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Cetacean presence and distribution in the central Mediterranean Sea and potential risks deriving from plastic pollution

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ABSTRACT

The Sardinian and Sicilian Channels are considered hotspots of biodiversity and key ecological passages between Mediterranean sub-basins, but with significant knowledge gaps about marine mammal presence and potential threats they face.

Using data collected between 2013 and 2019 along fixed transects, inter and intra-annual cetacean index of abundance was assessed. Habitat suitability, seasonal hot spots, and risk exposure for plastic were performed using the Kernel analysis and the Biomod2 R-package.

661 sightings of 8 cetacean species were recorded, with bottlenose and striped dolphins as the most sighted species. The north-eastern pelagic sector, the coastal waters and areas near ridges resulted the most suitable habitats for these species. The risk analysis identified the Tunis, Palermo, and Castellammare gulfs and the Egadi Island as areas of particular risk of plastic exposure.

The study represents a great improvement for cetacean knowledge in this region and contributes to the development of effective conservation strategies.

1. Introduction

Planning decisions for species requiring special legal protections (Baker et al., 2021), such as vagrant large marine pelagic cetaceans, needs robust and transparent information at an appropriate and relevant spatial scale. Effective information dealing with how, where, and when animals use the environment is crucial for disentangling the effects of human impacts on the ecological traits of wild populations in order to address conservation strategies, design appropriate measures (Ceballos and Ehrlich, 2002), and above all, to increase understanding of dynamics at a landscape scale to maintain connectivity and environmental flows (Baker et al., 2021). Thus, data collection frameworks should encompass all possible aspects enhancing the ability to protect biodiversity, including the potential effects generated by anthropogenic impacts, such as litter especially of plastic origin, on distributional ranges and habitat preferences. Cetaceans are central components of the biodiversity in all oceans, often playing an apical trophic role in maintaining food web stability and ecosystem functioning, although they are vulnerable to a number of anthropogenic impacts (Dolman and Simmonds, 2010; Fossi et al., 2012; Lewison et al., 2014; Turvey et al., 2007; Bearzi, 2002) and suffer habitat fragmentation and loss (Simmonds and Nunny, 2002). This is particularly true in the Mediterranean Sea where, of the ten species regularly inhabiting the basin (di Sciara and Birkun, 2010), three are considered “Vulnerable” (fin whale *Balaenoptera physalus* - Bp, striped dolphin *Stenella coeruleoalba* - Sc, bottlenose dolphin *Tursiops truncatus* - Tt), two “Endangered” (common dolphin *Delphinus delphis* - Dd, sperm whale *Physeter macrocephalus* - Pm), four “Data deficient” (Risso's dolphin *Grampus griseus* - Gg, long-finned pilot whale *Globicephala melas* - Gm, killer whale *Orcinus orca* - Oo, Cuvier's beaked whale *Ziphius cavirostris* - Zc), and one “Not assessed” (rough-toothed dolphin *Steno bredanensis* - Sb) (IUCN, 2012). While the current regulations based on the Habitat Directive (Art.17) and the Marine Strategy Framework Directive (Art.11, Descriptor 1) consider monitoring actions of cetacean’s distributional range, abundance and habitat of the species as crucial factors for designing effective conservation strategies, the collection of useful data for these purposes is complicated by cetacean biological and ecological features. The conservation status of cetacean species is indeed still considered data

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deficient for most taxa according to the last Habitats Directive Art. 17 Report (2013 - 2018) and the EEA Report (No 10/2020), mainly due to the fact that the species spend the majority of their life in remote offshore areas most difficult to monitor because of their extent, highly dynamic nature and the high costs involved in carrying out regular large scale surveys. Most of the information about cetacean abundance and distribution is reported mainly for the northern and western Mediterranean sectors and are concentrated to the summertime and on a few species (Panigada et al., 2011; Praca et al., 2009; Moulins et al., 2008; Laran and Gannier, 2008; Tepsich et al., 2020). Valuable information for conservation purposes is scant for other sectors, such as the Sardinian and Sicilian Channels (SSCC) (di Sciara and Birkun, 2010), where most studies are from coastal (Alessi et al., 2019; Papale et al., 2016; Naceur et al., 2004) and island waters of the southern Sicilian seas (Pulcini et al., 2014; Aïssi et al., 2008; Canese et al., 2006; Celona and Comparetto, 2006; La Manna et al., 2016) and from Maltese and Tunisian coastal waters (North-eastern coast of Tunisia) (Benmessaoud et al., 2012, 2013). Nevertheless, Mediterranean southern areas are crucial for connecting the population nuclei of cetaceans across the Mediterranean basins and maintaining meta-population dynamics. Thereby, the absence of effective information about the distribution and movement patterns of these priority species in these core zones of the distribution range in the Mediterranean Sea undermines the ability to protect marine biodiversity, not only locally but also at a Basin level, and weakens our ability to inform planning decisions (Baker et al., 2021). Indeed, the geographic area including Sicily, Sardinia, Malta, and Tunisia appears to be a key region for understanding of the exchanges between the Eastern and Western Mediterranean waters, because these zones of the Basin are characterized by peculiar environmental features. The Sicily Channel is a hotspot of biodiversity due to the hydrography and topographic features. A series of anti-cyclonic vortexes off the eastern coast of Tunisia and off Malta generates upwelling (Capodici et al., 2018) and increases the overall productivity making it among the most fished (and disturbed) zones in the Northern hemisphere (Falcini et al., 2020; Mangano et al., 2020). Due to its importance for biodiversity, the Sicily Channel has been identified as a priority for conservation (de Juan et al., 2012; Oceana, 2011) and declared as an Ecologically or Biologically Significant Area (EBSA) by the Convention on Biological Diversity (Bax et al., 2016). Nonetheless, the human impact in this area is getting stronger year by year reaching among the highest levels in the entire world. Trawling, shipping traffic, oil drilling, mining, recreational fishing tourism (Levi et al., 1998; FAO, G, 2016; Patruno, 2008) and aquaculture (Sarà et al., 2018; Giacoletti et al., 2021) are just the most striking examples of anthropogenic pressures that more or less directly may impair the wildlife in this area. Marine litter, in particular that of plastic origin, is abundant at exerting large detrimental effects on great pelagic species, such as fish, turtles, and above all cetacean species (Moore and Barco, 2013; Baulch and Perry, 2014; Gall and Thompson, 2015; Claro et al., 2020; Salerno et al., 2021). Giving its complex paths across the aquatic environment and the physical/chemical processes to which it may be subjected, the interactions with marine animals can be diverse and at various levels (Arcangeli et al., 2021). Recent studies confirmed that ingestion and entanglement are among the primary impacts of marine litter on marine species (Kühn et al., 2015; Wilcox et al., 2015; Claro et al., 2019); in particular, 13 of the 15 cetacean families interact with marine debris, and 81 of 123 of all marine mammal species appears to be involved in ingestion phenomena (Fossi et al., 2018; Kühn et al., 2015). This can cause the blockage of the digestive tract, suffocation or even starvation due to a false sense of satiety (Sheavly and Register, 2007; Roman et al., 2019). Entanglement, which was attested for almost the 30% of cetacean species (Fossi et al., 2018), can cause alterations in movements and buoyancy, preventing the animal from breathing, swimming, and feeding appropriately (Laist, 1997; Derraik, 2002; Jacobsen et al., 2010; De Stephanis et al., 2013; Moore et al., 2013). Above all, marine mammals' neck, flukes and flippers tend to get entangled in ghost or active fishing gears (Baulch and Perry, 2014; Moore et al., 2013). Moreover, plastic litter contain chemical additives like persistent organic pollutants (POPs) and heavy metals (Massos and Turner, 2017), many of which are neurotoxins or endocrine disruptors (Sussarellu et al., 2016). Therefore, its ingestion can start the process of bioaccumulation across all levels of the aquatic food web (Lavers et al., 2014; Bakir et al., 2016; Gutow et al., 2016), and of biomagnification, of particular concern when top predators like marine mammals are involved (Santana et al., 2017). Even if death can be caused by just one item of debris (Roman et al., 2019; Santos et al., 2015; Wilcox et al., 2018), not all of them contribute equally to mortality and the probability of ingesting a deadly item raises as more objects are ingested (Roman et al., 2019). In the case of marine megafauna and in particular of cetaceans, Roman et al., 2021 found that film-like plastic, plastic fragments, ropes/nets and fishing items are the most dangerous items among marine litter. Among the first category, plastic bags, sheets and packaging are the major cause of mortality for cetacean species (Panti et al., 2019).

The impact of marine litter on species is a combination of events that imply the exposure of the vulnerable animal to the threat, and then the different levels of impact from movement restriction to injury or death (Gregory, 2009). Being exposed to a pressure does not imply to be affected by it, depending by the individual behavior, the typology of litter item and the type of interaction between the two, so that only a fraction of all individuals potentially exposed to the threat is affected by it ("Potentially Affected Fraction" of Woods et al., 2019). Nevertheless, the identification of risk areas where marine fauna is mostly exposed to litter is the first step to prioritize conservation measures on the higher risk contexts (e.g. Darmon et al., 2017; Arcangeli et al., 2018; Campana et al., 2018; Fossi et al., 2017; Guerrini et al., 2019; Compa et al., 2019; Soto-Navarro et al., 2021).

The Mediterranean Sea is universally recognized as one of the most plastic polluted marine areas of the entire world (Lebreton et al., 2012; Cózar et al., 2015; Suaria et al., 2016). In the last decades, information has been collected about distribution, types, quantities and sources of marine debris in the Mediterranean waters (Suaria and Aliani, 2014; van der Hal et al., 2017; Schmidt et al., 2018). Simultaneously, scientists had tried to predict the faith of floating plastic litter through numerical modelling at basin and sub-basin scales, primarly implementing Lagrangian models of particle dispersion (Mansui et al., 2015, 2020; Maximenko et al., 2012; Liubartseva et al., 2016; Fossi et al., 2017; Palatinus et al., 2019), but this field is still in progress. The primary difficulty that lead to results that are different from model to model is the lack of accurate information about the sources and the amounts of litter discharged in the basin (Soto-Navarro et al., 2020). At present time, the models from Liubartseva et al., 2018, Soto-Navarro et al., 2020, and Guerrini et al., 2021 are the only ones that gave a realistic approximation of marine litter distribution for the entire Mediterranean Sea, taking into account different sources and considering respectively only floating litter or surface, neutrally buoyant and sinking particles, and floating microplastics. The detrimental effects of plastic on wildlife is so alarming that the scientific community is also trying to develop new methods to spectrally characterize the most common polymers and to quantify their spectral separability to determine those optimal band combinations to make plastics detectable through satellite imagery monitoring, so to help identifying the areas of accumulation of this threat (Corbari et al., 2020). However, at date, the most feasible way to identify marine litter accumulation in the large offshore Mediterranean areas still remain the collection of empirical data on floating marine litter at a seasonal temporal scale (Arcangeli et al., 2021).

With regards to SSCC area, studies reported the massive presence of litter entrapped in the seabed (Consoli et al., 2018a; Consoli et al., 2018b). Plastic is always the principal component of the anthropogenic litter recorded in the area (Suaria and Aliani, 2014; Arcangeli et al., 2018, 2019) and, even if the mean plastic density is lower with respect to other parts of the basin (Suaria and Aliani, 2014), plastic hotspots along the Tunisian coasts in the Sicily Channel, and in the gulf of Palermo are confirmed from both field surveys and models (Arcangeli et al., 2018, 2019; Liubartseva et al., 2018, Guerrini et al., 2021; Soto-Navarro et al., 2021, Atzori et al., 2021).

Such a "neglected" presence increases the alert level about the potential implications of plastic impact on biodiversity in general, and on cetaceans in particular. Spatial and temporal scales of data are crucial as the migratory nature of the species and the variability in litter distribution make the interaction largely dependent by seasonality. As a main consequence, to collect new information on how plastic may affect biodiversity at a relevant scale for conservation plays a crucial role when addressing decision planning. In doing so, here we integrated field observational data on cetaceans over a 7-year time series with plastic density obtained by field surveys to build a risk index over the different seasons. Moreover, the most important areas for cetacean species were investigated by modelling suitable habitat for the species. Species Distribution Models (SDMs) are valuable tools for drawing geographic distributional areas as a function of a suite of environmental variables (sensu Sarà et al., 2018), they are in fact a widely used tool to predict cetacean distribution and understand ecological precursors (Palacios et al., 2013; Gregr et al., 2013; Druon et al., 2012; La Manna et al., 2020). Here SDMs were used to predict suitable habitats for cetaceans in the whole area of the SSCC. The final goal of the study is to enhance the knowledge in this key area of the central Mediterranean Sea and produce information to address future conservation measures.

