that forces the upwelling of deeper nutrient-rich waters to the surface, thus increasing productivity.

### 2.2. Data Collection

Data analyzed in this study were collected during the summer seasons of 2018 (from July to September) and 2019 (from June to October) over 28 and 40 surveys, respectively. Each survey lasted an average of 4 h and 40 min (ranging from a minimum of 1 h to a maximum of 8 h), covering 4065.12 km. The expeditions started from the harbor in Porto Empedocle, using an inflatable boat with a rigid fiberglass keel (Selva 5.40 m) equipped with a 40 hp 4-stroke Selva outboard motor. According to previous studies [38,44,48] conducted in the study area, sightings of the concerned species are sufficiently uniform in the 0–150 m bathymetry range. Therefore, surveys were carried out following a random sampling design within the same depth range. An average sampling speed of 8 Kt was maintained during the surveys to ensure visual detection of the species and to reduce the disturbance [49]. Every survey was carried out with good sea weather conditions (Beaufort scale $\leq 3$) and with good visibility. The latter was at least 15 km, verified as the ability to see the cape of Punta Bianca (37.193981 N, 13.661275 E) from the exit of Porto Empedocle' harbor (37.273576 N, 13.529416 E). At least two observers, positioned on both sides of the boat, were present during each survey and visually scanned 180° sectors each, in order to cover a 360° area around the boat, with and without binoculars. During the surveys, the boat location was recorded every 2 s by a GPS (GARMIN GPS 72H). Whenever seabirds (classified by families), dolphins, or fishing boats in activity (with their name and identification number) were encountered, geographical coordinates of their location were estimated with the minimum error by navigating as close to them as possible without causing disturbance (maximum distance 300 m). Dolphins and seabirds were considered as "interacting" with fishing boats whenever they were observed taking advantage of the boat to feed. This includes feeding from the nets, the waste, or the fish surrounding the nets. For this purpose, the behavior of the species in relation to fishing boats was also noted in order to register the interactions observed.

### 2.3. Data Analysis

#### 2.3.1. Data Preparation

The geographical locations noted during surveys were organized through the creation of a separate datasheet for each category of metadata (avifauna families, cetacean species, commercial fishery activities). Before carrying out any predictive analysis, an analysis of the variance (ANOVA) was conducted with Microsoft Excel software [50], to make sure that interactions between dolphins and fishing boats were not by chance.

QGis 3.0.3 [51] software was used to visualize the tracks covered between 2018 and 2019, as well as to map the sighting points of seabirds and fishing boats, and the route travelled during sightings of bottlenose dolphins. Subsequently, to conduct predictive analyses, three environmental variables (extracted from 15 arc-second GEBCO gridded bathymetry data) and one anthropic variable were considered. The value of each variable was measured in QGis by dividing the study area in grid cells with 1.5 km side length. The cell size was selected by considering the distance from the survey boat that allows the visual detection of dolphins, seabirds, and fishing boats [52]. All of the variables were inserted into the MaxEnt software and associated to the geographical coordinates of the cell center. They are:

- the seabed index (difference between maximum and minimum depths);
- the mean depth of the seabed;
- the distance from the coastline, represented by the shortest distance between the center of the cell and the coastline, measured in meters;
- the fishing rate (FR), which is proposed to give an idea of how much the cell is used by fishing activities, also considering their temporal variability. This rate was elaborated to evaluate if the fishing effort can influence how the area is used by the species. The FR was obtained from frequency tables built in Microsoft Office for every cell. The tables displayed, for each cell, the number of fishing boats (FB) simultaneously present (e.g., 0 boat, 1 boat, 2 boats, . . . , n boats) and their rate of occurrence(s), namely the number of times that each number of fishing boats occurred. The FR is calculated as the follow arithmetic average:

$$\mathrm{FR} = \overline{\left(\frac{\mathrm{FB} * \mathrm{s}}{s_{tot}}\right)}$$

where $s_{tot}$ is the total number of surveys carried out in the cell.

#### 2.3.2. MaxEnt Model

Maximum entropy algorithm (MaxEnt) was applied to analyze the relative sighting locations of bottlenose dolphins and seabirds of the families Procellaridae and Hydrobathidae, using the MaxEnt software [53]. The algorithm allows the estimation of the most uniform distribution for a species (maximum entropy) in the study area [54] and the creation of habitat suitability models using data on presence only [55]. Therefore, it doesn't take into account data on absence, which would be difficult to validate, since a species could be present even if not observed, which could lead to errors in the species distribution [18]. This is commonly found in studies on cetaceans, given the nature of the species themselves, since a strictly visual survey does not allow one to observe animals if they are diving.

The maximum entropy model estimates the ecological niche of a species by finding a probability distribution that maximizes the entropy [56,57]. Maximizing the entropy of a probability distribution means generalizing its statistical behavior on everything that is not known (unsurveyed zones). The resulting distribution of probability reflects environmental suitability for the studied species [55]. Inside the suitable area for each species, MaxEnt follows a continuous prediction, and it also distinguishes between areas on the basis of habitat suitability [56]. This is represented through a color scale that can take values between 0 and 1, in which, according to Capizzi et al. [58], the habitat suitability can be classified as follows:

- null (0–<0.1);
- low (0.1–0.3);
- medium (>0.3–0.6);
- high (>0.6–1.0).

This allows the individuation of areas with high habitat suitability and their boundaries, in which to concentrate conservation efforts [18].

To avoid the overfitting of models when working with little data on a species' presence, MaxEnt uses the regularization process. This makes sure that the predictive distribution is grouped around presence points [57], thus promoting better predictions [55]. MaxEnt divides the study area into grid cells, from which it extracts a sample of data on geographical positions (background locations). These are compared with data from geographical positions where the focal species is present (sighting points) [59].

MaxEnt allows the use of continuous and categoric variables, and it shows the percentage contribution of every variable to the final model [18]. To understand the way in which each variable influences the species distribution, MaxEnt produces two set of curves. One set shows how the probability of the predicted presence changes as each variable varies, maintaining the average sampling value for all the other variables [18]. The other set displays the contribution offered by each variable separately, and it is the most suitable to use in the case of highly correlated variables, as was expected to occur in this study. Therefore, only the latter has been considered.

To spatially process the model, the geographic locations of bottlenose dolphins and seabirds sightings were inserted into MaxEnt, maintaining the default settings. The complementary format log-log (cloglog) was selected as an output because it allows the interpretation of the results as occurrence probability [60]. Ten combinations of the five features (L linear, Q quadratic, H hinge, T threshold, P product) of MaxEnt were used to identify the optimal model for each species or family (L, LQ, H, LQT, LQH, LQP, LQHP, LQHT, LQPT, and LQHPT). This was done by changing the value of the regularization multiplier from 0 to 10 for each combination [60] and making 10-fold cross-validation replicas of each [19]. Species sightings are divided into training data and test data. The first ones are used to build the predictive models, while the latter are for evaluating the training model accuracy [61,62]. The cross-validation method randomly splits the occurrence data into 10 folds (10 replicas, each containing an equal number of sightings). Predictive models are created omitting each fold in turn, which is used as test data [63] for every replica of the model.

