Regional Studies in Marine Science 68 (2023) 103256

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Distribution and behaviour of striped dolphins in the southwestern Mediterranean Sea based on whale-watching data

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ARTICLE INFO

Keywords:
Striped dolphin
Epizootics
Whale watching
Species distribution models
Random forest

ABSTRACT

The striped dolphin (*Stenella coeruleoalba*) is a cosmopolitan cetacean and the most commonly sighted dolphin in the Mediterranean Sea. It usually appears in groups of very different sizes, ranging from less than ten to more than 500 individuals, although it is usually found in groups of between 21 and 50 individuals. In the western Mediterranean, and more specifically in the Gulf of Mazarrón, *S. coeruleoalba* was the most frequently sighted cetacean during the 1042 whale-watching trips. The goal of this study was to establish the spatial and temporal distribution of striped dolphin sightings along the Gulf of Mazarrón between 2004 and 2014. Spatial patterns were analysed using a Random Forest based Species Distribution Model to estimate the presence of the species. Twentythree variables (three geographic, one temporal, eight geomorphometric and twelve oceanographic) were used as predictors. Out of the 1042 cruises, 872 records of striped dolphins were obtained. Some variations in the grouping patterns of these mammals were observed during the years 2006–2007, with an average shift in the size of the groups to fewer individuals (3−10). This variation is probably related to an epizootic event of *morbillivirus* occurring during those years, which was responsible for an abnormal rate of strandings of striped dolphins and long-finned pilot whales (*Globicephala melas*). The Random Forest model allowed to select 6 predictors related to morphometry and sea currents, suggesting the importance of specific habitat in offshore areas between 1000 and 3000 m depth in the continental slope.

1. Introduction

One of the main goals of the Marine Strategy Framework Directive (MSFD) (European Commission, 2008) is to achieve Good Environmental Status (GES) for all elements of the marine ecosystem; especially for those ecosystems and key species that justify the inclusion of marine protected areas in the Natura 2000 network. A full suite of ecological indicators for all the ecosystem components is not currently available for the ongoing assessment and regular updating of the GES targets (Carlucci et al., 2016).

Cetaceans have been considered a fundamental indicator to assess the ecological state of the ecosystems, as their habitat distribution responds, among others, to the impacts of different human activities (Carlucci et al., 2016; Fossi et al., 2020). The GES declaration of a given key species should be based on knowledge of the evolution of the spatio-temporal distribution of the population. In addition, it is necessary to identify possible changes in habitats due to adverse events or environmental pressures.

The striped dolphin, *Stenella coeruleolaba* can reach 2.56 m in length and 156 kg in weight, although it is smaller in the Mediterranean Sea (Archer and Perrin, 1999a, 1999b; Gaspari, 2004). This species has a worldwide distribution in tropical, subtropical, and temperate waters with preference for the continental shelf areas (Gaspari, 2004; Hammond et al., 2008). It is currently considered the most abundant cetacean species in the Mediterranean Sea, specifically in the western Mediterranean (Aguilar and Gaspari, 2012; Archer and Perrin, 1999a, 1999b; Cañadas and Sagarminaga, 1994; Gómez de Segura et al., 2006; Laran and Drouot-Dulau, 2007). Recent surveys (ACCOBAMS, 2021) have estimated a density of around 750.000 individuals for the whole Mediterranean Sea.

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https://doi.org/10.1016/j.rsma.2023.103256
Received 16 May 2023; Received in revised form 17 October 2023; Accepted 20 October 2023
Available online 31 October 2023

It is a generally gregarious species, although according to some authors it can be solitary or reach groups of up to 500 individuals (Cañadas and Sagarminaga, 1994; Archer and Perrin, 1999a, 1999b). However, it is more common to find groups whose size varies between 21 and 50 individuals (Cañadas and Sagarminaga, 1994; Canales-Cáceres, 2011). In the western Mediterranean, this species can be confused with the common dolphin, *Delphinus delphis* from de distance Both species can even swim together in mixed groups (Bearzi, 2005; Canales-Cáceres et al., 2011; Frantzis and Herzing, 2002). However, at close range it shows an easily identifiable unique colour pattern consisting of a small delphinid with a light-coloured spinal blaze, a dark strip from eye to anus with subtending accessory strip. It is a very sociable dolphin and often interacts with other species of cetacean and with boats (Aguilar and Gaspari, 2012a, 2012b; Antoniou et al., 2018; Cipriano et al., 2022; Forcada and Hammond, 1998).

In recent years, this dolphin has been included as a “Vulnerable” species according in the Red List of the International Union for Conservation of Nature (IUCN), the species is classified as "vulnerable" in the Mediterranean Sea due to food scarcity, poor habitat quality (Aguilar and Gaspari, 2012a, 2012b; Reeves et al., 2003) or the exposition to pathogens and pollutants which affect its reproductive and immune systems (Aguilar and Borrell, 1994) to “Least Concern” (ACCOBAMS, 2021; Lauriano, 2022).

One of the major epizootic events on the Spanish Mediterranean coast occurred from July to December 1990, when hundreds of striped dolphins were found stranded on beaches or swimming disoriented (Domingo et al., 1995; Duignan et al., 1992). In 2007, the increase of cetacean strandings, especially striped dolphins and pilot whales, revealed the periodic nature of these epizootic events (Fernández et al., 2008; Raga et al., 2008). Unfortunately, there is a gap of knowledge about the distribution and behaviour pattern and the consequences of this epizootic event in the southern western Mediterranean waters (Aguilar and Gaspari, 2012a, 2012b; Cañadas et al., 2002).

The Gulf of Mazarrón has a great interest because of its geomorphological characteristics. The continental shelf is quite narrow, averaging 2.5 km in front of Cabo Tiñoso and, consequently the coast is very close to a steep-walled V-shaped submarine canyons (Acosta et al., 2012; Giménez-Casalduero and Gomariz-Castillo, 2012; Mas, 1997). The canyons known as the Mazarrón Escarpment, extend from the narrow shelf towards the abyssal plains up to more than 2200 m deep, causing currents to flow upwards and towards the shore (Allen et al., 2001) fertilising the euphotic layer and allowing an increase in the plankton biomass, which favours the raising of fish and cephalopod populations (Mas, 1997). All of this makes the surrounding waters optimal areas for sighting seabirds, turtles and cetaceans which settle along the Gulf of Mazarrón more or less permanently (Cañadas and Sagarminaga, 1994).

Different categories of marine protected areas overlap in this area: The Special Areas for Conservation (SAC) ES6200029 "Submerged coastal strip of the Region of Murcia" and ES6200048 "Submarine Canyons of SAC Mazarrón Escarpment”. Additionally, in 2016, the Cabo Tiñoso Marine Reserve was declared within this study area due to its high ecological value (Decree No. 81/2016 of 27 July). Despite the different protection categories, there is a lack of information on the status of the striped dolphin population in the last decade.

Cetacean watching, most commonly named "whale- watching", is a booming activity worldwide that offers to its customers an approach to cetaceans in their natural habitat. Whale watching is relatively recent and began as an economic activity in 1955 in Southern California (Hoyt, 2001). Citizen science data collection has increased in the last decade because of the development of mobile applications and websites that allow to share information very efficiently (Hyder et al., 2015). Long-term monitoring study of highly mobile species is very expensive (Alessi et al., 2019), but data collected by observers from opportunistic platforms such as whale-sighting boats allow to increase the scientific databases (Goetz et al., 2015). Several studies carried out in Southern Spain reach the western limit of the SAC of the Mazarrón Escarpment (Cañadas et al., 2005, 2002; Cañadas and Hammond, 2006; Giménez et al., 2018), but these is a lack of information about the SAC itself. The present study contributes to extend and complete the knowledge about this species along the Spanish coast.