2. Methods

2.1. Study area

Cetaceans and marine litter were monitored in the SSCC (Fig. 1). Four trans-border transects covered this area from 2013 to 2019, connecting Palermo to Cagliari, Trapani and Tunis and Tunis to Civitavecchia. These routes cross both pelagic and coastal area, and pass close to two Marine Protected Areas (the Isole Egadi MPA, located off the north-western coast of Sicily, and the Capo Carbonara MPA, in the south-eastern part of Sardinia) and the Zembra and Zembretta National Park, located in the Gulf of Tunis.

2.2. Data collection

Surveys were performed using passenger ferries as platforms of observation, and data were collected following two different protocols defined by ISPRA (ISPRA, 2015a, Technical Annex I & ISPRA, 2015b, Technical Annex II) dedicated respectively to cetacean and floating marine litter. Of the four transects, two were carried out all year round (Palermo-Tunis PATU and Civitavecchia-Tunis TUCI) and two during the Summer season only (Cagliari-Palermo CAPA and Cagliari-Trapani CATRA), with a minimum of three surveys per season.

Experienced marine mammal observers were located on both sides of the ship's command bridge scanning within an angle of 130° ahead in order to avoid recounting animals. At the same time, one dedicated observer recorded data on floating marine macro litter using a standard protocol specifically developed for collecting data from ferries (Arcangeli et al., 2018) and conformed to the guidelines of the MSFD technical subgroup (Galgani et al., 2013). Observations were performed during daylight and only in good weather conditions (Beaufort scale ≤ 3 for cetacean and ≤ 2 for marine litter), monitoring the sea continuously by naked eye, and using binoculars (7×50 magnification) to confirm species identification, group size, or litter items type/material. The "on effort" track lines and each sighting, either of cetacean or litter, were recorded by two dedicated GPS and annotated on standard datasheets. For cetaceans, information about the distance and angle from the ship, species, number of individuals, direction of swimming, and surface behavior were recorded. Litter monitoring was carried out by the side of

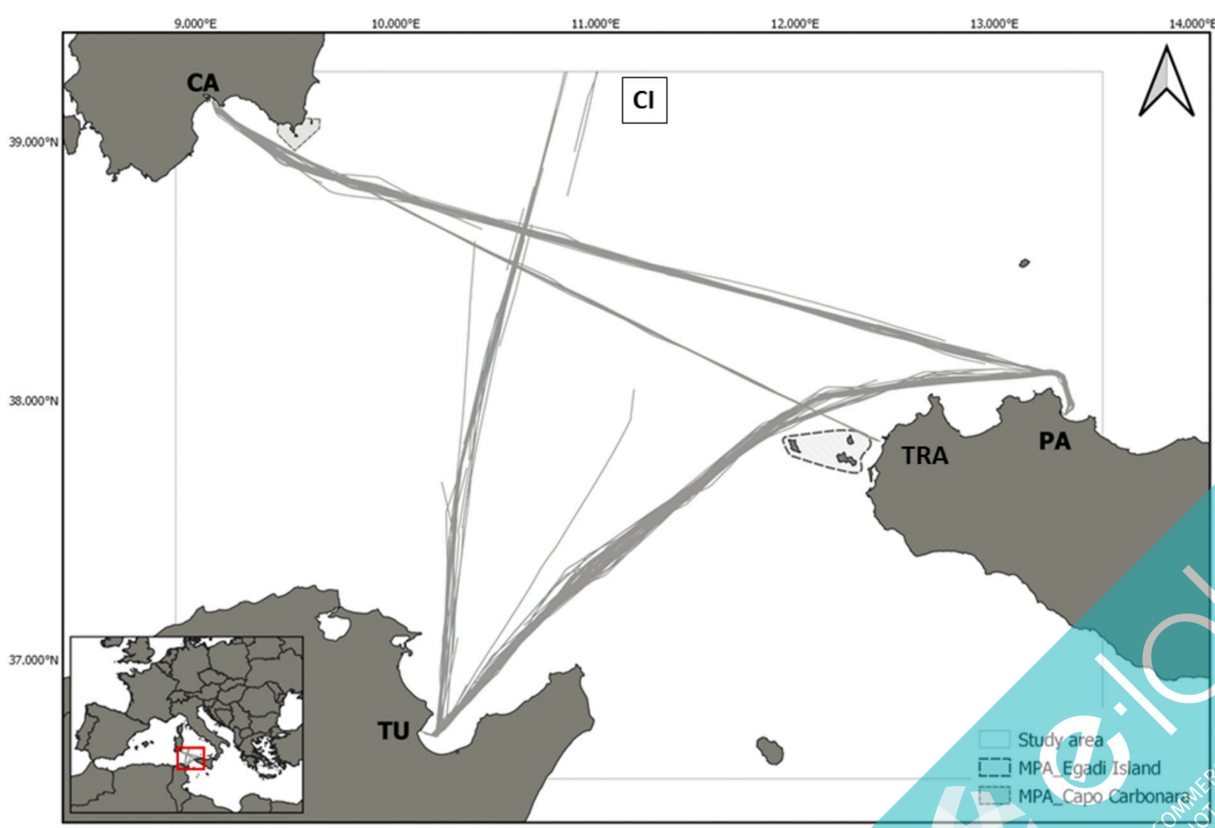

Fig. 1. Study area (in the box), with the Italian marine protected areas of the Egadi Island and Capo Carbonara. The effort performed along the surveyed transects (PATU, TUCI, CATRA and CAPA) between 2013 and 2019 is represented by the grey lines.

the ship's bridge with best visibility, and in the bow proximity in order to avoid the turbulence generated by the bow itself. Only items >20 cm and present in a fixed strip width (Thiel et al., 2003; Pyle et al., 2008) were recorded.

This strip was defined at the beginning of monitoring based on the sea state, glare, and ship's speed (Arcangeli et al., 2018). Litter characterization was based on the type of material (artificial polymer materials, processed wood, glass, paper, metal, textile, rubber, natural debris), and information about buoyancy, color, size, and state of the object (entire or fragment) were registered.

All the ferries used for monitoring belonged to the two categories "Passenger Ro-Ro Cargo ship" and "Ro-Pax passenger vessel", with a height of the command deck between 22 and 27 m above the sea level. The monitoring methodologies, both for cetaceans and marine litter, were consistent along all the study period.

2.3. Data analysis

For all statistical analyses, significant differences were investigated using the non-parametric Kruskal Wallis (KW) test and the post-hoc Mann-Whitney (MW) test with Bonferroni correction. Statistical analyses were performed using the software Past 4.1 (Hammer et al., 2001), while all the spatial analyses were carried out using the QGIS 2.14.21 software. The species habitat suitability was estimated using R 3.4.6.

2.3.1. Cetacean presence and distribution along the routes

The sighting rate (SPUE, Sightings Per Unit of Effort) was estimated per transect for each species and used as a proxy for cetacean abundance in order to compare changes over time. It was calculated as.

$$SPUE = \frac{Number\ of\ sightings}{Km\ in\ good\ weather\ conditions} \times 10$$

Inter-annual analyses were performed considering all monitored transects for the Summer season, while intra-annual seasonal analyses were performed on the PATU and TUCI transects continuously monitored during all the seasons from 2014 to 2019.

To study the spatial distribution of the species, a grid of 5 × 5 km was overlapped onto the study area and, for each cell, the $SPUE_{cell}$ was calculated as.

$$SPUE_{cell} = \frac{Number\ of\ sightings\ per\ cell}{Km\ on\ effort\ per\ cell} \times 10$$

Only the cells with at least one track of effort were selected, and a minimum total effort per cell was set at 10 km (Arcangeli et al., 2017). The Average Nearest Neighbor analysis was preliminarily conducted in order to check if sightings distribution followed a clustered or random pattern. The Kernel Density Estimation (KDE) was then performed based on the $SPUE_{cell}$ using a search radius of 20 km, to show the areas of highest probability of cetacean occurrence. The isopleths corresponding to the 80% of the total values of the entire region were then obtained to highlight the areas of highest species occurrence. In order to identify the statistically significant hotspot of cetacean species, the HotSpot Getis-ord G*Analysis was performed, using only the most significant values (>2.58) for displaying the hot clusters.

2.3.2. Habitat suitability modelling

With the aim of assessing the driving forces that define the habitat of the two most sighted species (Sc and Tt) and predicting their distribution for the entire study area, a habitat suitability analysis was carried out using the Ensemble Platform for Species Distribution Modelling "biomod2" package (Thuiller et al., 2016). This package runs consistently different single models on a presence/absence dataset and combines them into one ensemble model.

Only the Summer sightings from 2013 to 2019 of the two species were considered for the analysis. To avoid bias due to uneven effort, a minimum sampled effort value per cell was set to identify pseudo-absence cells ("absence" cells hereinafter). From the entire dataset (N tot cells = 1564) and for both species, only the cells where the sampling effort was greater than the median of 11 km were considered (N cells = 794). Sc presence cells were 23% of the total ($N = 185$), while for Tt they were only 4% ($N = 33$). Given the very unbalanced dataset for Tt, the Tt presence percentage was adjusted to that of Sc, sampling a number of 111 inferred absence cells from the 794 considered.

A set of eight topographic and oceanographic variables were associated with the dataset of presence/absence cells of Sc and Tt. These variables are those already known or considered as potential predictors of the species considered (Claro et al., 2020; Carlucci et al., 2016; Vassallo et al., 2018; Barragán-Barrera et al., 2019), and were: Sea Surface Temperature (SST, °C); Chlorophyll-a concentration (CHL-a, mg/m^{-3}); bathymetry (m); bathymetric slope (degrees); minimum distance from the nearest coastline, slopes, canyons, and ridges (km).

In order to obtain the most accurate CHL-a and SST seasonal means as possible, the raster files with the highest temporal resolution (8 days) and a spatial resolution of 4 × 4 km have been downloaded from NASA Ocean Color (http://oceancolor.gsfc.nasa.gov). Then, rasters were obtained by averaging each cell over time and calculating temporal standard deviation. Bathymetry values were extrapolated from the GEBCO raster file (GEBCO Compilation Group (2020) GEBCO 2020 Grid (doi: https://doi.org/10.5285/a29c5465-b138-234d-e053-6c86abc040b9), while bathymetric slope and minimum distance from the coastline raster files with a spatial resolution of 1 km were obtained from the MARSPEC dataset (Sbrocco and Barber, 2013). Vector layers of the geomorphic features, such as slopes, canyons, and ridges were obtained from the Blue Habitat dataset (Harris et al., 2014) and the rasters of the Euclidean distances from the nearest features were computed. Those rasters were matched to the same resolution of SST and CHL-a ones using the "raster" package in R. Moreover, before starting modelling, multicolinearity among explanatory variables was tested using VIF (Variance Inflaction Factors).

The influence of environmental predictors was initially investigated statistically comparing values of each variable in presence and absence cells, using Mann-Whitney *U* test to test for equal medians. Then, modelling analyses were performed using the R package biomod2 and GAM, GBM, GLM, RF, and MaxEnt models. For each model, a 10-fold cross validation with an 80-20 proportion for training set and test set was performed, obtaining 50 models for each species. Model performance was evaluated considering primarily AUC (Area Under the ROC Curve) but also TSS (True Skill Statistics), which combines the information of sensitivity and specificity. According to these metrics, and with the purpose of improving predictive power, biomod2 also creates an ensemble model whose performance was also evaluated and compared to other models. All resulting models were also visually inspected for detecting signs of overfitting. After obtaining the final models, variable importance was extracted in order to understand which were more useful for predicting the presence probability of the species. Finally, summary statistics of predictors were also observed in those points recording a presence probability higher than the 3rd quartile for Sc and higher than the threshold of 0.50 for Tt. With the assumption of stochastic independence between the presence of the two species, the probability to find both species (intersection) was also computed.

2.3.3. Floating plastic macro litter and cetacean risk assessment

In order to estimate the potential threat represented by plastic pollution on cetacean species, a seasonal case study considering only the annual transect PATU and the period 2016-2019 was carried out. Seasons were subdivided as follows: Winter (January-March), Spring (April-June), Summer (July-September), and Autumn (October-December).