#### 2.3.3. Model Testing

Different methods were applied to test the reliability of the models obtained.

A binomial test was used to evaluate if the distribution of the species was significantly different than a random one. To do this, the test considers the omission rate, which is the percentage of localities having null suitability for the investigated species. It works by comparing the omission rate obtained from the samples to the one expected in accordance with the MaxEnt distribution [56]. The more the omission line is under the line of predicted omission, the worse the predictive power of the model will be [64].

The value of the area under the ROC curve (AUC) was used to evaluate the precision of the obtained models. AUC values vary between 0 and 1: a value of 0.5 coincides with a precision of the model that is not better than a random analysis [65]; a value lower than 0.5 suggests that the model fits worse than a random analysis [18]; a value of 1 indicates a perfect fit of the model [65].

The jackknife resampling technique was used to evaluate the importance of each variable by excluding one variable at a time. It shows how much each variable influences the distribution of the species, and how much unique information is associated with each variable [18]. When the presences in the sample are lower than 25 [66], the jackknife approach can underline variables that are strongly correlated. This solves the problem of high collinearity that can influence the percentage contribution of the variables [18]. At the end of each run, conducted by means of the cross-validation, the gain shows how closely the model is concentrated around the presence samples [63]. The jackknife test evaluates how the regularized training gain, the test gain, and lastly the AUC change, considering, respectively, the training data, the test data, and the AUC values [63].

#### 2.3.4. Cartographic Analysis

The MaxEnt distribution maps were exported as ascii files and imported as raster files into the QGis software. Raster files were then converted to vector files to be more manageable. Areas with high habitat suitability (values > 0.6) were considered hotspots for the target species and have been identified using QGis. Afterwards, hotspots of the target species have been overlapped to determine and quantify the biodiversity hotspot, an area with higher biodiversity. Finally, both the extension (area covered by the hotspot, expressed in $km^2$) and the percentage of space occupied by the hotspots (compared to the whole area resulting from the predictive models) have been measured using the Qgis software.

## 3. Results

### *3.1. Monitoring Results*

Between 2018 and 2019, 62 sightings of bottlenose dolphins were recorded (28 in 2018 and 34 in 2019). During 52 of these sightings, the dolphins were interacting with commercial fishing boats (Table 1). The results for interactions observed between dolphins and fishing boats were significant ($p$ value < 0.05), as found by applying the one-way ANOVA (Table 2).

**Table 1.** Number of sightings of bottlenose dolphins in Agrigento waters between 2018 and 2019. The number of sightings in which dolphins interact with trawlers, interact with pair trawlers, or have no interactions are shown.

| No. of Sightings (Bottlenose Dolphin) | 2018 | 2019 | Total |
|---|---|---|---|
| Interactions with trawlers | 20 | 19 | 39 |
| Interactions with pair trawlers | 6 | 7 | 13 |
| No interactions | 2 | 8 | 10 |

**Table 2.** Results of the one-way ANOVA carried out on the sightings of bottlenose dolphins. It compares sightings with fishing boats interactions to those in which no interaction was observed.

| | SS | df | MS | F | $p$-Value | F crit |
|---|---|---|---|---|---|---|
| Between groups | 441 | 1 | 441 | 49 | 0.019803941 | 18.51282 |
| Within groups | 18 | 2 | 9 | | | |
| TOT | 459 | 3 | | | | |

During the two-year period, 155 observations of trawlers and 40 of pair trawlers were recorded (Figure 1).

Recorded sightings of seabirds were 674 for shearwaters and 92 for European storm petrels (Figure 2). Among the shearwaters, the Scopoli's shearwater was the most frequently sighted.

The overall encounter rate (ER) of bottlenose dolphin was 0.015 sightings/km in the 2018–2019 period, while those of European storm petrels and shearwaters equaled 0.023 sightings/km and 0.166 sightings/km, respectively (Table 3).

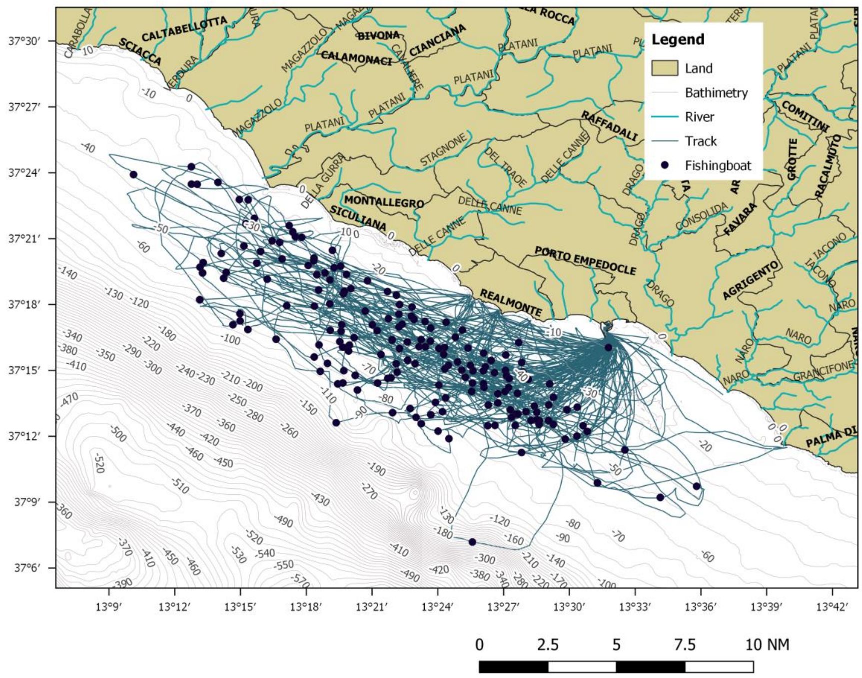


**Figure 1.** Geographical locations of fishing boats (blue dots, trawlers and pair trawlers) observed in the waters of the Agrigento province, in 2018–2019. Survey tracks are shown in light blue.

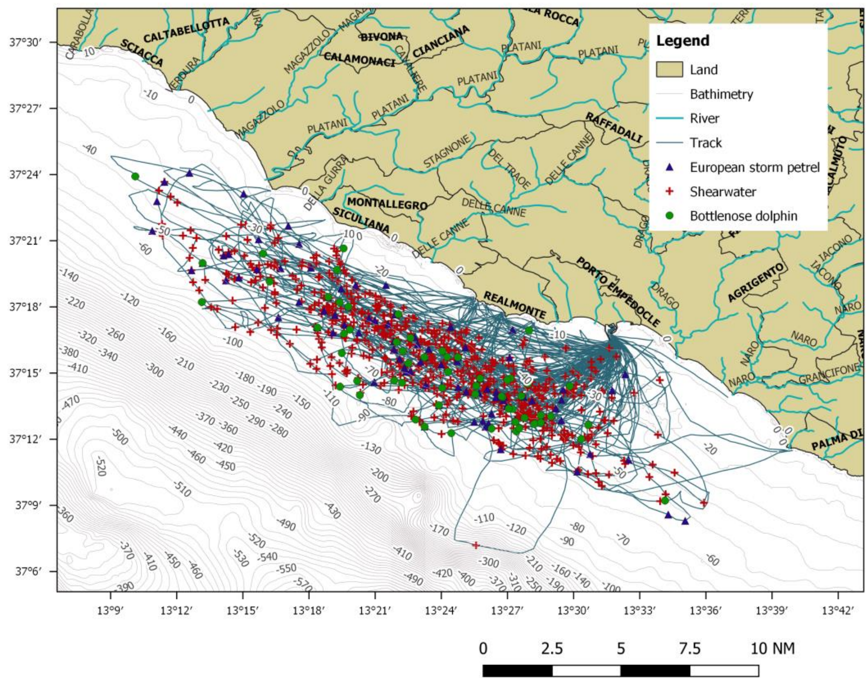


**Figure 2.** Sightings of bottlenose dolphin (green dots), shearwaters (red crosses), and European storm petrel (blue triangles) in the waters of Agrigento province during the field surveys (tracks in light blue) in the 2018–2019 period.