Species distribution modelling (SDMs) is a collection of techniques for constructing correlative models based on the combination of species occurrence and spatial data. SDMs are statistical models of species–environment relationships based on the location of individuals and environmental predictors that affect its distribution (Elith and Franklin, 2017) to explain observed patterns. The relevance of SDMs in the context of conservation science lies in the need for an accurate understanding of ecosystem processes and spatial patterns based on these predictors (Beery et al., 2021) with the aim of inferring its spatial distribution over a territory (Botella et al., 2018). SDMs are increasingly used because they can inform ecological and biogeographical theories even in sub-sampled study areas (Mi et al., 2017) and discovering potential habitats (Rew et al., 2021). In the marine environment, Guillaumot et al. (2021) and Robinson et al. (2017) reviewed and evaluated extensively various of these methods and their application to the marine environment; also relevant is the study by Bosch et al. (2018), which examines their use in relation to a variety of species and the relevance of the predictors, implementing the MarineSPEED benchmark dataset, or the study by (Oliveira e Silva et al., 2022), based on machine learning algorithms such as Random Forest (RF), marking the recent trend of this type of techniques in the context of SDMs. In Mediterranean Sea, Maglietta et al. (2023) confirms the good performance of this strategy using 28 environmental variables related to the abundance of three species of odontocetes and RF as SDM. For their part, Melo-Merino et al. (2020) carried out an exhaustive study of their use in the marine environment, classifying 324 studies according to their study objective, the type of techniques used (with Maxent standing out in 64% of the studies analysed) or the group studied (with only 14% of the studies analysed focusing on mammals). This type of study is now beginning to be carried out to study the spatial distribution of cetaceans as a fundamental tool for understanding their behaviour. Studies such as the one proposed by (Passadore et al., 2018) to model dolphin distribution as a toolkit for marine reserve planning in Coffin Bay (Australia), or those carried out by Haughey et al. (2021) and Hanf et al. (2022) in north-western Australia using Maxent to model the distribution of *Tursiops aduncus* and other dolphin species; Becker et al. (2020) comparing generalized additive models (GAM) and boosted regression trees in California to model the habitat distribution of several cetacean species, and (Self et al., 2021) will examine the distribution and vulnerability of four dolphin species in relation to ship traffic. Luan et al. (2020) use RF as SDM model for 21 marine demersal species to investigate their response to limited sample size.

The main objective of this study was to analyse both spatial and the interannual variations in the presence and the changes in the population structure of striped dolphin. Additional objectives were, to analyse group sizes and different behaviours, and to evaluate the possible changes between the cold and warm seasons. The data to carry out these objectives were obtained during the period 2004–2014 in the south-western Mediterranean, specifically in the Gulf of Mazarrón. To modelize the spatial behaviour of striped dolphin, a Species Distribution Model (SDMs) based on the Random Forest machine learning model was used, to determine how the selected geographical, temporal, geomorphometric and oceanographic variables can affect their behavioural pattern.

2. Materials and methods

2.1. Study area

The study area is located in the western Mediterranean Sea, in the Gulf of Mazarrón between Cabo de Palos and Cabo Cope (Fig. 1). This area is easily accessible from Mazarrón and Cartagena harbours and is

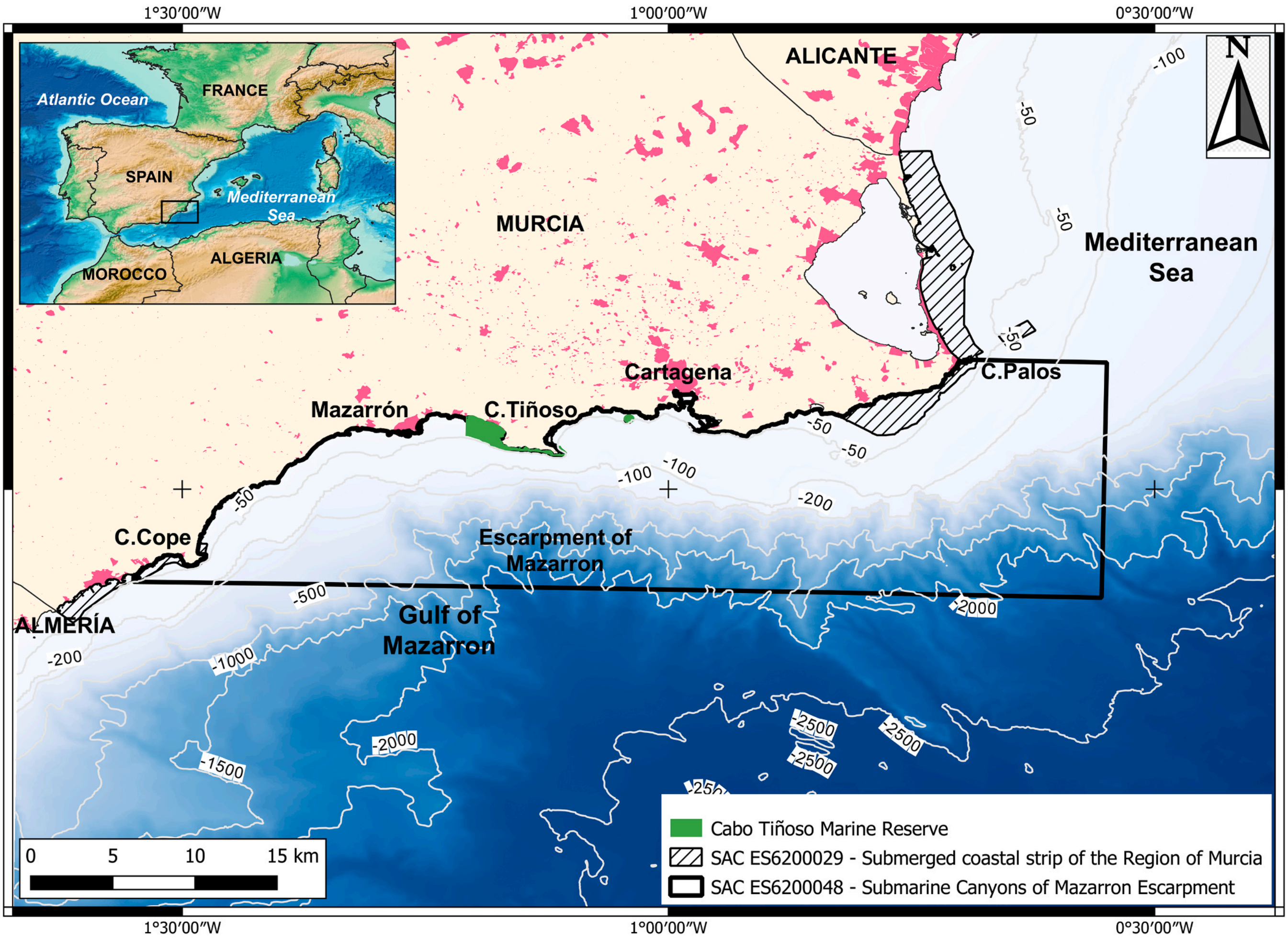

Fig. 1. Location of the study area. The 50, 100, 200, 500, 1000, 1500, 2000 and 2500 m isobaths are shown. Pink zones on the land represent urban areas. Legend corresponds to protection figures (the square area corresponds to the SAC Submarine Canyons of Mazarrón).
Source: BTN25 2006–2019 CC-BY 4.0 ign.es (administrative data); Data derived from MDT25 2015 CC-BY 4.0 ign.es; DGSCM (2009) (bathymetry).

one of the areas with the narrowest continental shelf areas in the western Mediterranean Sea. The continental shelf width is only 5.5 km in front of the town of Mazarrón and 2.5 km in front of Cabo Tiñoso (Acosta et al., 2012; Medialdea Vega et al., 1990), where erosion with a staggered appearance predominates, known as escarpments (MAGRAMA, 2012a). The end of the continental shelf is at a depth of around 200 m and has an E-W orientation. It is followed by abrupt submarine canyons known as "Escarpment of Mazarron" which reach a depth of 2200 m very close to the coastline (Águila Guillén et al., 2008; Martín-Serrano, 2005).

There is little information available on currents in the study area. Mesoscale water masses are mixed and an upwelling occurs due to the presence of submarine canyons of more than 1000 m in depth (MAGRAMA, 2012b). Due to the narrowing of the shelf off Cabo de Palos and the abrupt change in the direction of the coast, two different hydrodynamics can be distinguished: from Cabo de Palos to the north, the orientation of the coast is easterly, and from Cabo de Palos to Cabo Cope, the orientation is predominantly south-easterly. This more southerly stretch is more exposed to the deep waters of the Mediterranean Sea, with high salinity around 38.5 psu (MAGRAMA, 2012b).

2.2. Data-sets and sampling methods

2.2.1. Sighting procedure and data collection

The data collection was carried out during the commercial activity of marine fauna sighting of the ecotourism company *Cetáceos y Navegación S.L.* The sighting data correspond to the period 2004–2014, during which trips were carried out in both cold season (November to April) and warm season (May to October).

During the trips, two observers, using 7 × 50 binoculars and naked eyes, conducted watchkeeping, from the highest part of the boat in safety conditions (about 3 m above the water surface).

At least one observer was an experienced watcher in order to ensure greater efficiency in data collection, while the other one was a previously trained participant in the activity. To avoid visual fatigue, the main observer was relieved every hour. The profile of the accompanying observer was diverse as the tours were focused on whale sighting tourism, biology courses, volunteering, and diving, among other activities.