First, the percentage composition of marine litter items belonging to the different material categories *per* season was calculated, as well as the correspondent total amount of objects detected *per* year. As the characterization of the artificial polymers fraction was the main objective, this portion of the marine litter dataset was used to identify the percentage and density of plastic item categories for each transect, season, and year as:

$$\text{Density} = \frac{\textit{Number of items observed}}{\textit{width of the observed strip x lenght of the surveyed transect.}}$$

Moreover, the most represented dimensional item categories were identified.

Using the Geoprocessing tools in QGIS, a buffer equivalent to the transect width was built around the effort tracks and intersected with the effort cells. Within each cell, the amount of plastic was calculated as

$$\text{Density}_{\text{cell}} = \frac{\textit{Number of plastic items observed}}{\textit{area}}$$

The average Nearest Neighbor analysis was performed to test if plastic litter distribution followed a cluster pattern, as well as the KDE based on the $\text{Density}_{\text{cell}}$ with a search radius of 30 km to show the areas of highest probability of litter occurrence along the routes in the different seasons (Arcangeli et al., 2018). The isopleths corresponding to the 80% of the total values of the entire region were then obtained to highlight the areas of highest litter occurrence. In order to identify the statistically significant hotspot the HotSpot Getis-ord G*Analysis was performed, using only the most significant values (>2.58) for displaying the hot clusters. To identify the areas of particular risk of cetacean exposure to plastic threat, the $\text{SPUE}_{\text{cell}}$ grids of the most sighted species were joined to the one of litter density using the Join attribute by location tool in QGIS.

A risk index was calculated as follows:

$$\text{Risk index} = \text{SPUE}_{\text{cell}}\ \textit{rank} \times \text{Density}_{\text{cell}}\ \textit{rank}$$

considering as ranks four intervals (0, 1, 2, 3) of both variables identified using the Jenks Natural breaks in QGIS, a data clustering method designed to determine the best arrangement of values into different classes according to the distribution of the data. Four different classes of risk were then identified: Null (white), Low (green), Medium (yellow), and High (red).

3. Results

3.1. Cetacean presence and spatial distribution along the routes

From 2013 to 2019, 207 surveys were conducted in the study area, for a total of about 50,000 km covered on effort and 1359 h of observation (Table 1).

During the study period, 661 sightings of cetaceans were recorded (Table 1), and eight of the cetacean species living permanently in the Mediterranean Sea were registered. Sc and Tt were the most sighted species, while Dd, Pm, Bp, and Gg were less frequently recorded, even if sighted almost every year. Gm and Zc were registered only occasionally. In particular, Pm and Zc were recorded in the Sardinian Channel only.

On an annual basis, considering only the Summer season and with all data pooled together (PATU, TUCI, CAPA and CATRA), the mean SPUE value for all cetacean species ranged between 0.020 ± 0.006 (2017) and 0.008 ± 0.002 (2013); no statistical differences were found between the survey years (KW, $p > 0.05$) (Fig. 2).

Stratifying per species, no statistical differences between years were founded for any of them (KW, p > 0.05), with the only exception of Sc which showed some significant variability among years (Fig. 1, Supporting Material first panel) mainly driven by variability in the Sardinian Channel (Fig. 1, Supporting Material second panel). Tt showed instead some significant interannual variability in the Sicilian Channel (Fig. 1, Supporting Material, third panel), with no records during the Summer of 2016 and 2017.

Seasonal analysis performed on the annual transects PATU and TUCI shows no differences in the mean SPUE values for all years and species pooled together, even if the highest value was found in Winter (0.03 ± 0.007) (KW, H = 0.43, $p > 0.05$). Stratifying data per species, Sc, Tt, Dd were recorded all year-round, while no record of Gg was registered during the Winter season. No significant differences between seasons were found in the SPUE values of each species (KW, p > 0.05).

Sightings of mixed groups were recorded. The most common association was between Sc and Dd ($N = 8$), recorded during Summer and Spring. Associations of Tt and Gg ($N = 3$) were recorded in Autumn and Spring. In two occasions, the associations Tt with Sc (Winter) and Gm with Gg (Summer) were observed.

Further analysis on the seasonal spatial distribution were performed considering only the two most sighted species in the study area, namely Sc and Tt. Considering only the Summer season and pooling data from all years and routes together, Sc and Tt sightings showed a statistically significant clustered pattern (Nearest neighbor index < 1). Sc had a spotted spatial distribution along the routes, and a significant Summer hot-spot (Gi* analysis > 2.85) was identified north of the Island of Marettimo (Egadi Island) (Fig. 2, Supporting Materials). Conversely, Tt hotspots were located only near the coasts, corresponding to Tunis, Cagliari, and Trapani harbors (Fig. 3, Supporting Materials).

Spatial analysis on the other seasons along the PATU-TUCI routes showed a clustered pattern in every season (Nearest neighbor index < 1). The Kernel analysis highlighted that the waters around Egadi Island, the Gulf of Tunis, and the NW Sicily coast were, along the routes, the areas with a higher probability of the presence of the two species. Sc presence was concentrated from the NW part of Sicily until Egadi Island in all seasons while, during Spring, a Sc hotspot was highlighted also in the Sardinian Channel. Tt presence was concentrated in the Gulf of Tunis in all seasons and in the water outside Palermo harbor during Spring.

Even if it was not possible to conduct detailed spatial analysis on the less sighted species, due to their low number, Bp, Pm and Zc were recorded only in the northern sector of the study area in the pelagic realm (Fig. 4, Supporting Material). Bp and Zc were recorded in water beyond 1000 m of depth, while Pm beyond 2000 m. Gg presence was recorded in the northern sector until Egadi Island, in which its sightings were positioned along the 600 m isobath. Dd sightings were distributed more homogenously along the transects; near Sardinia this species was recorded beyond 2000 m of depth, in the Sicily Channel was found within and beyond the continental platform; near the Egadi Island, such as Gg, followed the 600 m isobath and in the north-west of Sicily was

Table 1
Summary of the sampling effort, hours of observation, number of transects and of sightings in the considered study period.

Year	Km on effort	Hour of obs	N of transects	N of sightings							
				Pm	Bp	Gg	Gm	Tt	Zc	Sc	Dd
2013	2996.72	108	15	2				3		16	1
2014	7759.27	250	37	1				20		44	7
2015	6258.58	230	27	1	1			19		49	1
2016	4088.65	125	17	2	1	1	1	13		38	1
2017	8613.11	290	37	1	1	1		11		106	7
2018	11,436.16	329	46	1	1	5		21		111	3
2019	6975.53	204	28			2		20	1	69	2

(Pm = *Physeter macrocephalus*; Bp = *Balaenoptera physalus*; Gg = *Grampus griseus*; Gm = *Globicephala melas*; Tt = *Tursiops truncatus*; Zc = *Ziphius cavirostris*; Sc = *Stenella coeruleoalba*; Dd = *Delphinus delphis*)

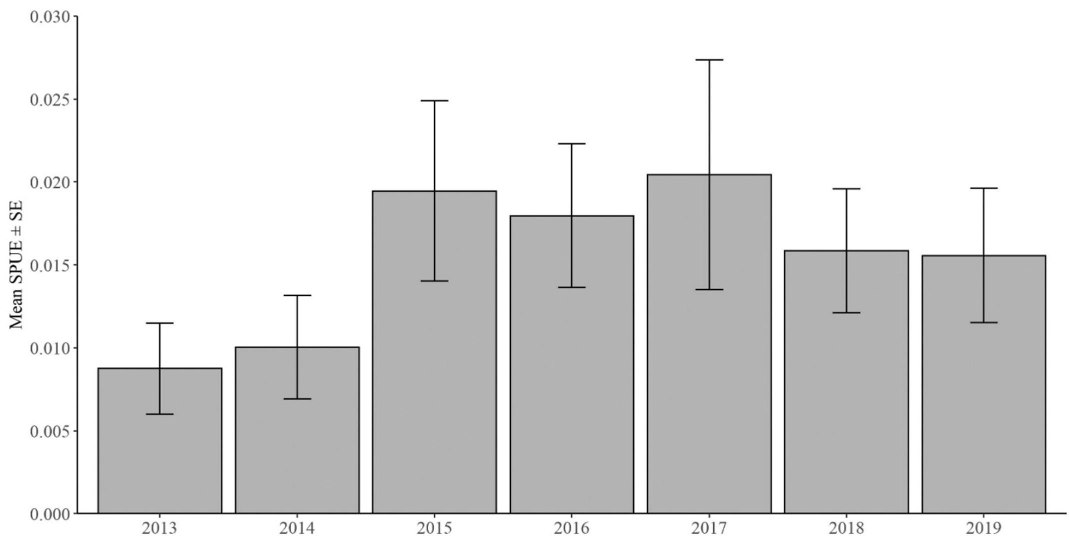

Fig. 2. Mean cumulative Sightings Per Unit of Effort (SPUE) values ± Standard Error (SE) for the Summer seasons in the SSCC for the years considered.

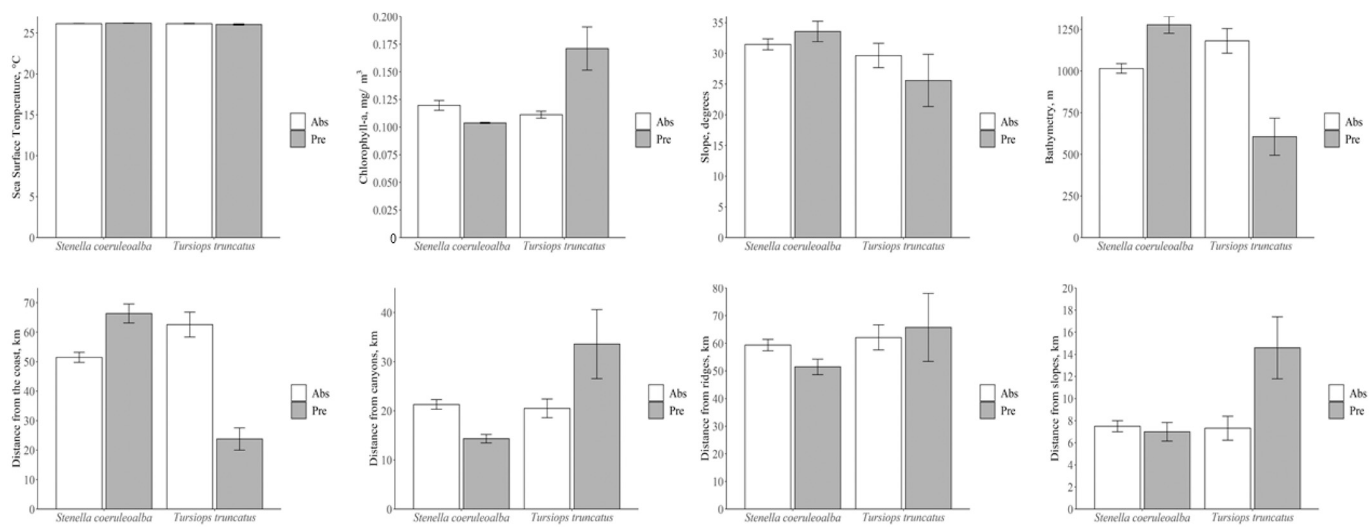

Fig. 3. Mean values of the environmental variables used to model Sc and Tt habitat suitability. White and grey columns represent respectively mean values for the pseudo-absence and presence cells.

located within 1000 m of depth.

3.2. Habitat suitability

The Habitat Suitability analyses showed for Sc a selection for areas furthest from the coast (MW, $p < 0.001$), with higher depths (MW, $p < 0.001$), nearest to canyons (MW, $p < 0.05$) and with water countersigned by lower mean CHL-a concentration (MW, $p < 0.001$). Most of the presence cells were in water with a depth > 1000 m, at a distance >40 km to the nearest coast (Fig. 3). Tt presence cells showed opposite features. These were indeed characterized by lower bathymetry (MW, $p < 0.001$) and distance from the coast (MW, $p < 0.001$) with respect to the pseudo-absence cells, and higher values of distance from slopes (MW, $p < 0.05$). Considering the environmental features of the presence cells only, the majority of them were characterized by bathymetry values either from 0 to 200 m or beyond 800 m within approximately 20, 60, 33, and 14 km of the nearest coast, ridge, canyon, and slope respectively (Fig. 3). No collinearity among variables was detected, and all VIF values were under 6. Best models results are shown in Table 2.