A co-occurrence between bottlenose dolphins and seabirds was observed in 54 sightings (26 in 2018 and 28 in 2019), out of which 47 were in the presence of fishing boats, and 7 in their absence. Shearwaters were found together with dolphins more often than the European storm petrels were, during 84% and 24% of the encounters (52 and 15 times), respectively.

**Table 3.** Annual sampling effort expressed in km and relative number of sightings by species. Encounter rate values (ER) for bottlenose dolphins and seabirds (shearwaters and European storm petrel) calculated as a ratio of the number of sightings and the survey effort (km covered).

| Year | Survey Effort (km) | Bottlenose Dolphin Sightings | European Storm Petrel Sightings | Shearwaters Sightings | Bottlenose Dolphin ER | European Storm Petrel ER | Shearwaters ER |
|---|---|---|---|---|---|---|---|
| 2018 | 1652.87 | 28 | 49 | 324 | 0.017 | 0.030 | 0.196 |
| 2019 | 2412.25 | 34 | 43 | 350 | 0.014 | 0.018 | 0.145 |
| Total | 4065.12 | 62 | 92 | 674 | 0.015 | 0.023 | 0.166 |

## 3.2. Predictive Models with MaxEnt

### 3.2.1. MaxEnt Model

As shown by the response curves, the higher probability of presence is found to be at 15 km from the coastline (Figure 3a), at 80 m of depth (Figure 3b), and at 165 m of slope for bottlenose dolphins (Figure 3c); while it is at 13 km from the coast (Figure 4a), 80 m of depth (Figure 4b), and 145 m of slope for shearwaters (Figure 4c). As for the European storm petrel, the higher probability is found at 14 km from the coast (Figure 5a), 90 m of depth (Figure 5b), and 145 m of slope (Figure 5c). Moreover, the probability of presence increases as the fishing rate grows, reaching a value of around 1 in bottlenose dolphins and in shearwaters, and of 0.45 in the European storm petrel, when the variable acquires a value of 1 (Figures 3d, 4d and 5d).

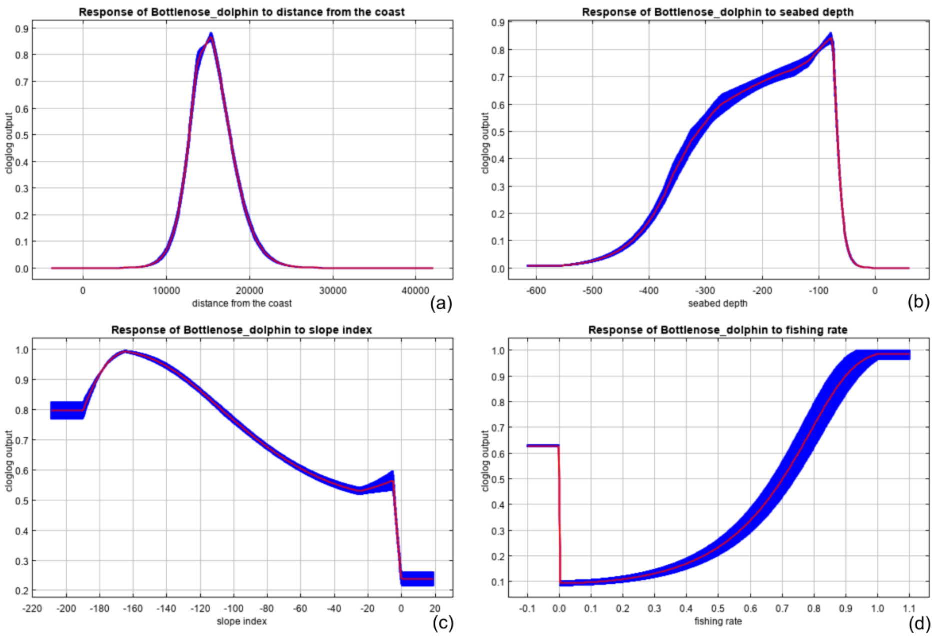


**Figure 3.** MaxEnt response curves for bottlenose dolphins, showing the probability of presence against each variable: distance from the coast (m) (**a**), seabed depth (m) (**b**), slope index (m) (**c**), and fishing rate (**d**).

Distribution maps of the species and the family under consideration are displayed in Figure 6. The area with high habitat suitability has similar geographical extension for bottlenose dolphins (Figure 6a), shearwaters (Figure 6b), and the European storm petrel (Figure 6c). Some minor differences in the depth of the area with high habitat suitability occur for shearwaters (Figure 6b) compared to the other two species (Figure 6a,c). The first one shows the highest habitat suitability at depth lower than 200 m and only reaches 250 m depth in the waters in front of Realmonte. On the other hand, the highest habitat suitability for bottlenose dolphin and European storm petrel reaches 250 m depth from Realmonte to Palma di Montechiaro.