The tracks of each sighting session were collected using the boat's GPS and a handheld GPS Garmin Etrex 10. The searching effort was interrupted when the wind force exceeded the four value on the Beaufort scale (Gannier, 2005; Morteo et al., 2004; Yen et al., 2004), or it was adverse weather conditions (big swell length, rain and fog) (Aerts et al., 2013). The boat maintained a constant speed of 6–7 knots during the trips. Trips started at 9:00 a.m. Sometimes, when noting a sighting, an encounter with other groups of animals occurred. It was also recorded.

A cetacean sighting was considered when an animal was located with an unequivocal identification, and a sighting group when several animals travelled like a more or less cohesive unit in the same direction (Dahlheim et al., 2009; Gaspari, 2004). During the time of contact with the animals, photographs and videos were taken and they were stored for further processing. Cetaceans were divided only in two age categories: adult and calves.

According to Kiefner's criteria (Kiefner, 2002), when dolphins are observed swimming in large groups, only about one third of the individuals are emerged from the water and can be counted, so a minimum and maximum number of individuals was always estimated. The average number of each group was used for the analysis (Cañadas and Sagarminaga, 1994). When the animals were observed behaving indifferently or swimming away from the boat, or if the sea conditions were inadequate, the sighting was terminated. When it was not possible to sail close enough to identify the species, the sighting was recorded as unidentified species.

The information collected included general data such as: date, name of observers, start and end time of the journey, sighting effort time at each journey, and meteorological data, as set out in the methodology proposed by the SEC (Sociedad Española de cetáceos, 2000). In addition, for each observation, after the identification of the species as striped dolphin, specific information was collected: i) start and end time of the observation; ii) position of the animals; iii) group size; iv) behaviour; v) dolphin course (direction in which they navigate); vi) presence of accompanying cetacean species and vii) presence of other vessels grouped in the area which in the following categories: a) whale watching b) recreational fishing; c) trawler; d) longline fishery; e) pleasure boat; g) merchant; h) military; i) NGO boats and j) others.

The observed behaviour of Striped dolphins was classified into 6 categories following the criteria of previous authors (Cañadas and Hammond, 2008; Kuit et al., 2019; Prado, 1998; Sini et al., 2005): i) evasive; ii) foraging; iii) socialising; iv) milling; v) travelling and vi) undetermined (Table 1).

2.2.2. Stranding records

Data on cetacean strandings in the Region of Murcia from different sources were analysed: i) data collected along the coast of the Murcia Region and provided by the Regional Office for the Socio-Economic Promotion of the Environment (OISMA) and, ii) data available in the Spanish Database of Cetacean Strandings (BEVACET) (MITECO, 2023), included in the international project Mediterranean Database of Cetacean Strandings (MEDACES) (MITECO et al., 2023). Stranding data from neighbouring regions were also analysed. The information available in the previous databases starts in 2005. This study analysed stranding between 2005 and 2014.

For classification of observed behavior of striped dolphins (Table 1), differences in space use were explored by examining the group size, behaviour, and season (warm=from May to October; cold=from November to April). The size of the group for each behaviour class observed was represented by each season.

The number of interactions of striped dolphins with other species of cetaceans and with different types of boats was also obtained.

2.2.3. Data analysis and *Stenella coeruleoalba* characterization

Sighting data were grouped into two seasons (Douglas et al., 2014): cold (November-April) and warm (May-October), according to the average water temperature for each month obtained from Guijarro et al. (2015).

Table 1
Observed activity classification.

Behavioural category	Description
Evasive	Avoiding the ships
Foraging	Repetitive prolonged dives in one location, splashes, prey pursuit, apparent capture, and ingestion of prey
Socialising	Touching other individuals, mating, playing
Milling	Slow, non-directional movements within the same location, usually, staying close to the surface
Travelling	Swimming at the same course all the time
Undetermined	Other

The frequency of sightings of a species was estimated from the number of sighting days of that species, regardless of the number of individuals per sighting or the number of sightings in a single day, over a given period of sampling days.

The temporal occurrence and group size pattern of striped dolphins was examined. Group sizes were classified with the natural breaks distribution method (North, 2009), with nine classes of sighting groups (Canales-Cáceres et al., 2010): i) 1 animal/individual, ii) 2, iii) 3–10, iv) 11–20, v) 21–50, vi) 51–80, vii) 81-, viii) 126–150 and ix) more than 150 individuals.

The number of trips in the cold season was much lower than in the warm season (Fig. 2 in the results section). To analyse the pattern of interannual and seasonal sighting frequency, those years in which more than 15 trips were made in the cold season were selected. Specifically, eight years within the study period were selected: 2006, 2007, 2008, 2010, 2011, 2012, 2013 and 2014, in each year the data were disaggregated by seasons (cold and warm) and three random periods of five consecutive tour days were selected for each season.

To confirm possible differences in the frequency of striped dolphins sightings between years or between seasons in the study area, two-way Analysis of Variance (ANOVA) was used with two fixed orthogonal factors: i) Years, with 8 levels (2006, 2007, 2008, 2010, 2011, 2012, 2013 y 2014) and ii) Season, with 2 levels (cold and warm). Three random periods of five tour days were selected per season and year. To evaluate the statistical assumptions of the ANOVA model (normality and homoscedasticity), we used the Shapiro test to assess normality and the Brown-Forsythe test to assess homoscedasticity. These tests were not significant. The Tukey HSD post-hoc test for multiple comparisons was then used to compare the different data sets. Annual trends and seasonal occurrence of dolphins were studied using the statistical software R version 4.3.1. (R Core Team, 2023).

The temporal behaviour pattern was also analysed by comparing the sightings frequency per month, standardised by the total number of tours each month, and using the factor "year" as replication (Alves et al., 2018). Data were analysed as the percentage of days on which striped dolphins were detected.

The average size of the sighting group was also analysed, groups size and a comparison between years and seasons was made with a non-parametric multivariate analysis (ANOSIM) and a percentage of similarity analysis (SIMPER) to determine the percentage contribution of each size class; both carried out with PRIMER-E (Clarke and Gorley, 2015).

2.3. Modelling framework for Species Distribution Models

2.3.1. Random Forest as Species Distribution Model

In this study we used SDM Random Forest (RF) (Breiman, 2001), a

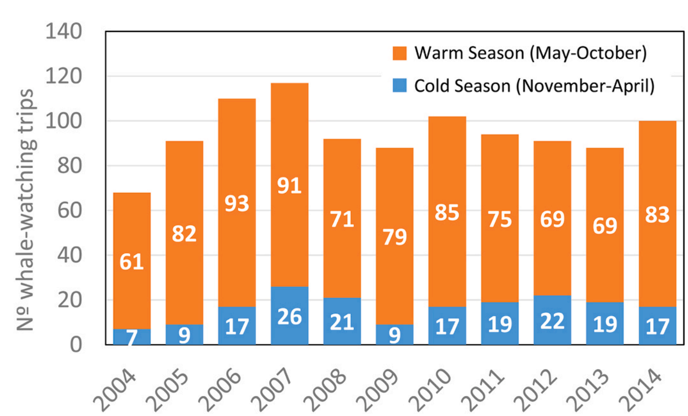

Fig. 2. Number of whale-watching trips per year during the period 2004–2014. The cold season runs from November to April, while the warm season runs from May to October.

machine learning model based on an ensemble of classification or regression trees (CART). Each of these trees is calibrated using a different data set for each of them, obtained by random sampling with replacement (bootstrapping). When classifying new cases, each of them is classified with all the trees, each of them makes an estimate of the class to which it would belong, and finally it is assigned to the class most frequently indicated by the trees. In this way, the classification errors of each individual tree (which may have a high variance) are compensated by the set of predictions and generalise better (Hastie et al., 2009), producing decorrelated trees, making overfitting less likely and allowing robust RF models to be calibrated with all available predictors (Prasad et al., 2006).

Although RF has not been widely used as an SDM, it has proven to be an algorithm that produces good results compared to other machine learning systems, such as Maxent, Support Vector Machines or Multilayer Perceptron neural networks (Giménez-Casalduero et al., 2020; Liaw and Wiener, 2002; Mi et al., 2017), and can achieve good results in the context of SDMs with few samples in large undersampled areas (Mi et al., 2017).

Another advantage of RF over other algorithms is that it performs well with the default values of its two main parameters without the need to optimise them (Hastie et al., 2009; Liaw and Wiener, 2002). These parameters are m_{try}, the number of candidate variables drawn in each split, whose default value in regression problems is the floor of the square root of the number of predictors, and n_{tree}, the number of trees in the ensemble, whose default value is usually 500. In this study, we used $m_{try} = \sqrt{p}$, default value in classification problems (Liaw and Wiener, 2002), where p is a number of predictors, and $n_{tree} = 1000$ as increasing the trees does not reduce accuracy but helps to reduce prediction variance (Probst et al., 2019).