Sc single models, and in particular MaxEnt, had better performance with respect to the ensemble model with AUC = 0.65 (Table 2). Sc presence probability in the study area was mainly driven by bathymetry, distance to the nearest ridge, CHL-a concentration, and SST while bathymetric slope, distance to canyon, coast, and slope were less relevant in the determination of this species habitat. Sc presence probability was almost evenly distributed in the northern part of the study area, with higher values in its north-eastern sector in the south Tyrrhenian. Less suitable habitats were instead all the coastal areas, the shallow portions of the Sicily Channel, and in the small pelagic area south-east of Capo Carbonara MPA characterized by the absence of geomorphic features (Fig. 4).

For Tt, the ensemble model had excellent performance, with AUC = 0.95 (Table 2). For this species, the most important environmental variables shaping the habitat was distance from the coast, followed by distance from slope and ridge and bathymetric slope. SST, CHL-a, bathymetry and distance from canyon were instead less relevant. Tt higher presence probability was found in the coastal areas of Tunisia and Sicily, in the Cagliari gulf and corresponding to the Carbonara ridge (Sardinia), in the Adventure Bank, around Egadi Island, and Ustica's coastal areas, ridge and bank (Sicily). Less suitable habitat was instead represented by

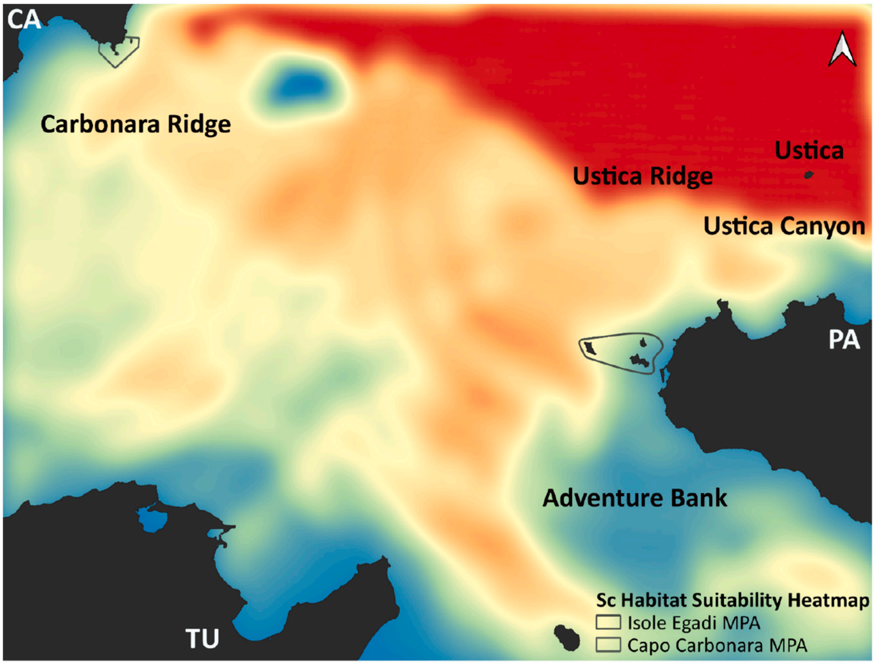

Fig. 4. MaxEnt of *Stenella coeruleoalba* probability of occurrence in the study area for the Summer season.

Table 2
Biomod2 best models results for Sc and Tt.

Species	Model	AUC	TSS	Sensitivity	Specificity
S. coeruleoalba	MaxEnt	0.65	0.29	94.59	34.95
T. truncatus	ensemble	0.94	0.82	93.93	88.28

(AUC = Area Under the ROC Curve; TSS = True Skill Statistics (sensitivity+-specificity-1)).

the central part of the study area (Fig. 5).

Fig. 6 showed the portions of the study area where it is more likely to find both species, resulting from the intersection between the two species presence probability: the waters of the north-eastern and of the north-western sectors, respectively around Ustica Island and near Sardinia, together with Castellammare Gulf in Sicily. Those areas are characterized by high bathymetry values (mean value >500 m) and by the presence of several geomorphic features, including slopes, ridges, and canyons. Moreover, the entire Ustica MPA (Sicily) and a portion of the Capo Carbonara MPA (Sardinia) fall in the detected portions of the study area.

3.3. Floating plastic and risk assessment

The marine litter monitoring was carried out from 2015 to 2019

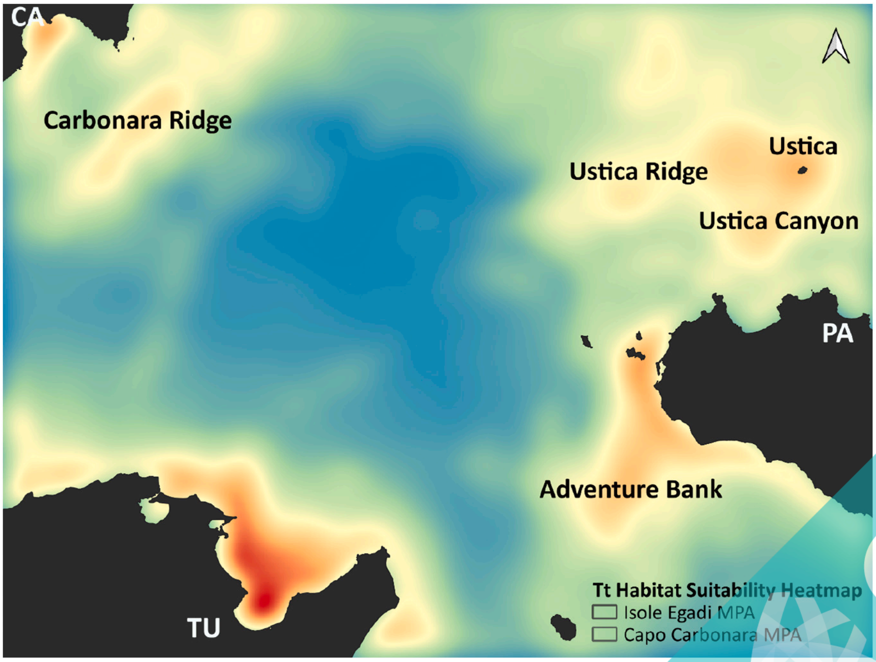

Fig. 5. Ensemble model of *Tursiops truncatus* probability of occurrence in the study area for the Summer season.

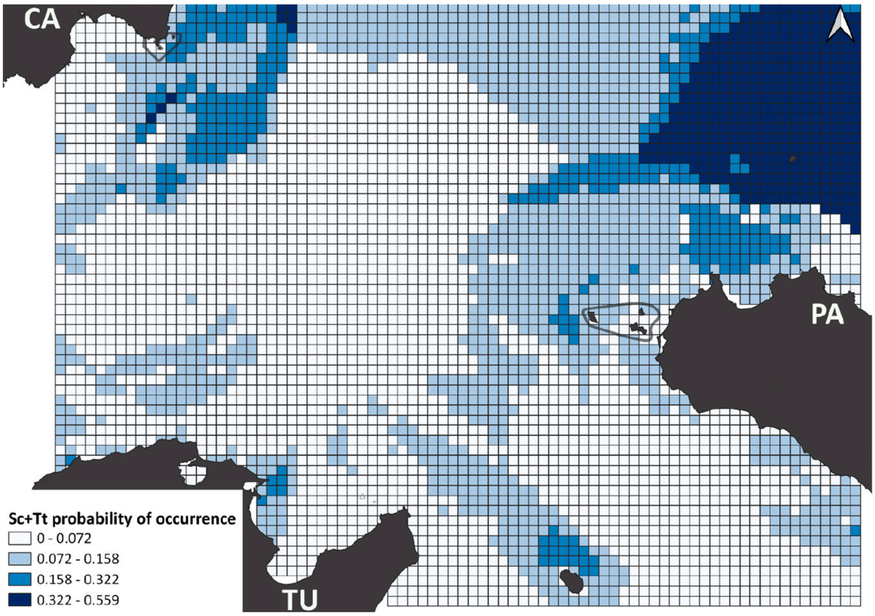

Fig. 6. Sc + Tt concurrent probability of occurrence in the study area for the summer season. Grey contours represent the Capo Carbonara (Sardinia) and Isole Egadi (Sicily) MPAs.

along the PATU and CAPA routes. For the seasonal risk evaluation, only the data recorded along the PATU transects were characterized and analyzed. During the years of monitoring (2016 - 2019), almost 19,600 km of effort have been traveled, and 3572 marine litter items were recorded (Table 1, Supporting Materials).

Of these, 84% was composed by artificial polymer materials. Plastic was the principal recorded fraction in all years and seasons, representing always more than the 75% of the total amount of litter recorded (Fig. 7). Plastic density in 2018 is significantly lower than 2017 and 2019 (MW, $p < 0.05$). No differences were found between seasons (KW, $p > 0.05$).

Among the artificial polymer materials, the most recorded sub-categories were shopping bags ($N = 645$, 22%), plastic sheets ($N = 460$, 16%), bottles ($N = 425$, 14%), buoys ($N = 234$, 7%), and polystyrene boxes ($N = 213$, 7%), followed by tableware, nets and lines, jerry cans, buckets, and plastic boxes. Density values do not differ between seasons with the only exception for that of the buoys and of the beach and coastal amenities, higher during summer and autumn, and summer respectively (MW, $p < 0.05$) (Fig. 5, Supporting Materials).

The second most abundant observed fraction was the organic material, followed by paper and processed wood. Rubber, glass, metal and textile were instead the less present (Table 3 and Fig. 7). No significant seasonal differences in their density values were found with the exception of the paper category, higher in summer with respect to winter or autumn (MW, $p < 0.05$).

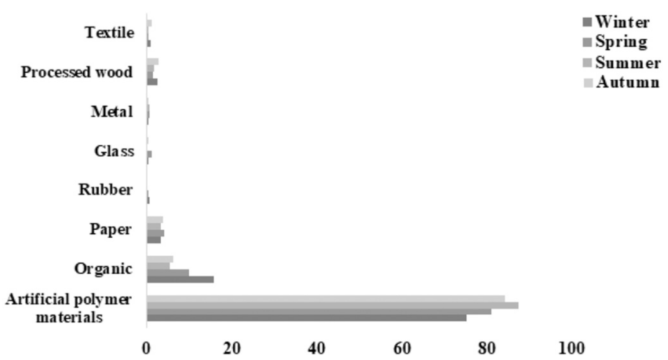

Fig. 7. Marine litter categories percentage composition in the different seasons.

The Nearest Neighbor Analysis for artificial polymer materials sightings showed that they had clustered patterns in all seasons (Nearest neighbor index <1). Areas with higher density values based on Kernel analysis and validated by the Gi* analysis changed slightly as seasons proceed. During Winter, plastic accumulation was concentrated in the water outside Palermo harbor while, during Spring, it expanded a little toward the west. Over Summer, in addition to the hotspot localized in the Carini Gulf, another area with high plastic density values is found in the Tunis Gulf. These two hotspots lasted until Autumn (Fig. 8).

The risk analysis identified the waters outside Palermo harbor until Castellammare Gulf and the Egadi Island as the areas of particular risk for Sc of exposure to plastic threats in almost all seasons (cells colored in yellow and red in Fig. 9). During Winter and Spring, even the Tunis Gulf became a potentially dangerous area for this species. For Tt, one of the area of major risk was located outside Palermo harbor. During Spring and Autumn, the Egadi Island became an area of particular risk of exposure, while higher risk values were detected during Winter and summer near the Tunis Gulf (cells colored in yellow and red in Fig. 10).