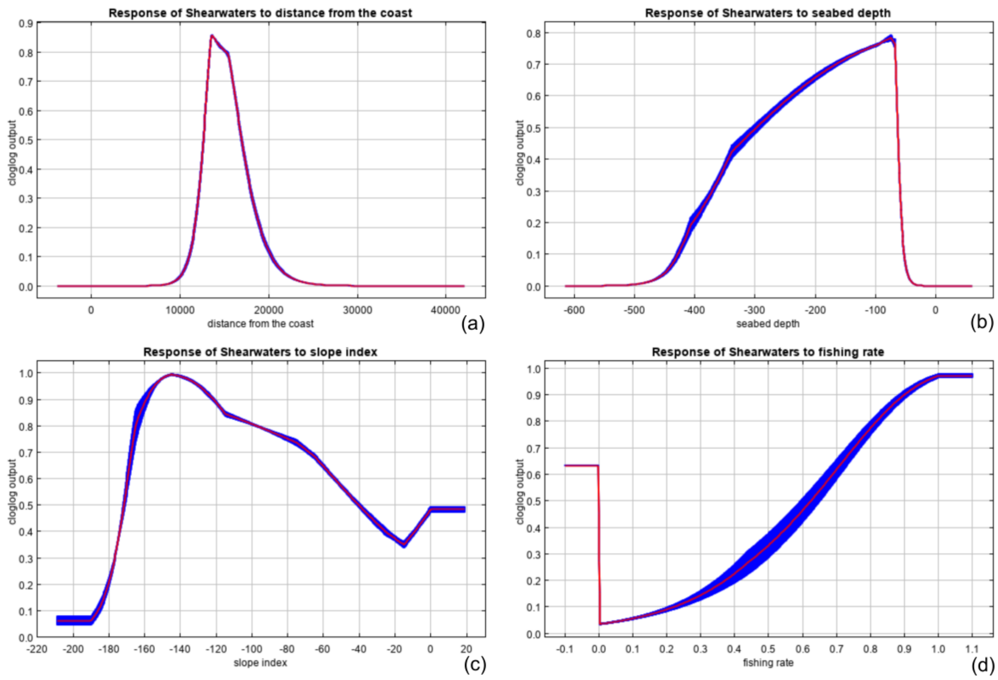


**Figure 4.** MaxEnt response curves for shearwaters, showing the probability of presence against each variable: distance from the coast (m) (**a**), seabed depth (m) (**b**), slope index (m) (**c**), and fishing rate (**d**).

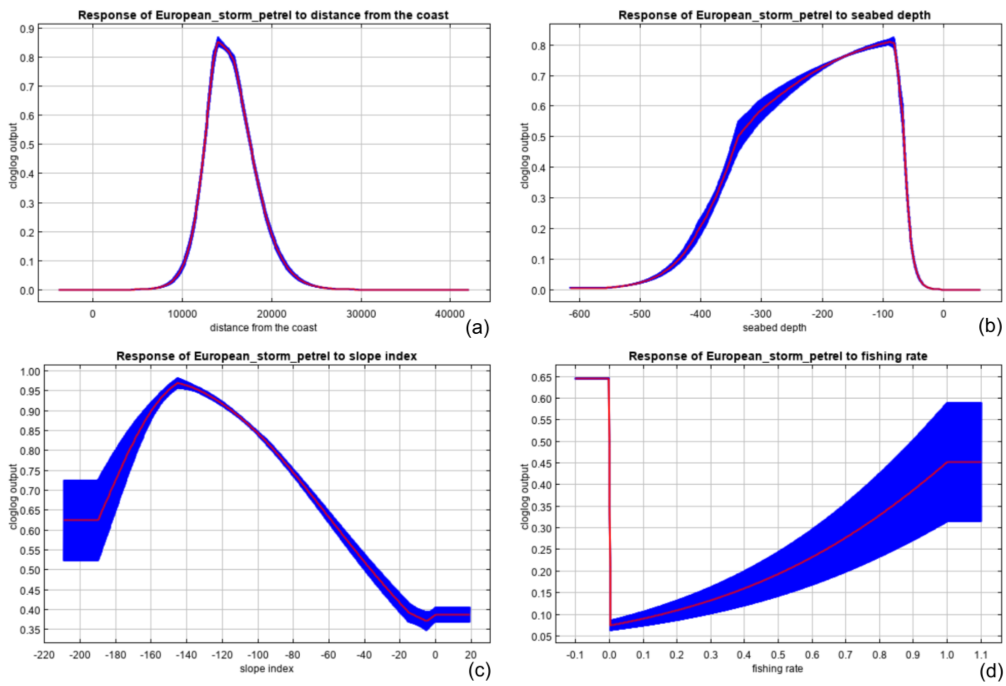


**Figure 5.** MaxEnt response curves for European storm petrels, showing the probability of presence against each variable: distance from the coast (m) (**a**), seabed depth (m) (**b**), slope index (m) (**c**), and fishing rate (**d**).

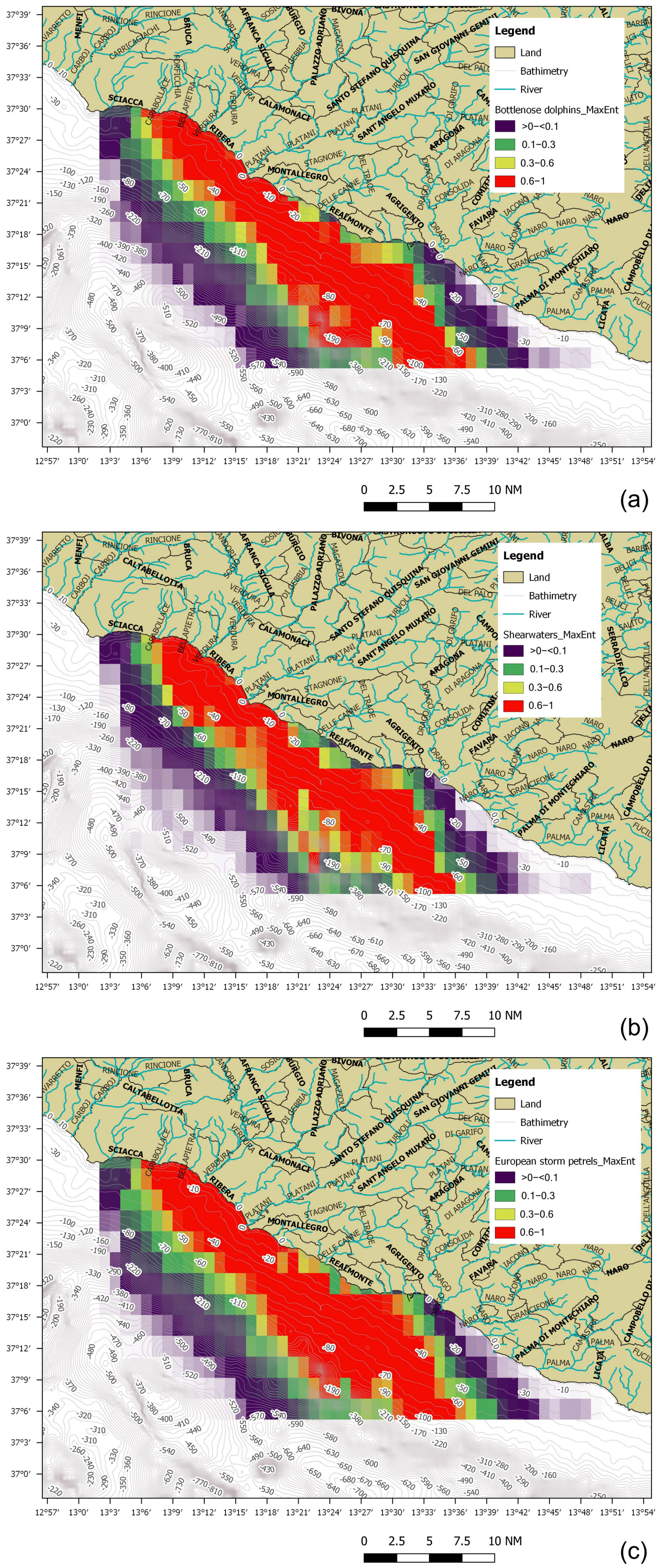


**Figure 6.** MaxEnt distribution maps of (**a**) bottlenose dolphins, (**b**) shearwaters, and (**c**) European storm petrels in the waters of the Agrigento province, built on the predictive model. The color scale indicates habitat suitability, where the red identifies the hotspot for each species (high habitat suitability).