One of the main problems with RF, as described in Valavi et al. (2021) specifically for its use as an SDM, is that its predictive ability can be seriously compromised by unbalanced data and/or overlapping classes in the case of presence-background data. In an attempt to address both issues, this study proposes a method to address the prediction of presence-background data by estimating pseudo-absences for specific dates on which sightings were observed, allowing values of dynamic variables such as currents, chemical properties, etc. to be assigned to them. This process is based on obtaining kernel functions for each of the points of presence obtained in the sampling. For this purpose, a Gaussian kernel was used with the following parameters: a= 500, u= 0.01 and s = 2500. The parameter a is the maximum distance of the sighting (metres), u is the cumulative kernel threshold and s is the width (metres) or the standard deviation of the bivariate normal density function, which is representative of the species' ability to move. In this work, the same pseudo-absence points were chosen as the observation points in order to obtain a balanced data set. For this purpose, the pseudo-absence points are randomly selected for each date on which there were departures between these points under two conditions:

a) They are within d metres or less of a sighting point on that date. d depends on the distance at which the species can be detected from the vessel.
b) The value of the point integrating the kernel functions must be less than the threshold u, which is a function of its mobility.

This guarantees: a) that the point was sampled on that date and b) that the species has never been sighted at that point.

To validate the variable selection process (see Section 2.3.2.) and of the final model, we used the internal validation procedure of the algorithm itself. This is possible because it has a validation procedure called out-of-bag cross validation (OOB-CV). Using this procedure, RF calibrates each of the trees with a subset of the data extracted by bootstrapping, of which about 33% is not used for calibration and constitutes the so-called out-of-bag. Each case will therefore appear in the out-of-bag of 33% of the trees and these trees can be used to estimate the class in that case, to obtain a joint estimate by "voting" between the trees and therefore to obtain an estimate of the error made.

2.3.2. Environmental data and variable selection

In this study, 23 environmental variables were used as predictors in the SDM and are summarised in Table 2. These variables have been selected on the basis of a review of previous studies on the spatial distribution of striped dolphins and previous knowledge of the study area. For example, Azzolin et al. (2020) include three topographic variables and two oceanographic variables: depth, slope, distance from shore, sea surface temperature and phytoplankton. Maglietta et al. (2023) use up to 28 variables. In addition to the usual variables, the TIME variable (Table 2) was included to try to capture some kind of temporal pattern such as trend or seasonality.

Geomorphometric variables (8 in total, Table 2) were included based on the hypothesis that depth variation is a fundamental driver of benthic community distributions, and that these variables can be used to infer the effects of bathymetric gradients on the species studied (Walbridge et al., 2018). To derive these, we used the Digital Model of Depth (DMD) with a resolution of 25 m, obtained by reinterpolation with the ANUDEM algorithm (Hutchinson and Dowling, 1991), to integrate the two sources of information used: detailed bathymetry of the first 50 m from the Spanish national ecocartography (DGSCM, 2009) and the Digital Terrain Model of the European Marine Observation and Data Network (EMODnet) project of 2018 (European Commission, 2020). Except for Multiresolution index of valley bottom flatness (MRVBF) and Multiresolution ridge flatness index (MRRTF), the rest of the geomorphological variables are scale dependent; therefore, in this study they were estimated at 3 different scales (150 ×150 m, 450 ×450 m and 1350 ×1350 m), obtaining three versions for them (named with the suffix 3, 9 and 27, respectively, relating the covariates to the three neighbourhood advantages used 3 ×3, 9 ×9 and 27 ×27).

Geographical and geomorphological variables are static in time, but oceanographic and temporal variables are dynamic. Therefore, to build the dataset from which to calibrate the models, they were aggregated to monthly averages and each sighting point was assigned the values of the layer of the corresponding date.

Once the environmental variables were identified, a selection process of these variables was carried out, considering that although RF is robust against uninformative or redundant predictors, these can increase model uncertainty and reduce its overall efficiency (Kuhn and Johnson, 2013) and interpretability (Giménez-Casalduero et al., 2020). To reduce their dimensionality, a double iterative selection process was performed:

1. We start from a calibrated model with all variables (full model) and estimate its accuracy using internal RF cross-validation.
2. The variable considered less important by the internal RF metric is eliminated and a new model is calibrated without taking it into account, and its accuracy is estimated again by means of the internal RF cross-validation.
3. Step 2 is repeated iteratively until a model with the most important variable is obtained.

   The results showing how accuracy increases as new variables are added to the model in decreasing order of importance. In this way we can determine the minimum set of variables that will produce a model that is not significantly less accurate than the model with all variables. Once the selection process is complete, the collinearity analysis between the selected covariates is performed:
4. The iteration starts with the least important covariate of the model and its coefficient of determination (r^2) with the most important predictors is estimated. If this coefficient exceeds a given threshold, this predictor is not included in the model.
5. Continue iteration with the next least important predictor and repeat point 4 until no predictor exceeds the set threshold.

Table 2
Environmental covariates used in SDM.

Type	Acronym	Description	Data source
Geographic	DISTC	Euclidean distance to coastline	
	DISTB	Euclidean distance to beaches greater than 100 m in length	
Temporal	TIME	Days elapsed since the start of the study (2004)	
Geomorphometric	DMD	Digital Model of Depth, integrating the two sources of information by reinterpolation	Derived from Ecocartography and EMODnet
	SLOPE	Elevation gradient in degrees	
	PCURV	Longitudinal curvature (Wood, 1996)	
	TCURV	Transverse curvature (Wood, 1996)	
	TPI	Topographic position index (Weiss, 2001) as a normalised vertical measure of the cell relative to its surroundings	
	MRVBF	Multiresolution index of valley bottom flatness (Gallant and Dowling, 2003)	
	MRRTF	Multiresolution ridge flatness index (Gallant and Dowling, 2003)	
	POP8	Topographic openness index (Yokoyama et al., 2002)	
Oceanographic	VVEL	Current velocity in S-N direction (m/s). Positive values indicate S-N direction and negative N-S direction	CEMS (Escudier et al., 2020)
	UVEL	Current velocity in W-E direction (m/s). Positive values indicating W-E direction and negative values indicating E-W direction	CEMS (Escudier et al., 2020)
	CLOR	Chlorophyll a concentration (mgm^{-3})	MODIS (NASA, 2018)
	PHIT	Phytoplankton	
	GELB	Monthly Suspended organic matter	CEMS (Teruzzi et al., 2021)
	PCO2	Surface partial pressure of carbon dioxide in sea water	CEMS (Teruzzi et al., 2021)
	SAL	Sea Surface Salinity (psu)	CEMS (Escudier et al., 2020)
	SST	Diurnal Sea Surface Temperature (°C)	CEMS (Buongiorno Nardelli et al., 2013)
	KD490	Diffuse attenuation coefficient at 490 nm in m^{-1}	CEMS (Escudier et al., 2020)
	DOC	Mole concentration of dissolved organic carbon in sea water	CEMS (Teruzzi et al., 2021)
	DIC	Mole concentration of dissolved inorganic carbon in sea water	CEMS (Teruzzi et al., 2021)
	AE	Angstrom Exponent over ocean	MODIS (Platnick, 2015)

For points 4 and 5, thresholds of 0.6, 0.7, 0.8 and 0.9 in r^2 were tested. The last, that is the model that included more variables, resulted the one that gave the best results.

3. Results

A total of 1042 trips were carried out, distributed irregularly throughout the year during the study period (Fig. 2). The average effort per day was 4.10 ± 1.8 h, ranging from 0.4 to 10.5 h.

Eight Cetacean species were sighted between 2004 and 2014 in the study area, six of them were odontocetes, and two were mysticetes. The odontocetes species were the bottlenose dolphin (*Tursiops truncatus*), striped dolphin, common dolphin (*Delphinus delphis*), long-finned pilot whale (*Globicephala melas*), Risso's dolphin (*Grampus griseus*) and sperm whale (*Physeter macrocephalus*). The fin whale (*Balaenoptera physalus*) and the minke whale (*Balaenoptera acutorostrata*) were the only mysticetes recorded in the Gulf of Mazarrón in all sighting tours, although the latter was sighted only once in 2011. The most abundant species in all sightings tours in the study area corresponds to the striped dolphin with 47.5% of sightings in the period 2004–2014, corresponding to 883 encounters.

3.1. *Stenella coeruleoalba characterization*

3.1.1. *Interannual analysis and seasonality*

Significant differences were found between group sizes by years studied and by season. The average group size of striped dolphins, expressed as number of individuals per year and season, showed a decrease, especially during the cold season in 2006 and 2007 (Fig. 3). This decrease is consistent with the public stranding information observed at different points along the Spanish south-eastern coast (Fig. 4).