4. Discussion

An effective management of wildlife populations requires robust evidence of species distribution and their threats. In the general framework of knowledge of cetacean spatial distribution in the Mediterranean Sea, the SSCC are still areas with scarce information about species distribution and habitat preferences (di Sciara and Birkun, 2010), and with scant evidence about the potential sources of risk generated by plastic pollution. The present study helped fill these gaps of knowledge. The 7-years of monitoring revealed a constant presence in the SSCC of at least 8 cetacean species (Sc, Tt, Dd, Bp, Pm, Zc, Gm, and Gg) regularly observed throughout the whole study period. These findings allowed us to derive that these species showed high fidelity for the area at least during the summer season. Moreover, the seasonal analysis performed in the Sicilian Channel confirmed the presence of at least four of these species (Sc, Tt, Dd, and Gg) almost all-year round, with only the last one absent during Winters. During the study period, various sightings of mixed groups were recorded. The most common association found in this study (Sc + Dd and Tt + Gg) were documented also in other areas of the world, like the Gulf of Corinth (Frantzis and Herzing, 2002), the Alboran Sea (García et al., 2000), and off southern California (Bacon

Table 3
Seasonal and yearly characterization of the recorded marine litter categories.

Material	Seasons								Years							
	Winter		Spring		Summer		Autumn		2016		2017		2018		2019	
	N obj	%	N obj	%	N obj	%	N obj	%	N obj	%	N obj	%	N obj	%	N obj	%
Artificial polymer materials	543	**75.21**	989	**81.00**	663	**87.47**	735	**84.39**	307	**90.56**	1002	**82.33**	1086	**79.44**	535	**82.43**
Organic	114	**15.79**	124	**10.16**	42	**5.54**	56	**6.43**	15	**4.42**	134	**11.01**	142	**10.39**	45	**6.93**
Paper	25	**3.46**	52	**4.26**	26	**3.43**	34	**3.90**	7	**2.06**	39	**3.20**	58	**4.24**	33	**5.08**
Rubber	6	**0.83**	6	**0.49**	2	**0.26**	1	**0.11**			4	**0.33**	4	**0.29**	7	**1.08**
Glass	4	**0.55**	16	**1.31**	2	**0.26**	4	**0.46**			6	**0.49**	14	**1.02**	6	**0.92**
Metal	4	**0.55**	9	**0.74**	5	**0.66**	4	**0.46**	2	**0.59**	7	**0.58**	10	**0.73**	3	**0.46**
Processed wood	18	**2.49**	20	**1.64**	14	**1.85**	26	**2.99**	8	**2.36**	21	**1.73**	34	**2.49**	15	**2.31**
Textile	8	**1.11**	5	**0.41**	4	**0.53**	11	**1.26**			4	**0.33**	19	**1.39**	5	**0.77**

Bold numbers in the table represent the percentage of marine litter items belonging to a particular category over the total number of items collected.

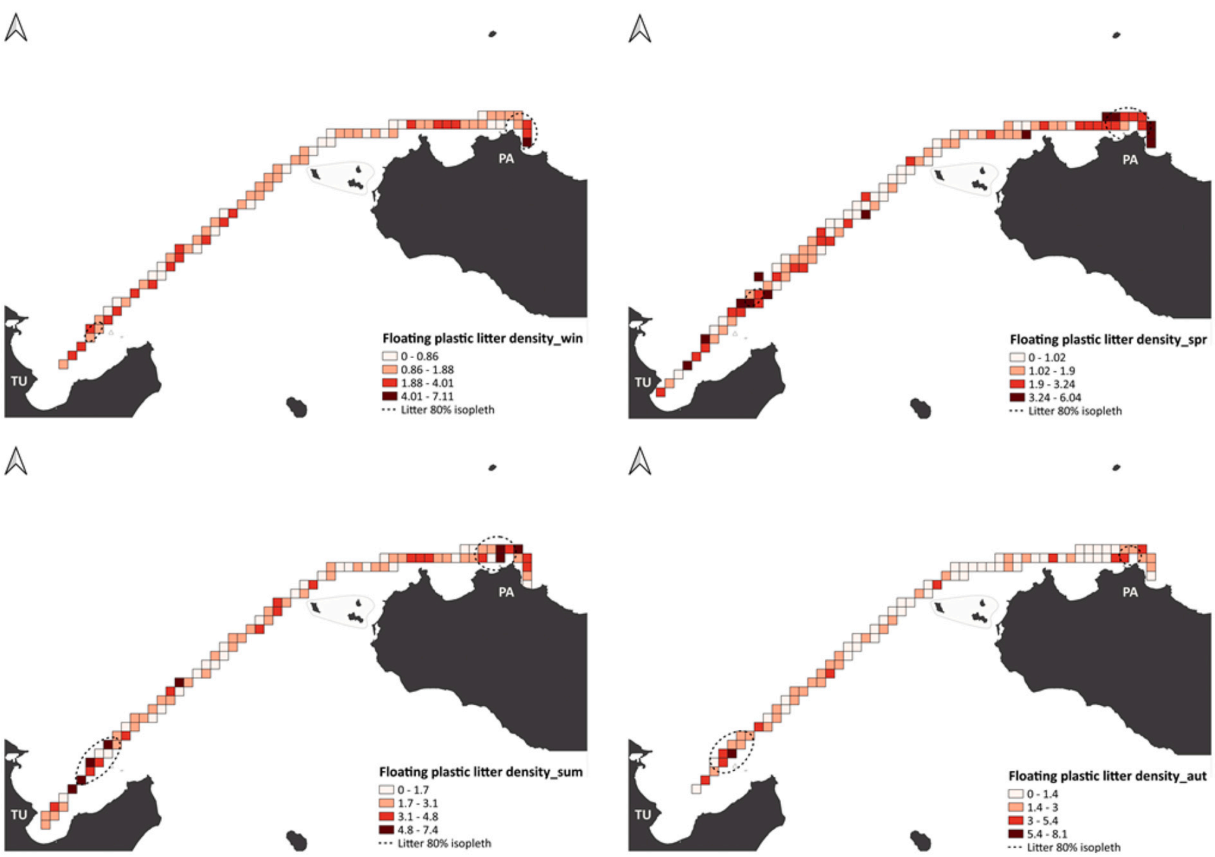

Fig. 8. Cumulative floating plastic litter density$_{cell}$ during the 4 seasons. Dotted line represent the 80% isopleth.

et al., 2017).

In the study area, the Odontocetes Sc and Tt were the most sighted species considering both annual and seasonal sighting data, even if variation in the abundance index values were found for both species. Both Sc and Tt showed a clustered pattern along the routes, despite having different seasonal distribution. Our data and models confirmed what we know about the habitat preferences of these two species: Sc seasonal hotspots were mainly linked to submarine canyons (Carlucci et al., 2018; Kenney and Winn, 1987; Mussi and Miragliuolo, 2003), while those of Tt were mostly detected in shallow waters (Benmessaoud et al., 2012; Alessi et al., 2019; di Sciara, 2002). This may be related to the species feeding habits, preying mostly on benthic and demersal fishes (Blanco et al., 2001; Santos et al., 2001).

Between the less common species, Bp was the recorded in the study area almost exclusively in the north-western pelagic sectors, in accordance with previous study (Aïssi et al., 2008; Canese et al., 2006; Celona and Comparetto, 2006). Deep and offshore waters are in fact the usual favorite habitat of Bp, found mainly in the western and central portion of the Mediterranean Sea; nevertheless, this species can occur in slope and coastal waters depending on the distribution of its prey (di Sciara, 2002; Panigada et al., 2005, 2008). In general, however, the use of this area as passage way for the seasonal latitudinal movement in the western Mediterranean basin was documented by different studies (e.g. Marini et al., 1996; Canese et al., 2006; Panigada et al., 2017) and findings of our study are in line with a relative low permanence of the species in this areas.

Dd was recorded in both coastal and pelagic habitats, as expected giving the mainly epipelagic and mesopelagic fish prey species (Silva and Sequeira, 1996; Ohizumi et al., 1998; Neumann and Orams, 2003). This species, once widespread and abundant in the Mediterranean Sea, has suffered a dramatic decline in the last decades (Bearzi et al., 2003). Indeed, it disappeared from wide portions of the basin even if, to date, it

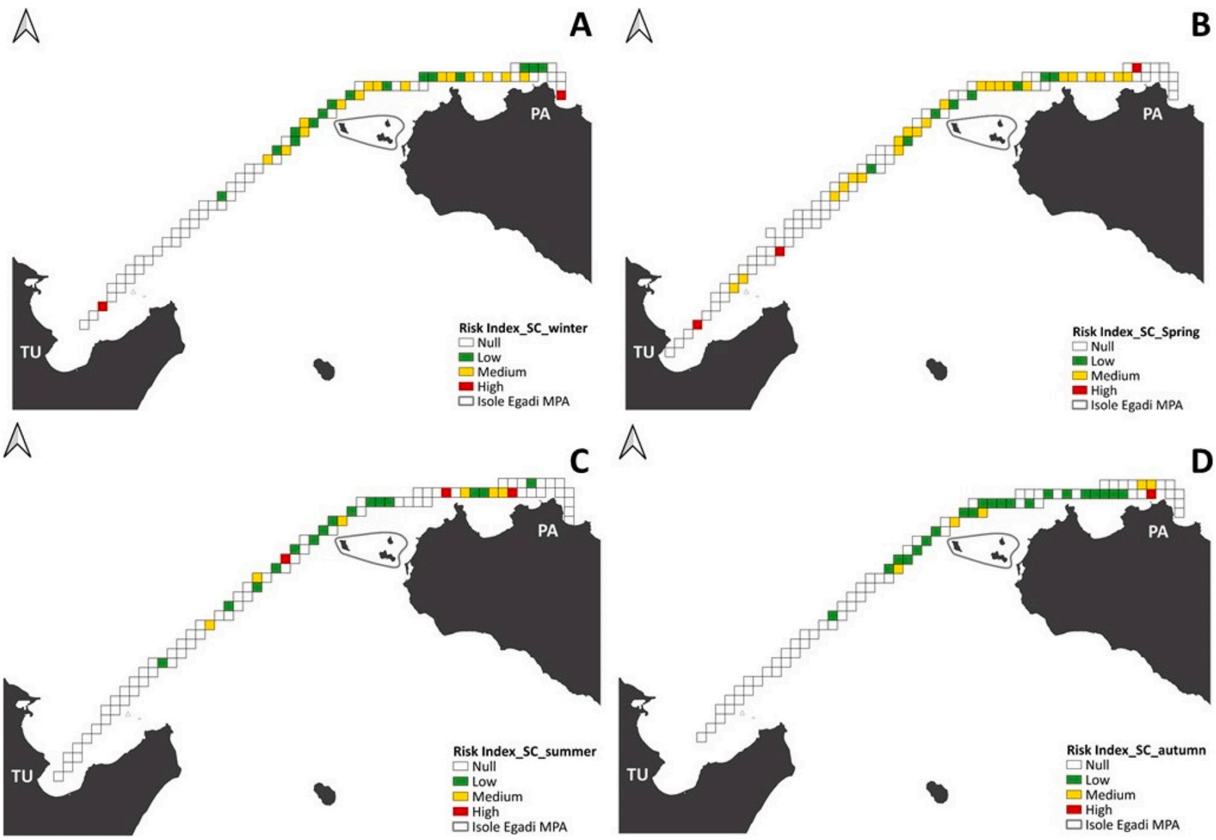

Fig. 9. Sc Risk Index per cell along the PATU route for A) Winter, B) Spring, C) Summer and D) Autumn. The four different levels of potential exposure to plastic (Null (white), Low (green), Medium (yellow) and High (red)) are obtained multiplying four classes of the SPUE $_{cell}$ values with the correspondent classes of Plastic Density $_{cell}$. The grey line identifies the Isole Egadi MPA. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

is more common in isolated clusters mostly in the westernmost portion of the basin, including the ones recorded in the Sicily Channel. Coastal groups of Dd can occasionally share their habitat with Tt, while the pelagic ones with Sc (Bearzi et al., 2003). This particular association occurred mostly at the Mediterranean northernmost latitudes (Cañadas and Hammond, 2008; Frantzis and Herzing, 2002; Pace et al., 2015; Arcangeli et al., 2017), where Dd is less abundant and cannot form single species schools. In the southern Tyrrhenian basin instead it is more present (Pace et al., 2015), and associations are less recorded (Santoro et al., 2015). Along the studied transects, in fact, the majority of Dd sightings were of single-species groups ($N = 14$), with eight Dd + Sc associations.