### 3.2.2. Model Testing

Below are reported the results of the binomial (Figure 7) and the AUC (Figure 8, Table 4) tests. These were used to determine the most suitable model to predict the distribution of bottlenose dolphins and seabirds. The selected models showed distributions that are not too condensed nor too dispersed around presence points. Moreover, the omission rate of these models was close to the expected omission, suggesting a strong predictive power.

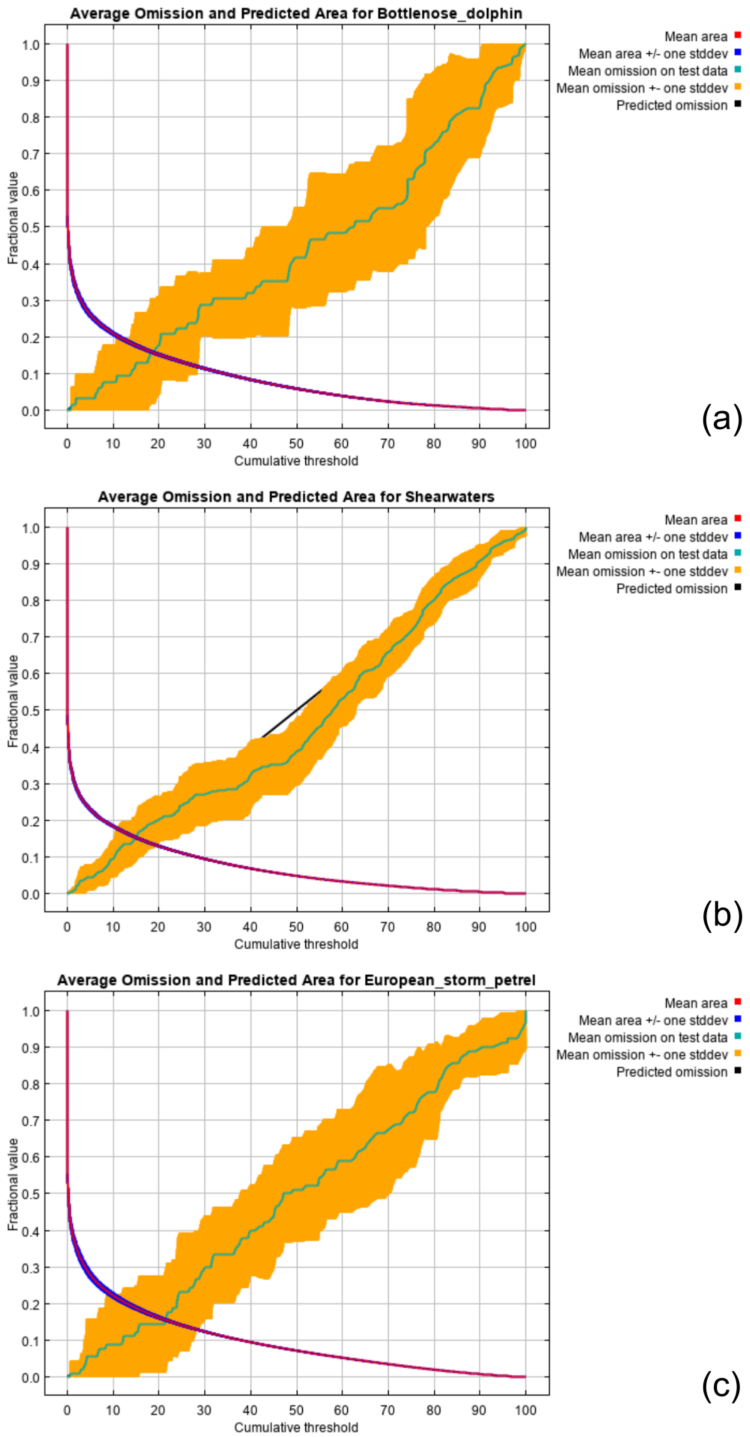


**Figure 7.** Resulting graphs from MaxEnt binomial test, showing the trend of the average omission rate and the predicted omission for (**a**) bottlenose dolphins, (**b**) shearwaters, and (**c**) European storm petrels.