However, the group size with the highest probability of occurrence during both seasons was of 21–50 individuals with a sighting frequency of 78%, and solitary individuals was the least frequent (13%). This pattern occurred in both seasons (Fig. 5). This trend in group size distribution is very similar in almost every year, but in 2012 and 2014 sightings of groups larger than 150 dolphins increased, while the lowest frequencies were observed in 2004–2005 and specially in 2006–2007, when a trend towards the formation of tiny groups (3−10) was observed (Figs. 5 and 6). Very small groups (1–2 individuals) or large groups (more than 100 individuals) were less frequent during both seasons (Fig. 5).

Two-way ANOVA analysis (Table S1) revealed significant differences and a large effect size in the frequency of sightings of striped dolphins by the factor Year [$F_{(7,32)}$= 3.168, p = 0.012, ω_p^2 = 0.24]. The factor Season was not significant at the α = 0.05 level, although it was close to this threshold (F1,32 =3.629, p = 0.066, ωp2 =0.05); the interaction Year: Season was not significant (F7,32 =1.122, p = 0.374, ωp2 =0.02). Fig. 6 shows the value distribution of striped dolphins sighting frequencies for

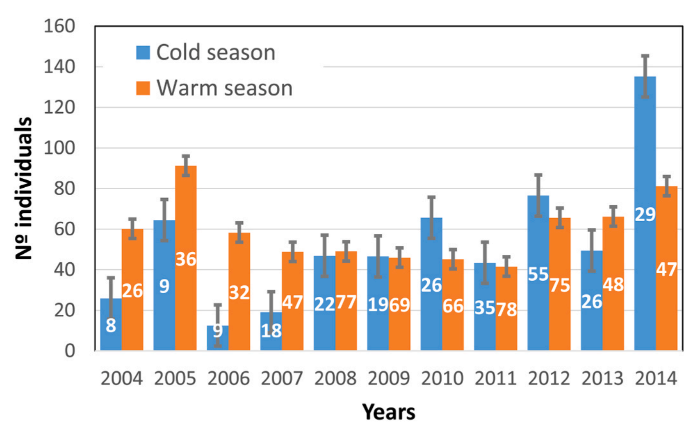

Fig. 3. Mean (± SE) size of striped dolphins groups (number of individuals) by season (warm and cold) for each year. Black bars indicate standard deviation errors bars.

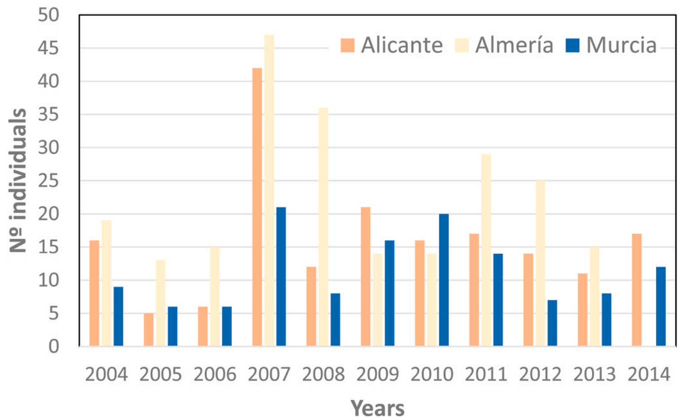

Fig. 4. Number of striped dolphins stranded in Alicante, Murcia and Almeria. Source: Data derived from BEVACET (MITECO, 2023).

the main effects, and the groupings obtained with the Tukey HSD post hoc test for multiple comparisons; so, the only significantly different years are 2006 and 2007 on the one hand, and 2012 on the other. The remaining years could be included in both groups. Regarding the season factor, there are no significant differences between warm and cold seasons.

Tukey HSD post-hoc test results for the main effects of the Year factor showed that the lowest frequency of sightings occurred in 2006–2008 and the highest in 2012, with the remaining years being intermediate (Fig. 6).

In the case of the seasonal factor, although not significant for $\alpha = 0.05$, it is close to the significance threshold, suggesting that the sighting rate decreases in the warm months. This behaviour is interesting, even though the effort (number of days with tours) increases significantly in summer and it is very low between November and February as can be seen in Fig. 7. This low effort in winter increases the uncertainty of such a conclusion.

The SIMPER procedure showed that the higher contribution to the

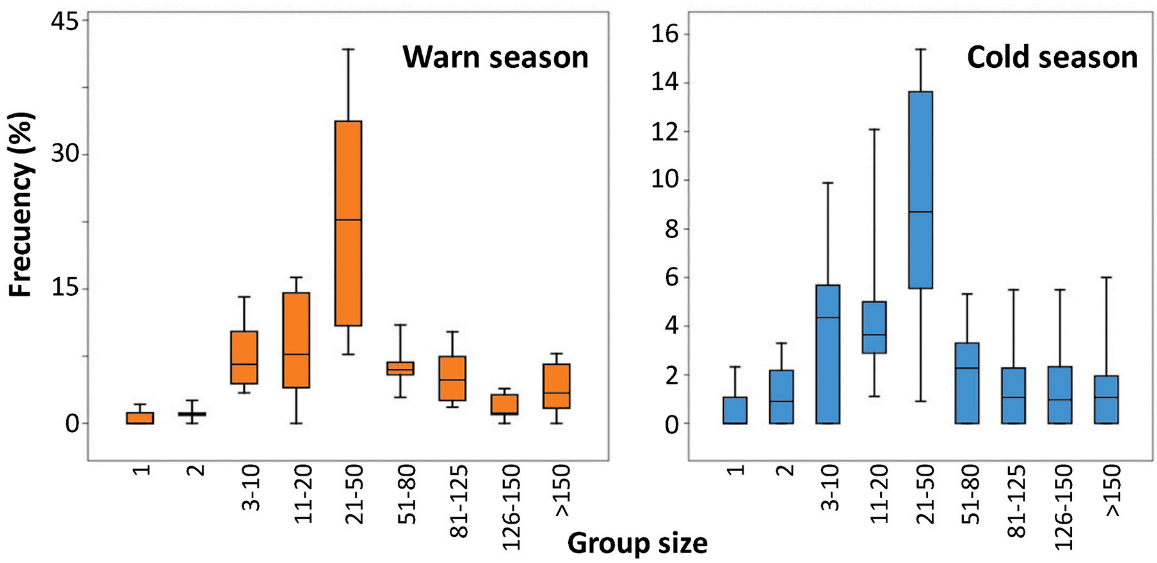

Fig. 5. Boxplot of sighting frequency of each group size class in each season.

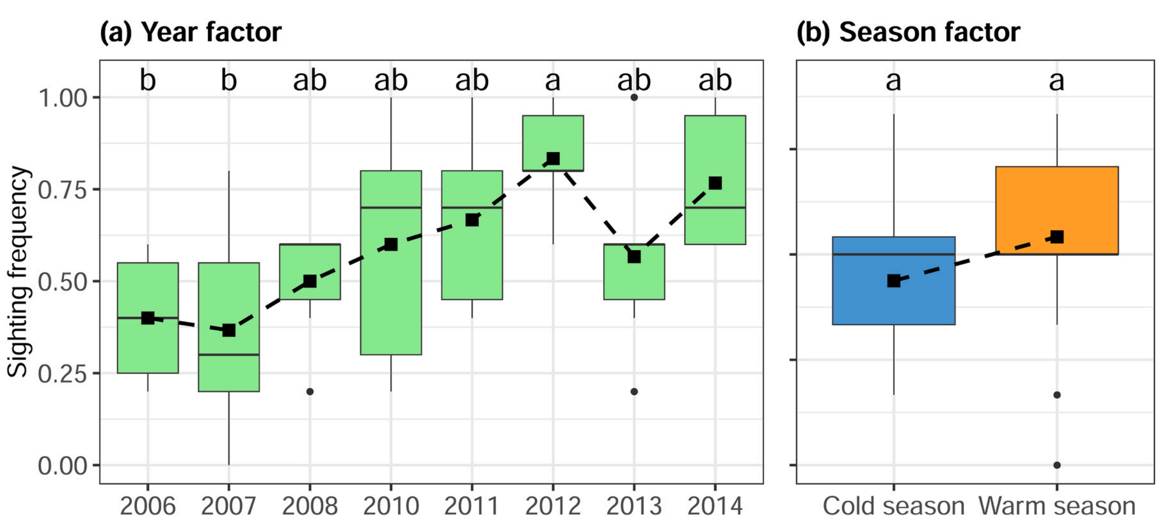

Fig. 6. Boxplot of striped dolphins sighting frequencies grouped by main effects: (a) factor Year[11] and (b) factor Season (N = 8 years × 2 seasons x 3 replications = 48 observations). The boxes graphically represent the value distributions according to the class showing the 25% quartile, median and 75% quartile. The squared dots represent the averages of the values by class. The dashed line connects the averages of each group. Significantly different groups (Tukey HSD post-hoc test, $\alpha = 0.05$) are indicated by different letters.