Gg was mainly recorded around the Egadi waters along the 600 m isobath, confirming the typical pelagic behavior reported for this species, usually sighted in deep areas between 500 and 2000 m, mainly over steep shelf slopes and submarine canyons (Azzellino et al., 2008, 2012, 2016; David and Di-Méglio, 2012). Similarly, Pm was mainly found near the underwater canyons south of Capo Carbonara, the typical habitat of its favorite preys, the cephalopods (Pace et al., 2018, 2019; Claro et al., 2020; Pirotta et al., 2020). Zc was seen halfway between Sardinia and Sicily, an area previously identified by the models of Cañadas et al. (2018) as suitable for this species. In the Mediterranean Sea, Gm is found most exclusively in its western portion (Boisseau et al., 2010; di Sciara and Birkun, 2010; Verborgh et al., 2016), with very sporadic records around the isle of Malta (Metzger et al., 2015; Environment and Resources Authority (ERA), 2020). In this framework, and although it was a single sighting, the record of Gm close to the canyon system of the Egadi Island (but in relatively shallow waters, 262 m) add new information about this species occasional presence.

4.1. Habitat suitability

The best prediction of performance was displayed by Tt model, with distance from the coast as the most important contributing variable, in line with the typical coastal habitat of the species. Nevertheless, in the northern sector of the study area, Tt appears to explore deeper sea sites far from the coasts and close to ridges and canyons. Ridges are continuous submarine mountain chains, and together with isolated sea mountains can be hotspots of biodiversity and can affect the productivity of offshore ecosystems, as well as the distribution of top predators and hence of Tt (Shank, 2010; Greene et al., 1992; Vetter et al., 2010; Morato et al., 2010; Fiori et al., 2015; Cañadas et al., 2002). Another factor that could lead Tt outside its preferred habitat can be the disturbance due to the increased coastal marine traffic in the study area during the summer season (Haviland-Howell et al., 2007; Marley et al., 2017; Nowacek et al., 2001).

Sc in general prefers areas characterized by high deep values; the pelagic environment is in fact the favorite habitat of the species throughout the Mediterranean Sea (Forcada et al., 1994; Gannier, 2005; di Sciara et al., 1993; Carlucci et al., 2016). Within these areas, Sc presence probability appeared to be driven by the distance from the nearest ridge, likely for the same reasons as Tt. Also SST appears to drive Sc spatial distribution, and indeed, in this study, the species showed preference for surface temperatures between 25 and 27 °C, as reported in the ADRION region (Azzolin et al., 2020). However, in other regions of the Mediterranean Sea like the Ligurian Sea, Sc shows a preference for lower range of SST between 22 and 24 °C, probably due to latitudinal differences (Panigada et al., 2008).

The intersection analysis between Tt and Sc more suitable summer habitats showed an overlap, when probably Tt exploit Sc traditional

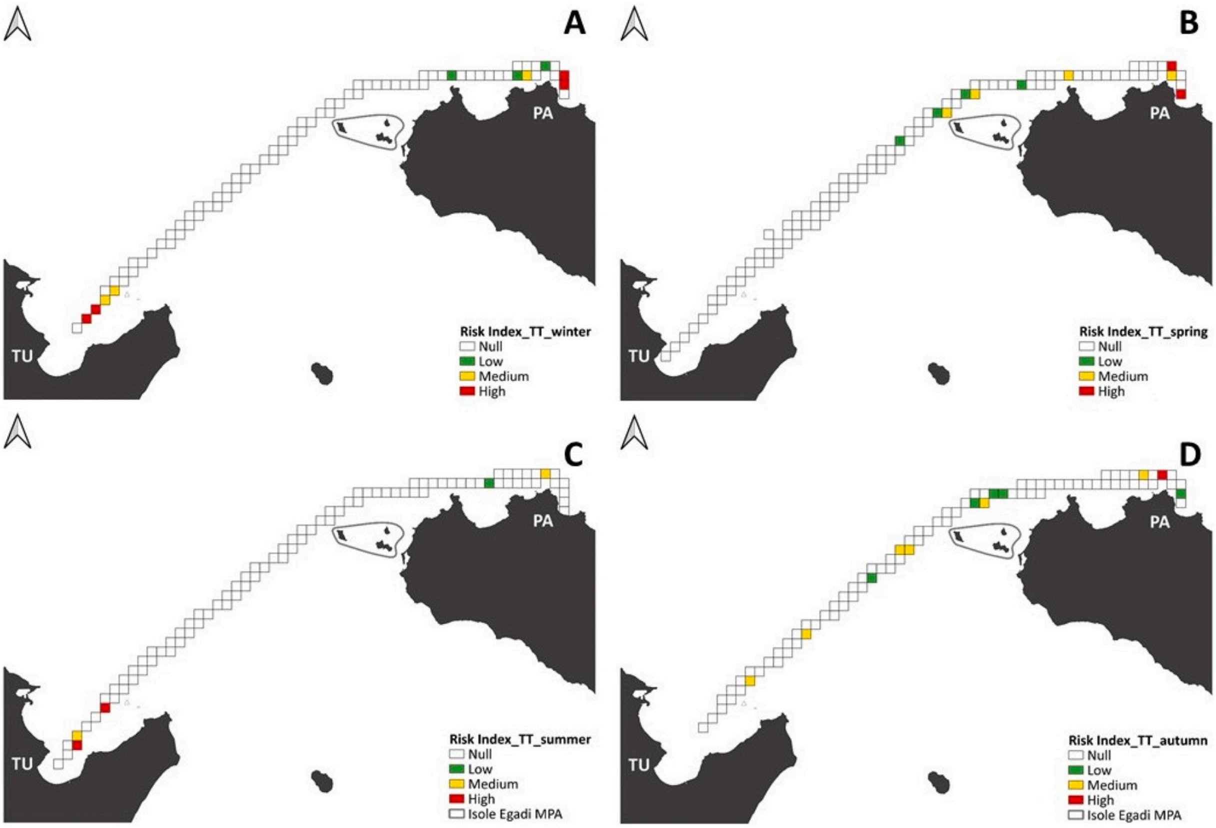

Fig. 10. Tt Risk Index per cell along the PATU route for A) Winter, B) Spring, C) Summer and D) Autumn. The four different levels of potential exposure to plastic (Null (white), Low (green), Medium (yellow) and High (red)) are obtained multiplying four classes of the SPUE $_{cell}$ values with the correspondent classes of Plastic Density $_{cell}$. The grey line identifies the Isole Egadi MPA. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

habitat for feeding purposes. Tt excursions from coastal to pelagic areas is also documented in the western Mediterranean Sea (Gnone et al., 2011; Arcangeli et al., 2017), and it is well known that this species is an opportunistic feeder that can vary its diet according to the availability of the most abundant and catchable prey (Klinowska, 1991). A small difference in prey preference may be enough to support the feeding requirements of more than one species, allowing sympatric dolphins to coexist (Hoelzel et al., 1998); otherwise, competition for the same prey may arise.

4.1.1. Model rationale and limitation

Despite several discussions within the scientific community regarding the predictive power and stationarity of SDMs, single-species distribution models have been and will continue to be invaluable tools for conservation applications (Baker et al., 2021). Nonetheless, there are many potential sources of bias that we need to control to fix the reliability of the modelling effort. For example, SDMs often rely on the collection of both real presence and absence data (Brotons et al., 2004). In the study cases with vagrant and elusive species, such as cetaceans, to get reliable absence data is complicated by the mobility and wide home range that makes it difficult to spot them on the water surface (availability bias). Although mistake rate decreases with observational effort (Barbet-Massin et al., 2012), the correct attribution to the "true" absences (where animals are actually not present) and "false" absences (where animals are present but undetected) is however difficult and the analysis may be impaired by a certain uncertainty degree that should be quantified before to interpret results (Hall, 2000; Martin et al., 2005). There are a number of statistical adaptations to reduce this inherent uncertainty. The random selection of a number of cells, for example, is used to establish where no presence was recorded equal to the number of presence cells (Azzellino et al., 2012; Carlucci et al., 2016; Vassallo et al., 2018) or almost three times higher (Smith, 2010; Arcangeli et al., 2016) or incorporating the survey effort in the definition of absences (Phillips et al., 2009; Gu and Swihart, 2004). In cetacean studies, true absences are usually not available and thus, for the present study, we generated inferred absence data as the cells with the highest survey effort where animals were not detected, and selected among them a number almost three times higher than that of the presence cells. This definition of inferred absence data assumed that the selected cells were close to the real absence data, since they were surveyed several times without the species being detected.

We are aware that, having considered only the environmental features of the study area, our modelling results represent the purely potential suitable habitats of the species, not considering the influence that human activity could have on their presence and distribution. Moreover, in this study only summer suitable habitats were modelled. The other seasons were excluded from the analysis due to the limited number of sightings, not sufficient to adequately sample the study area.

4.2. Marine litter and risk assessment

The marine litter monitoring carried out along one of the analyzed transects underlined that plastic was the most abundant fraction in all years and seasons considered. Those results are in line with the previous field studies in the area (Suaria and Aliani, 2014; Arcangeli et al., 2018). In particular, the most recorded plastic objects were shopping bags, plastic sheets, bottles, buoys and polystyrene boxes, and the majority of these items was smaller or equal to 50 cm. Even if few studies mentioned the specific object ingested, these kind of items (especially plastic bags and sheets) are the ones that could cause cetacean fatal gastric obstructions (Alexiadou et al., 2019; Roman et al., 2021).

Some of the most important Italian fisheries exploit the Sicily Channel area, and this is probably the cause of the high occurrence, in all seasons, of abandoned buoys and polystyrene boxes. This can explain also the seasonal presence of FADs (Fish Attractive Devices), traditionally used in the southern Mediterranean waters to attract pelagic fishes. This kind of floating objects could be very dangerous for marine megafauna, that could be trapped in their ropes and then have serious problems of movements.

The semi enclosed seas like the Mediterranean Sea had particularly high concentrations of marine debris (Lebreton et al., 2012; Cózar et al., 2015), and plastic accumulation is known to occur in different areas. Nevertheless, no evidence of big and stable "garbage patches" are known for the Mediterranean, and plastic accumulates but then distributes with currents through mesoscale processes (Mansui et al., 2015; Liubartseva et al., 2018; Arcangeli et al., 2018). In this study, the only statistically significant detected plastic accumulation area that lasted during all seasons was localized near the gulfs of Palermo and Carini (Sicily), whereas the one in the Tunis gulf appears during the Summer and Autumn only. Those results are consistent with the study of Liubartseva et al., 2018, that classified the gulfs of Palermo and Tunis between the areas with higher sea surface plastic density. Also Suaria and Aliani, 2014 found the highest anthropogenic litter density along the North-Western African coasts.

Those same areas were identified as the ones of major risk for both cetacean species considered, together with the waters around Egadi Island and the Castellammare Gulf for Sc. The region of the Sicily Channel, and the Tunisian and Sicilian coasts were already identified by the models of Soto-Navarro et al., 2021 and Compa et al., 2019 as areas of medium-high potential risk of plastic ingestion in general for pelagic species and in particular for marine mammals.

4.3. Conclusion and implication for cetacean conservation

The study area provides a migratory corridor and nursing and foraging grounds for 8 species of cetaceans. The coastal waters of Kelibia (northeast Tunisia) are recently classified as IMMA (Important Marine Mammals Area), because they support a resident subpopulation of Tt that consistently occupy the area and appears to have long term fidelity. Moreover, the Marine Mammal Protected Area Task Force individuates two more Areas of Interest (AoI): the Egadi Island (Sicily) and the Bay of Bizerte (Tunisia). Those AoI are considered to be of interest for potential marine mammal conservation, requiring enhanced effort for monitoring those species, and may be future candidates in becoming IMMAs.

This study corroborates the hypothesis about the importance of the waters near the Egadi Island MPA for cetacean species. Furthermore, the Tunis gulf, in addition to the Bay of Bizerte and Kelibia, were added as areas of particular interest for Tt. Moreover, the outcome of the study emphasizes the relevance of the northern sector of the study area, in particular near the Carbonara and Ustica Ridges, as aggregation zones of multiple marine mammal species at least during the Summer season. Further analysis, to be conducted throughout the years, is needed to investigate if this condition is maintained.