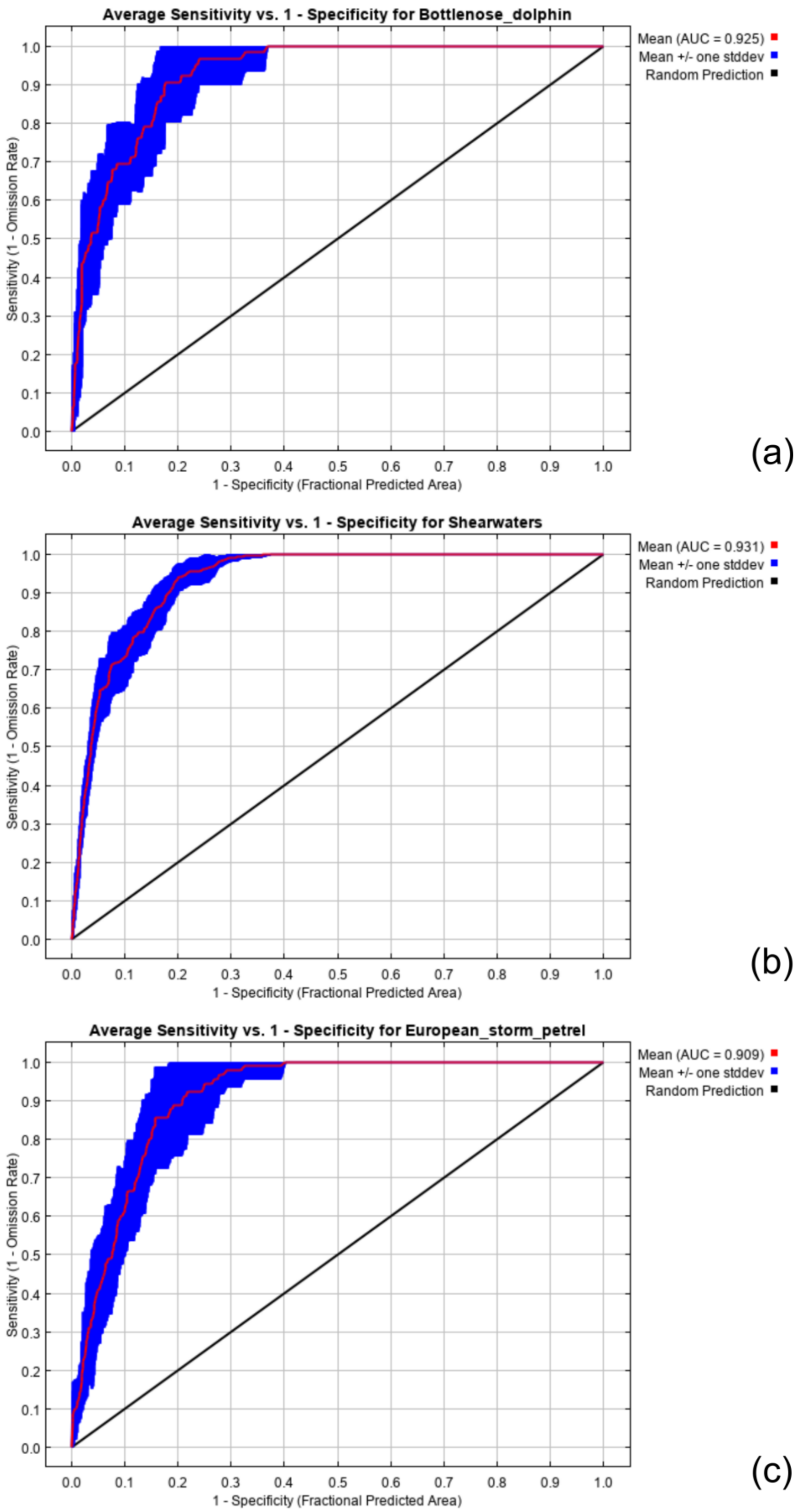


**Figure 8.** MaxEnt AUC for (**a**) bottlenose dolphins, (**b**) shearwaters, and (**c**) European storm petrels. The graphs show average sensitivity (mean AUC, red) against random precision (black) to evaluate the precision of the model.

**Table 4.** MaxEnt AUC and standard deviation (SD) values relative to the predictive model (LQH) analyzed for bottlenose dolphins, shearwaters, and European storm petrel.

| Species or Family | Model | Regularization Multiplier | AUC | SD |
|---|---|---|---|---|
| Bottlenose dolphin | LQH | 1 | 0.925 | 0.025 |
| Shearwaters | LQH | 1 | 0.931 | 0.014 |
| European storm petrel | LQH | 1 | 0.909 | 0.028 |

Distance from the coast is the variable providing the highest percentage contribution to the models, followed by seabed depth, seabed index, and lastly, fishing rate (Table 5).

**Table 5.** Percentage contribution that each of the variables tested (distance from the coast, seabed depth, slope index, fishing rate) has on the distribution of bottlenose dolphins, shearwaters, and European storm petrels.

| Variable | Bottlenose Dolphin | Shearwaters | European Storm Petrel |
|---|---|---|---|
| % of distance from the coast | 75.9 | 77.8 | 80 |
| % of seabed depth | 17.4 | 14.9 | 14.8 |
| % of slope index | 7.1 | 7.2 | 3.3 |
| % of fishing rate | 0.6 | 0.1 | 1.9 |

The jackknife test graphs (Figures 9–11) show that the variable that appears to generate the biggest "gain", and that reduces it the most if omitted, is the distance from the coast. The seabed depth is the second contributor to the model, probably because of the strong correlation with the distance from the coastline. The slope index and fishing rates appear to be weak predictive variables, compared to the first two (Figures 9–11).

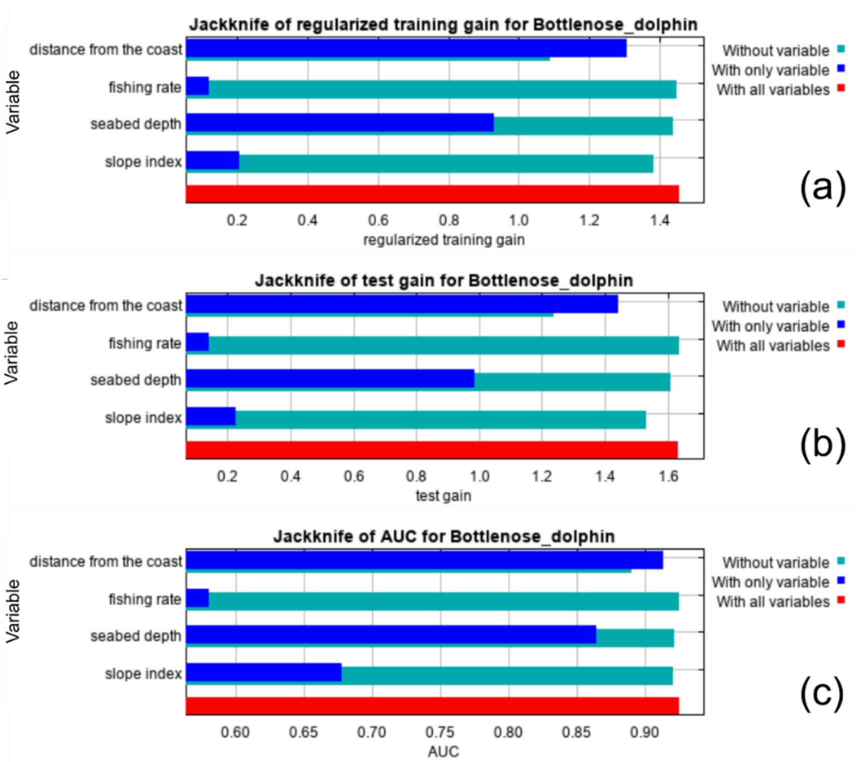


**Figure 9.** Results of the MaxEnt jackknife test of (**a**) regularized training gain, (**b**) test gain, and (**c**) AUC, for bottlenose dolphins. It shows the importance of each variable (distance from the coast, fishing rate, seabed depth, slope index) by excluding each variable (light blue), by considering only that variable (blue), and then by considering all the variables together (red).

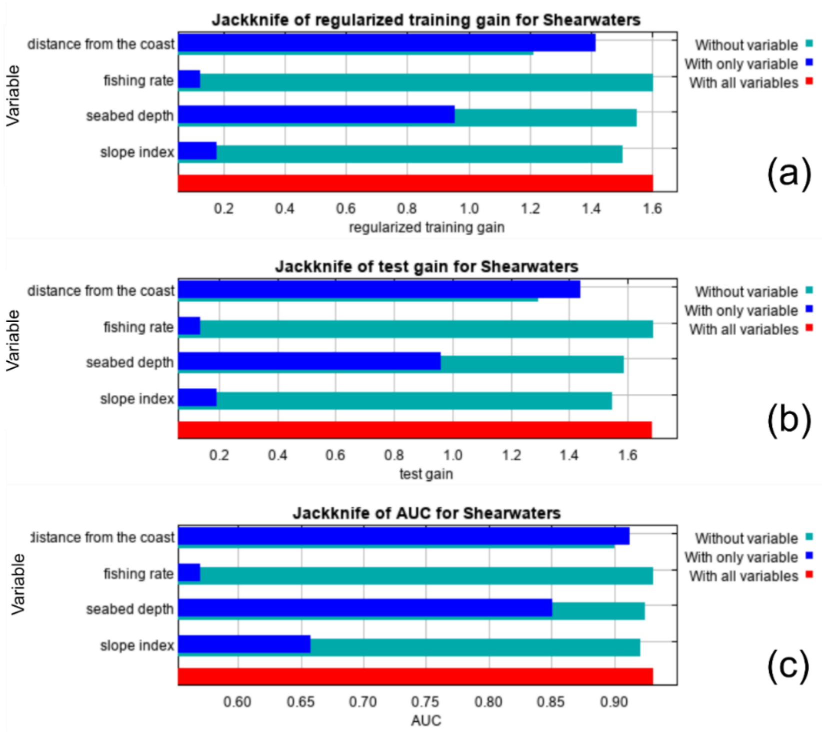


**Figure 10.** Results of the MaxEnt jackknife test of (**a**) regularized training gain, (**b**) test gain, and (**c**) AUC, for shearwaters. It shows the importance of each variable (distance from the coast, fishing rate, seabed depth, slope index) by excluding each variable (light blue), by considering only that variable (blue), and then by considering all the variables together (red).