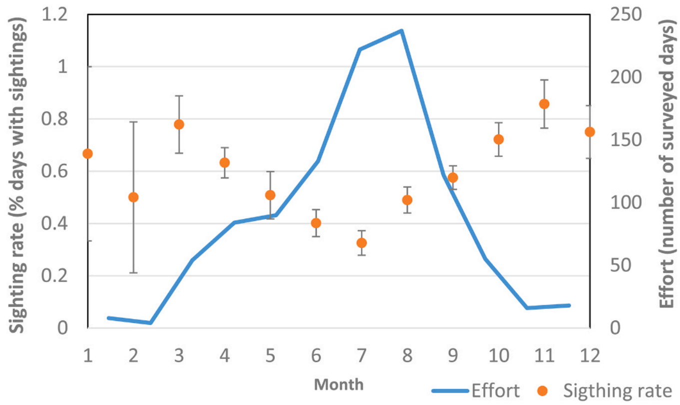

Fig. 7. Mean (± SE) monthly sighting rates (left y-axis) and search effort (right y-axis).

dissimilarity of group sizes between seasons was mainly due to groups of 3–10, 11–20 and 21–50 individuals, accounting for 60% of the cumulative dissimilarity (Table S2). The percentage of similarity in the warm season was 66% (Table S3), mainly due to the group size of 21–50 individuals. The cold season presented a similarity percentage of 60% and the same size group (21–50 individuals) had a contribution value of 46%. Furthermore, the SIMPER analysis showed that the highest percentages of dissimilarity were identified between the years 2006–2012 (64%), 2005–2006 (61%), 2006–2011 (59%) and 2006–2014 (58%) (Table S4). A spatial representation of common striped dolphin behaviours and group sizes has been made (Appendix A, Figs. S1 to S5). The behaviour with the most evident changes, is avoidance.

3.1.2. Interactions

Interactions of striped dolphins with other cetacean species were observed, mostly forming mixed groups with common dolphins (74 observations), with pilot whales (59 records) and with *G. griseus* (34 records). Observations with bottlenose dolphins and sperm whales were anecdotal (2 records each) (Fig. 8). Only 75 interactions with vessels were observed, mostly with another whale watching boat, trawlers and recreational fishing boats (Fig. 9).

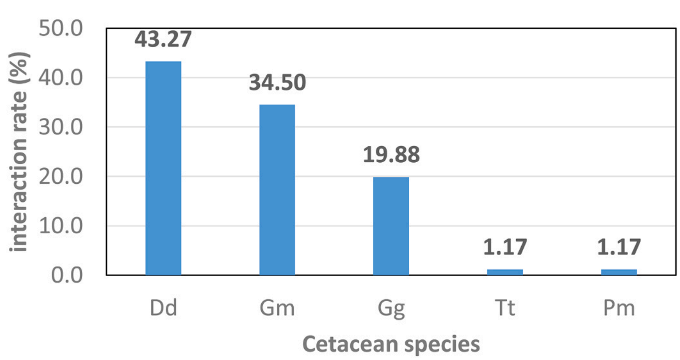

Fig. 8. Percentage of interactions between striped dolphin and other species. Dd: *Delphinus delphis*; Tt: *Tursiops truncatus*; Gm: *Globicephala melas*; Gg: *Grampus griseus*; Pm: *Physeter macrocephalus*.

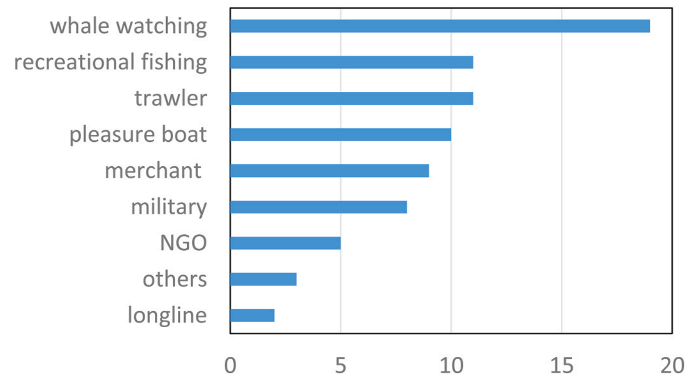

Fig. 9. Number of interactions between striped dolphin and vessels. More than one vessel may be involved in the same sighting journey.

3.2. Spatial distribution based on SDM Random Forest

3.2.1. Variable selection and effects of environmental variables

Fig. 10 shows the results of the selection of environmental variables and their importance in explaining striped dolphins sightings, and consequently their contribution to the dolphin habitat suitability model. After filtering correlations between covariates and significance analysis, the 6 most relevant variables were selected: depth on a scale of 1350 × 1350 m (DMD_27), distance to the coast (DISTC), topographic openness index on a scale of 150 × 150 m (POP8_3), valley bottom flatness (MRVBF), ridge flatness (MRRTF) and south-north current direction (VVEL). For this reduced variable model, the validation accuracy reached 96%.

The effects of these predictors on the probability of occurrence of striped dolphin are shown in Fig. 11. DMD_27 was the most important variable in the distribution of striped dolphins, which seems to have a higher probability of occurrence in the slope zone in relation to the depth data (Fig. 11(A)). Furthermore, as can be seen in Fig. 11(B), a maximum in the probability of presence is observed at 15 km from the coast (DISTC predictor, second in importance), with a sharp decrease as this distance decreases; the sharp decrease in the probability of presence at distances greater than 40 km may be due to the fact that trips do not usually exceed this distance. With regard to the topographic openness index (POP8_3), Fig. 11(C) shows a greater preference of striped dolphin for narrow and steep environments, which is consistent with the results of the valley bottom flatness (MRVBF, Fig. 11(D)) and ridge flatness (MRRTF, Fig. 11(E)) variables, which show a preference for areas with sharper ridges and steep valleys. As for the S-N current velocity direction (VVEL, Fig. 11(F)), the trend of the estimated probability of occurrence indicates a greater preference of striped dolphin for low-velocity currents in the N-S direction (negative values), which can be interpreted in the study area as a species that is not commonly observed with currents that direct it towards the coast.

3.2.2. Spatial distribution of striped dolphins based on SDM

Fig. 12 shows the potential distribution of striped dolphin, as the probability of presence, resulting from the presence-absence RF model. The accuracy obtained by internal validation in the final model was 0.96, indicating a good performance. They are mainly absent from the continental shelf (flat zone from 0 to −200 m depth) especially from 0 to 100 m depth. Then the probability of occurrence increases almost linearly until around the depth of − 400 to − 500 m (which coincides with the transition of medium slope cliffs in the study area), where the probability reaches 0.5. A band of preference is also identified, which becomes maximum from − 1000 to − 1500 m depth.

[1] 2009 was not included due to the paucity of data.

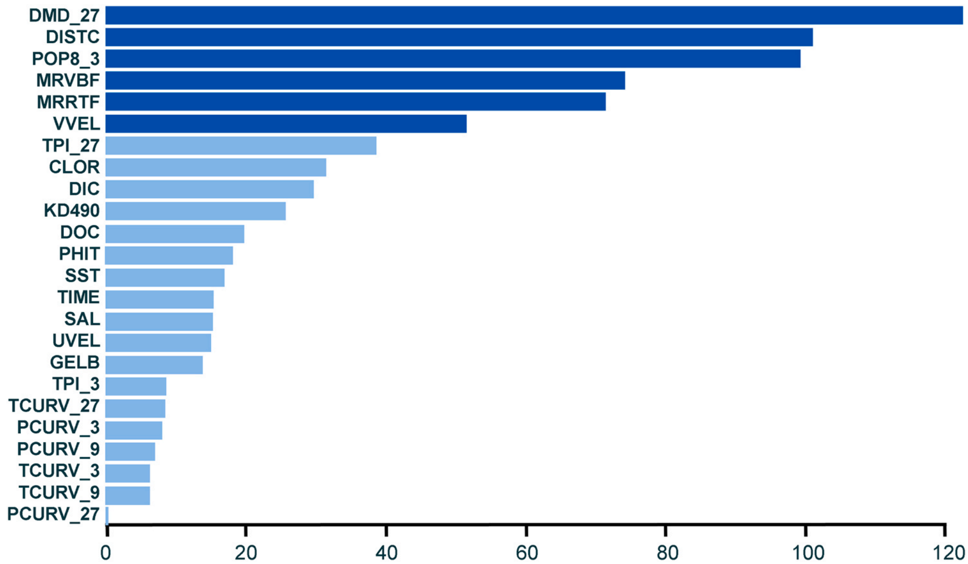

Fig. 10. Importance of independent variables included as predictors after prior collinearity analysis. The dark blue bars represent the 6 most relevant environmental variables selected in the final model.