Despite the growing concern of the adverse effect of marine litter and potential effects on ecosystems, the 'Risk Assessment' topic is still underrepresented (Maes et al., 2019). The identification of risk areas where marine fauna is mostly exposed to litter is the first step to prioritize conservation measures on the higher risk contexts. However, to predict the areas where the animals are most likely to be affected by the risk linked to marine litter is challenging as the needed data on spatio-temporal distribution of the pressure and the vulnerable species are difficult to collect. Most of the animals vulnerable to entanglement or ingestion are highly migratory (e.g. seabirds, sea turtles, and marine mammals) and tend to be scattered across marine areas. On the other and, in the Mediterranean Sea there are no permanent structure able to retain floating items in the long-term (Mansui et al., 2015; Zambianchi et al., 2017; Liubartseva et al., 2018; Mansui et al., 2020) so that the hazard debris is scattered over broad areas, with high seasonal variability both in the amount and composition of items (Darmon et al., 2017; Fossi et al., 2017; Arcangeli et al., 2018; Campana et al., 2018). As a consequence, the interactions between the vulnerable species and the pressure is possible almost anywhere in the species range, but with different intensity depending on areas and seasons. By building a spatially explicit risk index based on plastic density value and vulnerable species encounter rate this study individuated area/season at higher exposure risk for cetacean in the SSCC, taking in consideration also the presence of the most harmful items.

Moreover, integrating species distribution information into marine spatial planning (both inside and outside MPAs) is essential for understanding the risk represented by anthropogenic activities impacting cetacean populations (Azzellino et al., 2012; Cañadas et al., 2005). Results of this study can contribute to design strategies whose ultimate purpose is to protect cetacean species, such as implementing regulations for marine traffic or reducing the impact of fishing activities in the more important areas and seasons for the species, or even individuating new areas to protect. This study is the first to model the potential suitable habitat of the two most abundant cetacean species in the SSCC, hence representing a great improvement for cetacean knowledge in this region.

CRediT authorship contribution statement

M. Gregorietti: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **F. Atzori:** Validation, Investigation, Resources, Writing – review & editing. **L. Carosso:** Formal analysis, Investigation, Data curation, Writing – review & editing. **F. Frau:** Investigation, Data curation, Writing – review & editing. **G. Pellegrino:** Investigation, Data curation, Writing – review & editing. **G. Sarà:** Resources, Writing – review & editing, Supervision, Project administration. **A. Arcangeli:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2021.112943.

References

Aïssi, M., Celona, A., Comparetto, G., Mangano, R., Würtz, M., Moulins, A., 2008. Large-scale seasonal distribution of fin whales (Balaenoptera physalus) in the Central Mediterranean Sea. Marine Biological Association of the United Kingdom. J. Mar. Biol. Assoc. U. K. 88 (6), 1253.

Alessi, J., Bruccoleri, F., Cafaro, V., 2019. How citizens can encourage scientific research: the case study of bottlenose dolphins monitoring. Ocean Coast. Manag. 167, 9–19.

Alexiadou, P., Foskolos, I., Frantzis, A., 2019. Ingestion of macroplastics by odontocetes of the greek seas, eastern Mediterranean: often deadly! Mar. Pollut. Bull. 146, 67–75.

Arcangeli, A., Campana, I., Marini, L., MacLeod, C.D., 2016. Long-term presence and habitat use of Cuvier's beaked whale (Ziphius cavirostris) in the Central Tyrrhenian Sea. Mar. Ecol. 37 (2), 269–282.

Arcangeli, A., Campana, I., Bologna, M.A., 2017. Influence of seasonality on cetacean diversity, abundance, distribution and habitat use in the western Mediterranean Sea: implications for conservation. Aquat. Conserv. Mar. Freshwat. Ecosyst. 27 (5), 995–1010.

Arcangeli, A., Campana, I., Angeletti, D., Atzori, F., Azzolin, M., Carosso, L., et al., 2018. Amount, composition, and spatial distribution of floating macro litter along fixed trans-border transects in the Mediterranean basin. Mar. Pollut. Bull. 129 (2), 545–554.

Arcangeli, A., Maffucci, F., Atzori, F., Azzolin, M., Campana, I., Carosso, L., Hochscheid, S., 2019. Turtles on the trash track: loggerhead turtles exposed to floating plastic in the Mediterranean Sea. Endanger. Species Res. 40, 107–121.

Arcangeli, A., Santini, E., Cadiou, F.S., 2021. Report on the risk induced by floating litter. Assessment of risk exposure areas. In: MEDREGION Project, Deliverable 6.5.

Atzori, F., Carosso, L., Cadoni, N., Frau, F., Gutierrez, M.L.G., De Lucia, G.A., Arcangeli, A., 2021. Loggerhead Sea turtle, Caretta caretta, presence and its exposure to floating marine litter in the Sardinia Channel and the strait of Sicily: results from seven years of monitoring using ferry as platform of observation. Mediterr. Mar. Sci. 22 (2), 422–435.

Azzellino, A., Gaspari, S., Airoldi, S., Nani, B., 2008. Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea. Deep-Sea Res. I Oceanogr. Res. Pap. 55 (3), 296–323.

Azzellino, A., Panigada, S., Lanfredi, C., Zanardelli, M., Airoldi, S., di Sciara, G.N., 2012. Predictive habitat models for managing marine areas: spatial and temporal distribution of marine mammals within the pelagos sanctuary (Northwestern Mediterranean sea). Ocean Coast. Manag. 67, 63–74.

Azzellino, A., Airoldi, S., Gaspari, S., Lanfredi, C., Moulins, A., Podestà, M., Tepsich, P., 2016. Risso's dolphin, Grampus griseus, in the Western Ligurian Sea: trends in population size and habitat use. Adv. Mar. Biol. 75, 205–232.

Azzolin, M., Arcangeli, A., Cipriano, G., Crosti, R., Maglietta, R., Pietroluongo, G., Carlucci, R., 2020. Spatial distribution modelling of striped dolphin (Stenella coeruleoalba) at different geographical scales within the EU adriatic and Ionian Sea region, Central-Eastern Mediterranean Sea. Aquat. Conserv. Mar. Freshwat. Ecosyst. 30 (6), 1194–1207.

Bacon, C.E., Smultea, M.A., Fertl, D., Würsig, B., Burgess, E.A., Hawks-Johnson, S., 2017. Mixed-species associations of marine mammals in the Southern California bight, with emphasis on Risso's dolphins (Grampus griseus). Aquat. Mamm. 43 (2), 177–184.

Baker, D.J., Maclean, I.M., Goodall, M., Gaston, K.J., 2021. Species distribution modelling is needed to support ecological impact assessments. J. Appl. Ecol. 58 (1), 21–26.

Bakir, A., O'Connor, I.A., Rowland, S.J., Hendriks, A.J., Thompson, R.C., 2016. Relative importance of microplastics as a pathway for the transfer of hydrophobic organic chemicals to marine life. Environ. Pollut. 219, 56–65.

Barbet-Massin, M., Jiguet, F., Albert, C.H., Thuiller, W., 2012. Selecting pseudo-absences for species distribution models: how, where and how many? Methods Ecol. Evol. 3 (2), 327–338.

Barragán-Barrera, D.C., Do Amaral, K.B., Chávez-Carreño, P.A., Farías-Curtidor, N., Lancheros-Neva, R., Botero-Acosta, N., et al., 2019. Ecological niche modeling of three species of stenella dolphins in the Caribbean Basin, with application to the seaflower biosphere reserve. Front. Mar. Sci. 6, 10.

Baulch, S., Perry, C., 2014. Evaluating the impacts of marine debris on cetaceans. Mar. Pollut. Bull. 80 (1–2), 210–221.

Bax, N.J., Cleary, J., Donnelly, B., Dunn, D.C., Dunstan, P.K., Fuller, M., et al., 2016. Results of efforts by the convention on biological diversity to describe ecologically or biologically significant marine areas. Conserv. Biol. 30 (3), 571–581.

Bearzi, G., 2002. Interactions between cetacean and fisheries in the Mediterranean Sea. In: Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies. A Report to the ACCOBAMS Secretariat, Monaco.

Bearzi, G., Reeves, R.R., di Sciara, G.N., Politi, E., Cañadas, A., Frantzis, A., Mussi, B., 2003. Ecology, status and conservation of short-beaked common dolphins Delphinus delphis in the Mediterranean Sea. Mammal Rev. 33 (3–4), 224–252.

Benmessaoud, R., Chérif, M., Bradai, M.N., Bejaoui, N., 2012. Distribution of bottlenose dolphin around kelibia (Northeastern of Tunisia). Asian J. Contemp. Sci. 1, 1–11.

Benmessaoud, R., Chérif, M., Bejaoui, N., 2013. Baseline data on abundance, site fidelity and association patterns of common bottlenose dolphins (Tursiops truncatus) off the northeastern tunisian coast (Mediterranean Sea). J. Cetacean Res. Manag. 13 (3), 211–219.

Blanco, C., Salomón, O., Raga, J.A., 2001. Diet of the bottlenose dolphin (Tursiops truncatus) in the western Mediterranean Sea. Marine Biological Association of the United Kingdom. J. Mar. Biol. Assoc. U. K. 81 (6), 1053.

Boisseau, O., Lacey, C., Lewis, T., Moscrop, A., Danbolt, M., McLanaghan, R., 2010. Encounter rates of cetaceans in the Mediterranean Sea and contiguous Atlantic area. J. Mar. Biol. Assoc. U. K. 90 (8), 1589–1599.

Brotons, L., Thuiller, W., Araújo, M.B., Hirzel, A.H., 2004. Presence-absence versus presence-only modelling methods for predicting bird habitat suitability. Ecography 27 (4), 437–448.

Campana, I., Angeletti, D., Crosti, R., Di Miccoli, V., Arcangeli, A., 2018. Seasonal patterns of floating macro-litter across the Western Mediterranean Sea: a potential threat for cetacean species. Rend. Lincei. Sci. Fis. Nat. 29 (2), 453–467.

Cañadas, A., Hammond, P.S., 2008. Abundance and habitat preferences of the short-beaked common dolphin Delphinus delphis in the southwestern Mediterranean: implications for conservation. Endanger. Species Res. 4 (3), 309–331.

Cañadas, A., Sagarminaga, R., Garcia-Tiscar, S., 2002. Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. Deep-Sea Res. I Oceanogr. Res. Pap. 49 (11), 2053–2073.

Cañadas, A., Sagarminaga, R., De Stephanis, R., Urquiola, E., Hammond, P.S., 2005. Habitat preference modelling as a conservation tool: proposals for marine protected areas for cetaceans in southern spanish waters. Aquat. Conserv. Mar. Freshwat. Ecosyst. 15 (5), 495–521.

Cañadas, A., De Soto, N.A., Aissi, M., Arcangeli, A., Azzolin, M., B-Nagy, A., Roger, T., 2018. The challenge of habitat modelling for threatened low density species using heterogeneous data: the case of Cuvier's beaked whales in the Mediterranean. Ecol. Indic. 85, 128–136.

Canese, S., Cardinali, A., Fortuna, C.M., Giusti, M., Lauriano, G., Salvati, E., et al., 2006. The first identified winter feeding ground of fin whales (Balaenoptera physalus) in the Mediterranean Sea. Marine Biological Association of the United Kingdom. J. Mar. Biol. Assoc. U. K. 86 (4), 903.

Capodici, F., Ciraolo, G., Cosoli, S., Maltese, A., Mangano, M.C., Sarà, G., 2018. Downscaling hydrodynamics features to depict causes of major productivity of sicilian-maltese area and implications for resource management. Sci. Total Environ. 628, 815–825.

Carlucci, R., Fanizza, C., Cipriano, G., Paoli, C., Russo, T., Vassallo, P., 2016. Modeling the spatial distribution of the striped dolphin (Stenella coeruleoalba) and common bottlenose dolphin (Tursiops truncatus) in the Gulf of Taranto (Northern Ionian Sea, Central-Eastern Mediterranean Sea). Ecol. Indic. 69, 707–721.

Carlucci, R., Cipriano, G., Paoli, C., Ricci, P., Fanizza, C., Capezzuto, F., Vassallo, P., 2018. Random Forest population modelling of striped and common-bottlenose dolphins in the Gulf of Taranto (Northern Ionian Sea, Central-Eastern Mediterranean Sea). Estuar. Coast. Shelf Sci. 204, 177–192.

Ceballos, G., Ehrlich, P.R., 2002. Mammal population losses and the extinction crisis. Science 296 (5569), 904–907.

Celona, A., Comparetto, G., 2006. Presenza della balenottera comune Balaenoptera physalus (Linnaeus, 1758) nell'area di Lampedusa (arcipelago delle Pelagie) in relazione alla temperatura superficiale delle acque. In: Annales: Series Historia Naturalis, Vol. 16. Scientific and Research Center of the Republic of Slovenia, p. 49. No. 1.