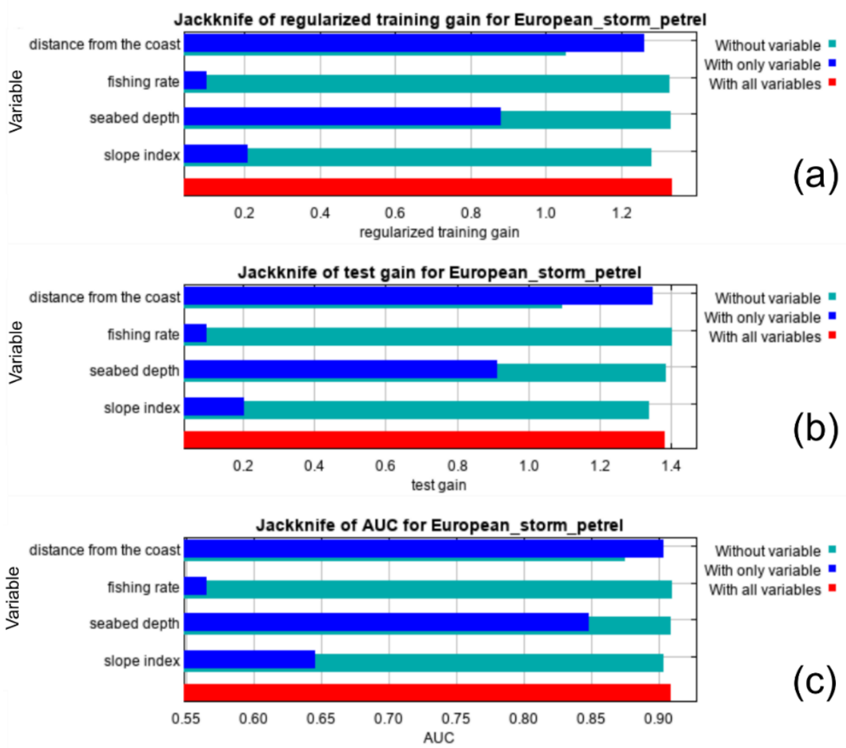


**Figure 11.** Results of the MaxEnt jackknife test of (**a**) regularized training gain, (**b**) test gain, and (**c**) AUC, for the European storm petrel. It shows the importance of each variable (distance from the coast, fishing rate, seabed depth, slope index) by excluding each variable (light blue), by considering only that variable (blue), and then by considering all the variables together (red).

### 3.3. Cartographic Analysis

The extension and the percentage of space occupied by the dolphins and seabirds' hotspots compared to the whole area in the predictive models (1889 km$^2$) are shown in Table 6. The hotspot for European storm petrels shows the highest values, followed by bottlenose dolphins and shearwaters (Table 6).

**Table 6.** Extension and percentage of area occupied by the hotspots (areas with high habitat suitability, red in Figure 6) identified through the MaxEnt algorithm for bottlenose dolphins, shearwaters, and European storm petrels.

| Species or Family | Hotspot Extension (km$^2$) | Area Occupied by the Hotspot (%) |
|---|---|---|
| Bottlenose dolphin | 633.39 | 33.53 |
| Shearwater | 563.22 | 29.82 |
| European storm petrel | 660.67 | 34.97 |

From the overlapping of all the hotspots (Figure 12), the presence of one area shared by the focal species and the family can be observed. This area shows higher biodiversity compared to the adjacent waters; it is a biodiversity hotspot with an overall extension of 529 km$^2$, and it occupies 28% of the total study area, localized between Sciacca and Palma di Montechiaro. The biodiversity hotspot extends from the coast to a maximum of 250 m depth (Figure 12). However, this trend is not uniform in the study area: from Sciacca to Siculiana, it extends from the shoreline to 50 m depth, while from Siculiana to Palma di Montechiaro, it extends to depths between 20 and 250 m. In these two sub-areas, however, there is no difference in the distance from the coast, which is maintained throughout the biodiversity hotspot at about 9 km.

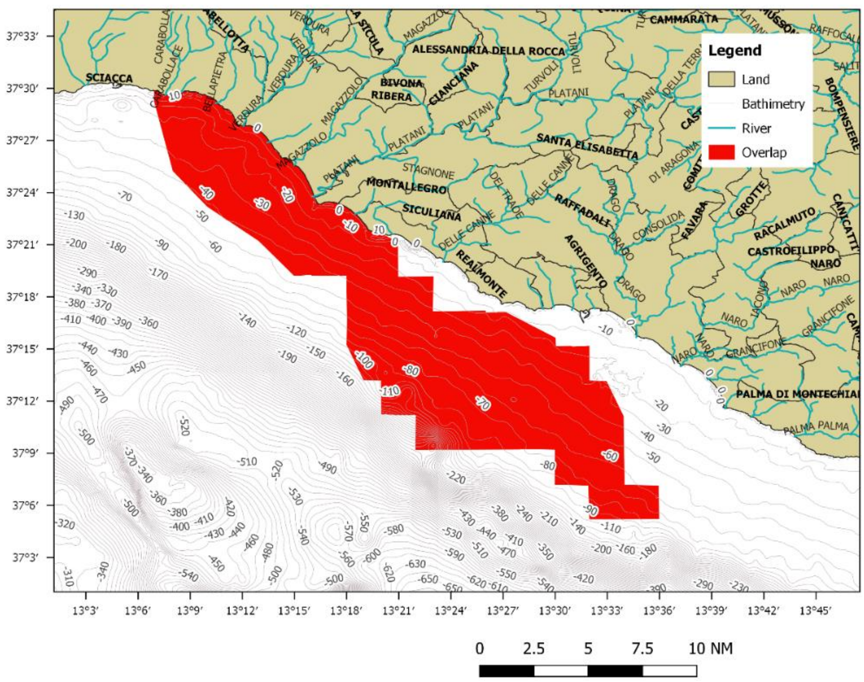


**Figure 12.** Map of the biodiversity hotspot found by overlapping the hotspots (areas with high suitability, red in Figure 6) for each species (bottlenose dolphins, shearwaters, and European storm petrels).

## 4. Discussion

The lack of information on marine species is often used by decision-makers as a pretext to delay conservation measures [67] in a specific area. Therefore, setting up studies designed to develop useful methods to bridge this knowledge gap is of the utmost importance to a successful protection of the species.

In this study, data on the presence of bottlenose dolphins and of protected seabirds (the European storm petrel, the Scopoli's and Yelkouan shearwaters) were recorded and used in order to test a predictive model able to increase the knowledge on their distribution. For this purpose, environmental characteristics and trawling activities were used as predictive variables to describe the distribution of these species. The waters off Agrigento province are an ideal case study, since they are characterized by a great co-occurrence of dolphins, seabirds, and fishing activities [38].