4. Discussion

This study, as well as numerous other campaigns carried out in different parts of the Mediterranean Sea, shows that the most abundant species in the southeaster Iberian Peninsula is the striped dolphin (Cañadas et al., 2002; Cañadas and Sagarminaga, 1994; Forcada et al., 1995; Gannier, 2005; Gómez de Segura et al., 2006; Marini et al., 1996). This dolphin interacts with other cetacean species, especially with common dolphins and pilot whales. Interactions with common dolphins are the most usual in other parts of the Mediterranean Sea (Frantzis and Herzing, 2002), where cases of hybridisation have been studied (Antoniou et al., 2018; Bearzi et al., 2016).

The results of the present study showed a significant decrease in sightings in 2006–2007, and a decrease in the number of individuals sighted, with a possible recovery in later years. During the cold season of that period, an increase in cetacean mortality, specially striped dolphins, was observed along the coasts of Andalusia, Murcia, Balearic Islands and Valencia (Fernández et al., 2008; Raga et al., 2008). More than 100 dead striped dolphins were found along the Spanish Mediterranean Sea in just one month (July, 2007) (Raga et al., 2008). It is very likely that this variation in the striped dolphin groups is related to a morbillivirus epizootic that occurred in those years and which was responsible for an abnormal stranding rate of striped dolphins and pilot whales (Fernández et al., 2008; Raga et al., 2008; Wierucka et al., 2014).

The striped dolphin does not show a seasonal occurrence in this area and can be sighted at any time of the year. In a study carried out by Gómez de Segura (2006) in 2001–2003 along the SW Mediterranean coast, no seasonal variation in population density was observed for this species of dolphin. Nevertheless, in other areas of the Mediterranean Sea such as the Ligurian Sea, the relative abundance of these cetaceans is higher in the summer months than in the winter months (Laran and Drouot-Dulau, 2007). This seasonality could indicate the presence or absence of prey in the area (Gómez de Segura et al., 2006). It is important to highlight the importance of the underwater canyons in front of Cabo Tiñoso as a concentration area for this species, especially in the warm season. This makes it a *de facto* "hotspot" for the striped dolphin. There is more avoidance behaviour in the warmer months than in the colder months. This may be due to several factors, the most important of which may be the increase in recreational boat traffic during the summer season. The largest group sizes correspond to travel and socialisation behaviours, which do not seem to show any obvious changes over the years studied and across seasons.

The number of interactions observed with other vessels is low (Fig. 7). However, an analysis of these and other pressures on cetaceans is needed to see their influence on the distribution of the species.

The sighting of a single individual is considered exceptional, as in other areas of the Mediterranean Sea (Gaspari, 2004). During the whole study period, groups of 21–50 animals were more common, but a change was observed in 2006–2007, with an increase in the number of smaller groups (3−10). Different epizootic episodes could at least partially explain this decrease in group size be the cause (Aguilar and Gaspari, 2012a, 2012b; Cotté et al., 2010; Gaspari, 2004; Gómez de Segura et al., 2006; Hammond et al., 2008; Reeves et al., 2003).

Anthropogenic pressures and cyclical episodes of infectious-contagious diseases (Cotté et al., 2010; Fernández et al., 2008; Raga et al., 2008) seem to significantly alter the population dynamics of striped dolphins (Carlucci et al., 2021; López-López, 2017).

Regarding the spatial distribution obtained from the presence-absence RF model, there are not many studies of this type of techniques applied to striped dolphins, and even less in the Mediterranean Sea. The use of GAM and RF was proposed as an effective tool for the study of delphinids in the work of Carlucci et al. (2016) and Carlucci et al. (2018). They obtained very similar results to those studied with other methods, such as the Conventional Distance Samplig (CDS) for the distribution of striped dolphins in the central eastern Mediterranean and the Ionian Sea. More recently, Maglietta et al. (2023) used RF, neuronal networks and LSBoost, with 28 environmental variables to predict cetacean abundance in Central-eastern Mediterranean Sea, demostrating the usefulness of this type of framework for dealing with large volumes of data. It is precisely in the current context of citizen science and the information society, characterised by a large amount of information with a spatial component, that scientific projects based on this framework takes on a particular relevance. The new concept of Geographical Data Science, a synergy between Data Science and Geography Spatial Data, (Singleton and Arribas-Bel, 2021) makes it possible to extract knowledge and ideas from large volumes of structured and unstructured data, in addition to the variables usually used a priori.

However, our results are consistent with recent studies such as Azzolin et al. (2020) in the EU Adriatic and Ionian Sea region, in which areas characterised by a large distance from the coast, deep waters and a steep slope, typical of a pelagic environment, are found as selected by the species. They also identify topographic variables as more explanatory predictors, although they only use depth and distance from the coast; the importance of depth in the spatial distribution of striped

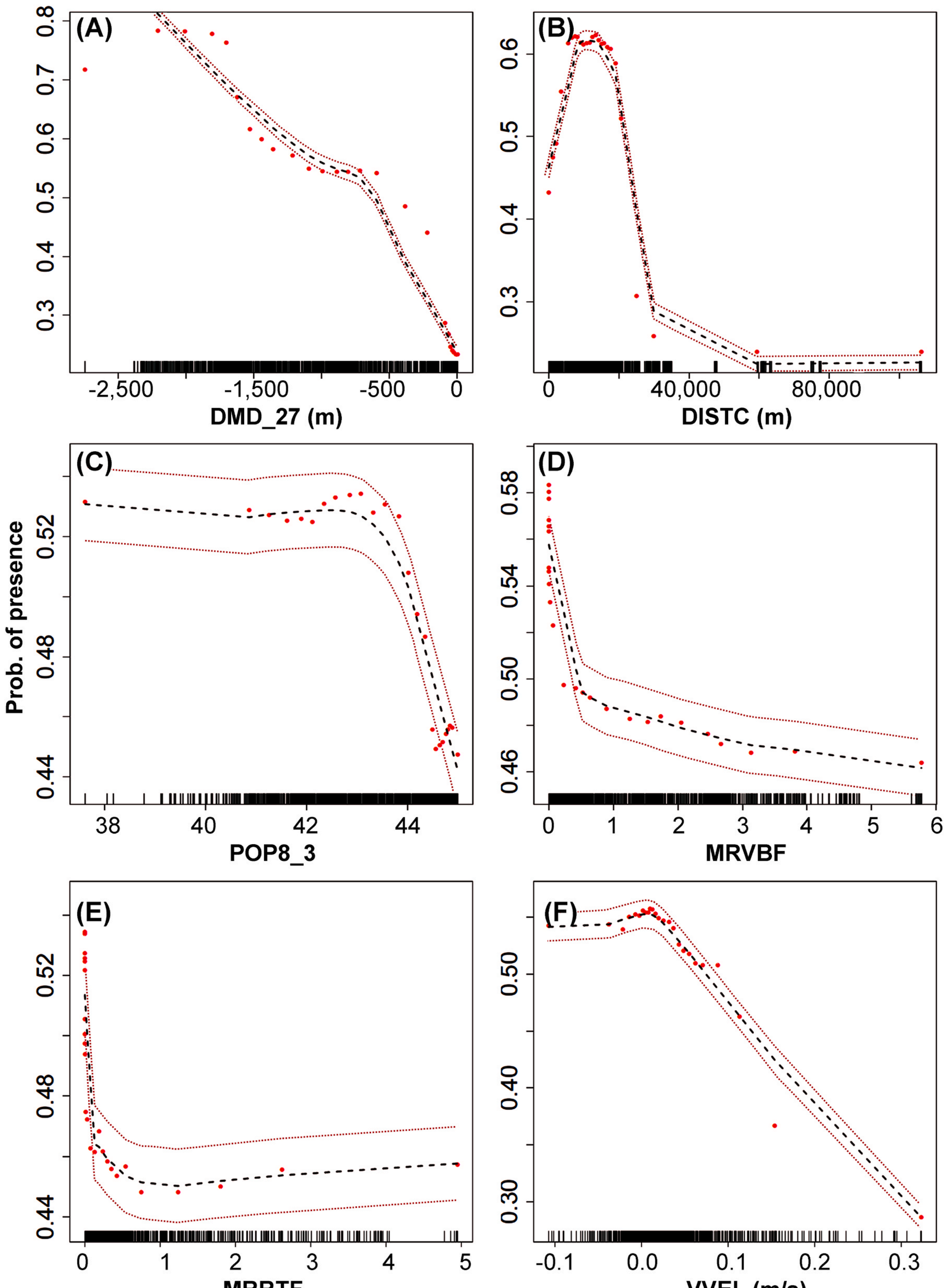

Fig. 11. Effects of predictors in the RF presence-absence model with the selected variables. The variables are ordered from highest to lowest importance in the model. The rest of the variables are not considered relevant. The black dashed line represents the estimated effect, the red dotted lines the 95% confidence intervals, and the red dots indicate partial values for observed data.