The area is exposed to numerous anthropic activities, the most important of which, for our study, is the presence of three fishing fleets comprised of 288 trawling boats (trawlers and pair trawlers). Bottlenose dolphins and fishing activities, especially trawlers, interacted during 52 out of the 62 registered sightings of bottlenose dolphins. This behavior, already registered in previous studies [28,31,36,38], could be justified by both the predatory activity inside or around the fishing nets, and the passive foraging opportunity offered by waste products [36]. Negative interactions (i.e., by-catch event) between these species and fisheries have never been observed during this study. Regarding bottlenose dolphins, this agrees with previous studies in Italian waters [31,68]. In addition, an association between bottlenose dolphins and sea birds, especially with shearwaters, was observed during 54 sightings, 87% (47 times) of which were at the wake of fishing boats. This could confirm the inclination of seabirds to take advantage of cetacean hunting behavior to access prey patches [69,70]. By "pushing" their prey towards the surface, bottlenose dolphins make them available to seabirds [69], thus strengthening their association.

A fishing rate was specifically designed in this study to consider a variable linked to human activities together with environmental variables (distance from the coast, seabed depth, slope index), in the predictive MaxEnt model. This approach has been tested with the data collected in the waters off the Agrigento province during 68 surveys, conducted in the summers of 2018 and 2019.

Distance from the coast was the variable with the strongest influence on the distribution and habitat preference of the species. This has been already observed in previous studies conducted on shearwaters [24,71] and on bottlenose dolphins in the Strait of Sicily [19,44], as well as in other areas [72,73]. The strongest probability of presence for the considered species was found between 13 and 15 km from the coast, at a depth of 80–90 m. The preference for these distances in the case of the bottlenose dolphin confirms its coastal habits in the Mediterranean [74]. Furthermore, the distance from the coast is largely proportional to the seabed depth and to the commercial fishing activities, and it could potentially be indirectly related to prey distribution. In fact, the greatest fishing effort in the area, measured as the average number of hours of activity, was recorded along the coast [75] and coincides with the waters with the greatest habitat suitability described in this study. The findings about depth preferences agree with studies on bottlenose dolphins [76–80] and shearwaters [24]. However, they differ from other studies in which our focal species prefer offshore waters [81–83]. A greater difference in habitat preference was displayed by the species in relation to the seabed index, with seabirds showing the highest presence at 145 m and bottlenose dolphins at 165 m, in agreement with another study in which sightings occurred over steep slopes [84]. These results contrast with the habitat preferences in the Tyrrhenian waters [70], where bottlenose dolphins and shearwaters were observed in areas with a gently sloping seabed.

The data collected show that the second variable in order of influence is depth, followed by the slope index, and lastly, the fishing rate. The fishing rate appeared to have a very weak power in predicting habitat suitability. It is possible that the low percentage of contribution showed by the fishing rate is largely due to the masking effect of the stronger environmental variables, which should be investigated in the future. Despite the weak percentage contribution, habitat suitability increases gradually as the fishing rate grows, reaching a value of 1 when the variable is equal to 1 for the bottlenose dolphin and shearwaters, and a value of 0.45 for the European storm petrel. This confirms the habit of bottlenose dolphins and shearwaters to feed at the wake of fishing boats, as described in several areas globally [28,31,33,35–38,68]. For this reason, as observed in previous studies, bottlenose dolphins [77] and shearwaters [82] aggregate in areas that are exploited by fishery. The low values found for European storm petrel would support its tendency to follow trawlers irregularly and with fewer specimens than other seabirds, as seen in the western Mediterranean Sea [34]. Furthermore, the species does not feed on the fishing waste thrown off the fishing boats during the summer season, since it probably consists of fish of unsuitable size for its diet [85].

The higher habitat suitability for species at specific environmental factors could be linked to the distribution of their preys [70,74,86]. Therefore, the distribution of bottlenose dolphins and seabirds could mirror that of epipelagic fishes [86] and planktonic organisms. These preys can be found between the sea surface and 200 m of depth and are at the basis of the trophic needs of sea birds [87]. Sharing preys and habitat could increase the competition for the same marine resources, which are also targeted by fishing fleets in the Strait of Sicily. Foraging in association with fishing activities could be speculated to be a stronger advantage for bottlenose dolphins, compared to the noise disturbance created by the boats themselves. Furthermore, the Scopoli's shearwaters' scavenging behavior, frequently recorded during this study, has been observed in other Mediterranean areas, like the Ionian Sea [37] and the Balearic Sea [34].

Bottlenose dolphins and seabirds showed a similar distribution, with the hotspots extending in a contiguous area from Sciacca to Palma di Montechiaro. Some small differences occur for the shearwaters compared to other species for which the extension of the area with high habitat suitability is lower. This results in one biodiversity hotspot covering 529 km$^2$, occupying 28% of the surveyed area. It could be a foraging hotspot, and this reveals the urgency of developing conservation measures to safeguard these species and their habitats.

The institution of marine protected areas is linked to the management and conservation of protected species [88]. The approach described here has important implications for management, mitigation, and conservation activities. Further evaluating the impact of commercial fishery will be fundamental in the future for the institution of a protected area in Agrigento waters. Trawling could contribute to aggregate preys, thus creating a food resource for the target species of this study. Hence, the advantage that species gain from fishing boats may be greater than their disturbing effect, so a management plan should take this into account. This is particularly true for bottlenose dolphins, which show strong specialization in hunting techniques. When generations of bottlenose dolphins feed mostly, or exclusively, in association with fishing boats, the effect that stopping fishing activities could have on the population is largely unknown [28]. If commercial fisheries ceased or were banned, we hypothesize either of two scenarios. The first hypothesis is that species could move away, definitively or temporarily, to other fishing areas. The second one is that they could adapt to the new condition created in the absence of the fisheries. The latter hypothesis is more plausible for bottlenose dolphins than for seabirds, given the high behavioral plasticity of this species, as observed in Australia [89]. Given that the species reaction to the removal of commercial fisheries is not predictable a priori, the best solution to manage this area would probably be to regulate the number of vessels present in the zone at the same time.

## 5. Conclusions

In conclusion, this study made it possible to identify a single large biodiversity hotspot (common to all the species), delimiting the boundaries of an area that should be protected. This suggests the urgency to implement management measures and to institute a conservation zone in this area.

The fishing rate, designed for this study, showed a weak power in predicting species distribution within the current study, compared to environmental features. However, it is plausible that the low percentage of contribution showed by the fishing rate is largely due to the masking effect of the environmental variables. Nonetheless, the use of this variable is very interesting since habitat suitability for the focal species increases as the fishing rate grows. Furthermore, the fishing rate can be applied in other areas and to other species and has the potential to be adapted to other fishing techniques as well as other anthropic activities (i.e., marine traffic).

In addition, this study increases the knowledge about habitat suitability and on the interactions with fishing activities for the bottlenose, the European storm petrel, and the Scopoli's and Yelkouan shearwaters in the waters off Agrigento province. The model provides a current characterization of the habitat of the species examined.

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