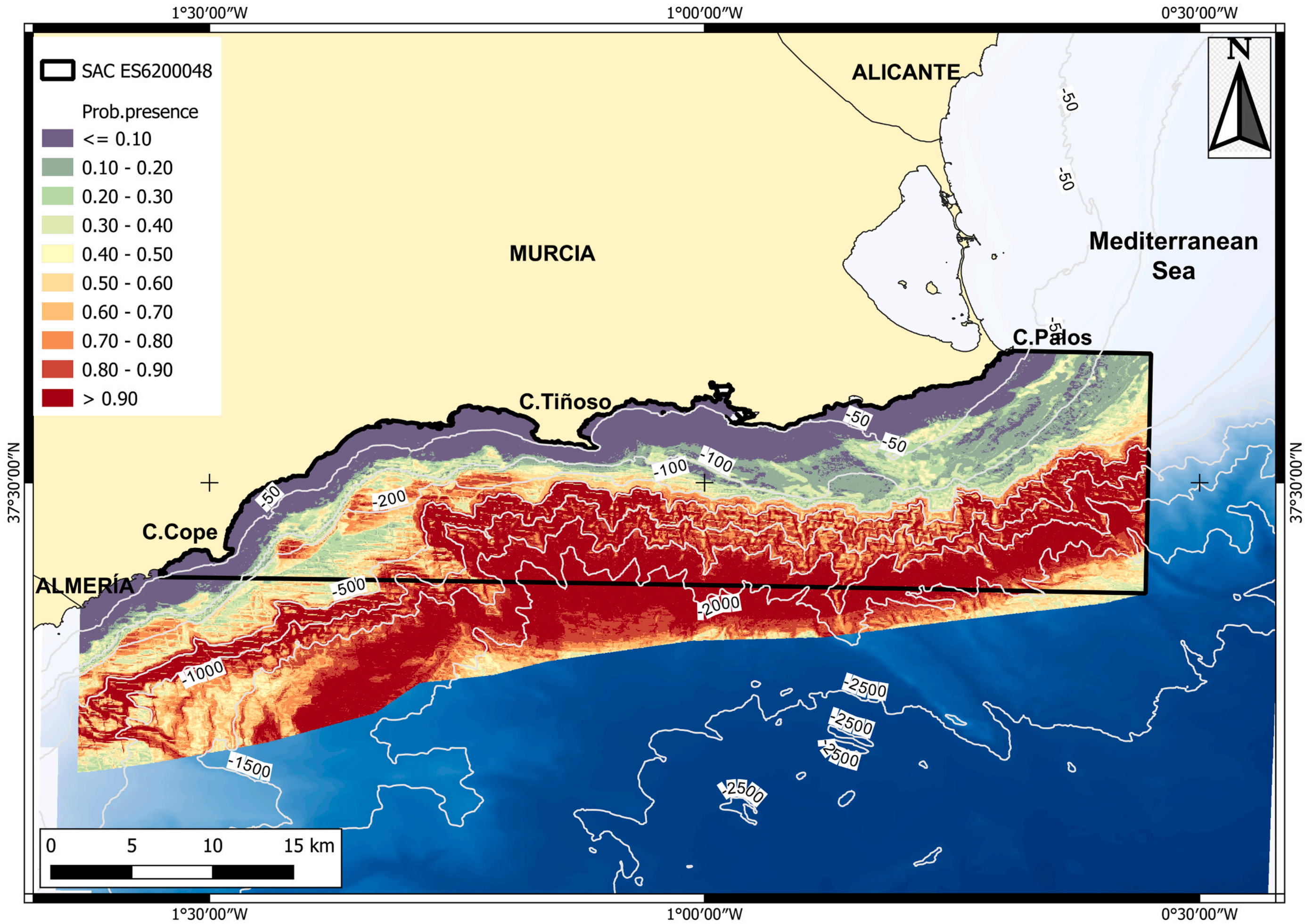

Fig. 12. Spatial prediction of presence-absence RF model for striped dolphin. Predictions outside the study area, but where observed data are available, are included.

dolphin using SDM can be seen in other works, such as Gómez de Segura et al. (2008), or Torreblanca et al. (2023) in Western Mediterranean Sea, although the spatial scale of these two studies is different from the scale used in the present study. They relate the distribution of striped dolphin to depth (preference for sites above deeper waters) and its relationship with pelagic habitat preference.

However, it is of great interest, especially in more detailed studies, to include additional depth predictors that can relate their distribution to aspects such as geoforms defined in geomorphometric variables such as the topographic openness index (POP8, predictor 3 in Fig. 10), the multiresolution valley bottom flatness index (MRVBF, predictor 4 in Fig. 10) or the multiresolution ridge flatness index (MRRTF, predictor 5 in Fig. 10), which in our study are of great relevance in the final SDM and identify the presence of geoforms such as ridges or valleys. Contrary to the previous authors, we did not find SST to be a relevant predictor in the model (predictor 13 in Fig. 10). This may be related to the local scale of the work; as suggested by Gómez de Segura et al. (2008), SST does not play a relevant role unless there is a strong contrast of this variable within the area. Something similar occurs with phytoplankton (predictor 12 -PHIT- in Fig. 10); Azzolin et al. (2020) also indicate, as in our study, that phytoplankton, although an important variable, is not relevant in the spatial distribution pattern of their models. Such problems may be due to the fact that the data used have a spatial resolution of 1 km; this is not the case for the variables where the process of reinterpolation of EMODnet data with the more detailed bathymetry allowed to obtain grids with a resolution of 25 m.

RF has proven to be an effective tool for estimating cetacean abundance and identifying the most influential environmental predictors of cetacean distribution (Maglietta et al., 2023). Changes in key physical and biological oceanographic features can alter marine ecosystems. The habitat-based cetacean models used here are able to explore potential changes in cetacean distribution and abundance in response to these changes (Chavez-Rosales et al., 2019), facilitating decision making in the management of these species and associated ecosystems.

In conclusion, data collected continuously over time can be exploited with the use of analysis techniques based on SDMs models, providing distribution and habitat use models that are fundamental to good habitat management. It is necessary to extend these techniques to other cetacean species users of the SAC Mazarrón submarine canyons, to check if it is suitable for the needs and uses of these protected species.

The characteristics of the southwestern Mediterranean coast facilitate the frequent sighting of different cetaceans species relatively close to the coast, both from sighting and recreational boats (Aguilar et al., 1994). The present study has shown that the whale watching platform, an effective method of environmental education (Christensen et al., 2007), provides also a large amount of data. These activities contribute to obtaining information with the participation of citizens. Over time, it has become a very useful citizen science experience to study patterns of distribution and population trends (Alessi et al., 2019; Bruce et al., 2014; Embling et al., 2015; Lodi and Tardin, 2018). Scientific dissemination actions can help the users to get involved in data collection and share them in citizen science platforms, which can allow the monitoring of species population dynamics, as well as events that could affect them (Hyder et al., 2015).

Ethics approval and consent to participate

Not applicable.

Funding

This research was supported by the Biodiversity Foundation of the Ministry for Ecological Transition and the Demographic Challenge "*Optimización de la información para la mejora la planificación espacial marina en los cañones del Escarpe de Mazarrón, Seco de Palos y 'campo de pockmarks*" (CAMONMAR3) [grant number FBIO18-01], through the EMFF PLEAMAR Programme.

CRediT authorship contribution statement

Rosa Canales-Cáceres: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Francisco Gomariz-Castillo:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Francisco Alonso-Sarría:** Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Supervision. **Isabel Abel:** Investigation, Resources, Data curation. **Francisca Gimenez-Casalduero:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The dataset used and analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

Helpful information about strandings was provided by BEVACET (www.bevacet.uv.es), managed by the University of Valencia, *Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible* (*Junta de Andalucía*), and the Biodiversity Service of *Conselleria de Infraestructuras, Territorio y Medio Ambiente, Generalitat Valenciana*.

The authors are also grateful to the *Cetáceos y Navegación* for their work in those years of study.

This study has been conducted using E.U. Copernicus Marine Service Information for variables.

We thank the referees and editors for their constructive feedback regarding the initial version of the manuscript.

Consent to publication

Not applicable.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rsma.2023.103256.

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