Claro, F., Fossi, M.C., Ioakeimidis, C., Baini, M., Lusher, A.L., Mc Fee, W., Hardesty, B.D., 2019. Tools and constraints in monitoring interactions between marine litter and megafauna: insights from case studies around the world. Mar. Pollut. Bull. 141, 147–160.

Claro, B., Pérez-Jorge, S., Frey, S., 2020. Seafloor geomorphic features as an alternative approach into modelling the distribution of cetaceans. Eco. Inform. 101092.

Compa, M., Alomar, C., Wilcox, C., van Sebille, E., Lebreton, L., Hardesty, B.D., Deudero, S., 2019. Risk assessment of plastic pollution on marine diversity in the Mediterranean Sea. Sci. Total Environ. 678, 188–196.

Consoli, P., Falautano, M., Sinopoli, M., Perzia, P., Canese, S., Esposito, V., et al., 2018a. Composition and abundance of benthic marine litter in a coastal area of the Central Mediterranean Sea. Mar. Pollut. Bull. 136, 243–247.

Consoli, P., Andaloro, F., Altobelli, C., Battaglia, P., Campagnuolo, S., Canese, S., et al., 2018b. Marine litter in an EBSA (Ecologically or biologically significant Area) of the Central Mediterranean Sea: abundance, composition, impact on benthic species and basis for monitoring entanglement. Environ. Pollut. 236, 405–415.

Corbari, L., Maltese, A., Capodici, F., Mangano, M.C., Sarà, G., Ciraolo, G., 2020. Indoor spectroradiometric characterization of plastic litters commonly polluting the Mediterranean Sea: toward the application of multispectral imagery. Sci. Rep. 10 (1), 1–12.

Cózar, A., Sanz-Martín, M., Martí, E., González-Gordillo, J.I., Ubeda, B., Gálvez, J.Á., Duarte, C.M., 2015. Plastic accumulation in the Mediterranean Sea. PLoS One 10 (4), e0121762.

Darmon, G., Miaud, C., Claro, F., Doremus, G., Galgani, F., 2017. Risk assessment reveals high exposure of sea turtles to marine debris in french Mediterranean and metropolitan Atlantic waters. Deep-Sea Res. II Top. Stud. Oceanogr. 141, 319–328.

David, L., Di-Méglio, N., 2012. Role and importance of submarine canyons for cetaceans and seabirds in the North-Western Mediterranean Sea. Mediterr. Submarine Canyons 113.

De Stephanis, R., Giménez, J., Carpinelli, E., Gutierrez-Exposito, C., Cañadas, A., 2013. As main meal for sperm whales: plastics debris. Mar. Pollut. Bull. 69 (1–2), 206–214.

Derraik, J.G., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44 (9), 842–852.

Dolman, S., Simmonds, M., 2010. Towards best environmental practice for cetacean conservation in developing Scotland's marine renewable energy. Mar. Policy 34 (5), 1021–1027.

Druon, J.N., Panigada, S., David, L., Gannier, A., Mayol, P., Arcangeli, A., Gauffier, P., 2012. Potential feeding habitat of fin whales in the western Mediterranean Sea: an environmental niche model. Mar. Ecol. Prog. Ser. 464, 289–306.

Environment and Resources Authority (ERA), 2020. Update on articles 8, 9, and 10 of the marine strategy framework directive (2008/56/?C) in Malta's Marine Waters. March 2020. Available at: http://www.era.org.mt.

Falcini, F., Corrado, R., Torri, M., Mangano, M.C., Zarrad, R., Di Cintio, A., Lacorata, G., 2020. Seascape connectivity of european anchovy in the Central Mediterranean Sea revealed by weighted lagrangian backtracking and bio-energetic modelling. Sci. Rep. 10 (1), 1–13.

FAO, G, 2016. The State of Mediterranean and Black Sea Fisheries. FAO, Rome.

Fiori, C., Alessi, J., Mandich, A., Paoli, C., Vassallo, P., 2015. Indagine sul potere attrattivo delle montagne sottomarine tirreniche su Stenella coeruleoalba/

Assessment of tyrrhenian seamounts attractiveness on Stenella coeruleoalba. Biol. Mar. Mediterr. 22 (1), 250.

Forcada, J., Aguilar, A., Hammond, P.S., Pastor, X., Aguilar, R., 1994. Distribution and numbers of striped dolphins in the western Mediterranean Sea after the 1990 epizootic outbreak. Mar. Mamm. Sci. 10 (2), 137–150.

Fossi, M.C., Panti, C., Guerranti, C., Coppola, D., Giannetti, M., Marsili, L., Minutoli, R., 2012. Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (Balaenoptera physalus). Mar. Pollut. Bull. 64 (11), 2374–2379.

Fossi, M.C., Romeo, T., Baini, M., Panti, C., Marsili, L., Campani, T., Lapucci, C., 2017. Plastic debris occurrence, convergence areas and fin whales feeding ground in the Mediterranean marine protected area pelagos sanctuary: a modeling approach. Front. Mar. Sci. 4, 167.

Fossi, M.C., Panti, C., Baini, M., Lavers, J.L., 2018. A review of plastic-associated pressures: cetaceans of the Mediterranean Sea and eastern australian shearwaters as case studies. Front. Mar. Sci. 5, 173.

Frantzis, A., Herzing, D.L., 2002. Mixed-species associations of striped dolphins (Stenella coeruleoalba), short-beaked common dolphins (Delphinus delphis), and Risso's dolphins (Grampus griseus) in the Gulf of Corinth (Greece, Mediterranean Sea). Aquat. Mamm. 28 (2), 188–197.

Galgani, F., Hanke, G., Werner, S.D.V.L., De Vrees, L., 2013. Marine litter within the european marine strategy framework directive. ICES J. Mar. Sci. 70 (6), 1055–1064.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92 (1–2), 170–179.

Gannier, A., 2005. Summer distribution and relative abundance of delphinids in the Mediterranean Sea. Rev. Écol. 60 (3), 223–238.

García, S., Knouse, D., Sagarminaga, R., Canadas, A., 2000. An insight on the biological significance of mixed groups of common dolphins (Delphinus delphis) and striped dolphins (Stenella coeruleoalba) in the Alboran Sea. In: Evans, P.G.H., Pitt-Aiken, R., Rogan, E. (Eds.), European Research on Cetaceans, 14. European Cetacean Society, Rome, pp. 135–137.

Giacoletti, A., Lucido, G.D., Mangano, M.C., Sarà, G., 2021. Functional trait-based layers-an aquaculture siting tool for the Mediterranean Sea. Aquaculture 532, 736081.

Gnone, G., Bellingeri, M., Dhermain, F., Dupraz, F., Nuti, S., Bedocchi, D., Wurtz, M., 2011. Distribution, abundance, and movements of the bottlenose dolphin (Tursiops truncatus) in the pelagos sanctuary MPA (north-West Mediterranean Sea). Aquat. Conserv. Mar. Freshwat. Ecosyst. 21 (4), 372–388.

Greene, C.H., Wiebe, P.H., Burczynski, J., Youngbluth, M.J., 1992. Acoustical detection of high-density krill demersal layers in the submarine canyons off Georges Bank. Science 241 (4863), 359–361.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc., B 364 (1526), 2013–2025.

Gregr, E.J., Baumgartner, M.F., Laidre, K.L., Palacios, D.M., 2013. Marine mammal habitat models come of age: the emergence of ecological and management relevance. Endanger. Species Res. 22 (3), 205–212.

Gu, W., Swihart, R.K., 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. Biol. Conserv. 116 (2), 195–203.

Guerrini, F., Mari, L., Casagrandi, R., 2019. Modeling plastics exposure for the marine biota: risk maps for fin whales in the pelagos sanctuary (North-Western Mediterranean). Front. Mar. Sci. 6, 299.

Guerrini, F., Mari, L., Casagrandi, R., 2021. The dynamics of microplastics and associated contaminants: data-driven lagrangian and eulerian modelling approaches in the Mediterranean Sea. Sci. Total Environ. 777, 145944.

Gutow, L., Eckerlebe, A., Giménez, L., Saborowski, R., 2016. Experimental evaluation of seaweeds as a vector for microplastics into marine food webs. Environ. Sci. Technol. 50 (2), 915–923.

van der Hal, N., Ariel, A., Angel, D.L., 2017. Exceptionally high abundances of microplastics in the oligotrophic israeli Mediterranean coastal waters. Mar. Pollut. Bull. 116 (1–2), 151–155.

Hall, D.B., 2000. Zero-inflated poisson and binomial regression with random effects: a case study. Biometrics 56 (4), 1030–1039.

Hammer, Ø., Harper, D.A., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol. Electron. 4 (1), 9.

Harris, P.T., Macmillan-Lawler, M., Rupp, J., Baker, E.K., 2014. Geomorphology of the oceans. Mar. Geol. 352, 4–24.

Haviland-Howell, G., Frankel, A.S., Powell, C.M., Bocconcelli, A., Herman, R.L., Sayigh, L.S., 2007. Recreational boating traffic: a chronic source of anthropogenic noise in the Wilmington, North Carolina intracoastal waterway. J. Acoust. Soc. Am. 122 (1), 151–160.

Hoelzel, A.R., Potter, C.W., Best, P.B., 1998. Genetic differentiation between parapatric 'nearshore'and 'offshore'populations of the bottlenose dolphin. Proc. R. Soc. Lond. Ser. B Biol. Sci. 265 (1402), 1177–1183.

ISPRA, 2015a. Technical Annex I. Fixed line transect using ferries as platform for observation monitoring cetacean macro fauna and main threats protocol. ISPRA, Rome.

ISPRA, 2015b. Technical Annex II. Marine litter and marine macro-fauna protocol for the agreement 'Fixed line transect using ferries as platform of observation for monitoring cetacean populations'. ISPRA, Rome.

IUCN, 2012. Marine Mammals and Sea Turtles of the Mediterranean and Black Seas. IUCN, Gland, Switzerland and Malaga, Spain, 32 pages.

Jacobsen, J.K., Massey, L., Gulland, F., 2010. Fatal ingestion of floating net debris by two sperm whales (Physeter macrocephalus). Mar. Pollut. Bull. 60 (5), 765–767.

de Juan, S., Moranta, J., Hinz, H., Barberá, C., Ojeda-Martinez, C., Oro, D., et al., 2012. A regional network of sustainable managed areas as the way forward for the implementation of an ecosystem-based fisheries management in the mediterranean. Ocean Coast. Manag. 65, 51–58.

Kenney, R.D., Winn, H.E., 1987. Cetacean biomass densities near submarine canyons compared to adjacent shelf/slope areas. Cont. Shelf Res. 7 (2), 107–114.

Klinowska, M., 1991. Dolphins, Porpoises and Whales of the World: The IUCN Red Data Book.

Kühn, S., Rebolledo, E.L.B., Van Franeker, J.A., 2015. Deleterious effects of litter on marine life. Mar. Anthropogenic Litter 75–116.

La Manna, G., Ronchetti, F., Sarà, G., 2016. Predicting common bottlenose dolphin habitat preference to dynamically adapt management measures from a marine spatial planning perspective. Ocean Coast. Manag. 130, 317–327.

La Manna, G., Ronchetti, F., Sarà, G., Ruiu, A., Ceccherelli, G., 2020. Common bottlenose dolphin protection and sustainable boating: species distribution modeling for effective coastal planning. Front. Mar. Sci. 7, 955.

Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Marine Debris. Springer, New York, NY, pp. 99–139.

Laran, S., Gannier, A., 2008. Spatial and temporal prediction of fin whale distribution in the northwestern Mediterranean Sea. ICES J. Mar. Sci. 65 (7), 1260–1269.

Lavers, J.L., Bond, A.L., Hutton, I., 2014. Plastic ingestion by flesh-footed shearwaters (Puffinus carneipes): implications for fledgling body condition and the accumulation of plastic-derived chemicals. Environ. Pollut. 187, 124–129.

Lebreton, L.M., Greer, S.D., Borrero, J.C., 2012. Numerical modelling of floating debris in the world's oceans. Mar. Pollut. Bull. 64 (3), 653–661.

Levi, D., Ragonese, S., Andreoli, M.G., Norrito, G., Rizzo, P., Giusto, G.B., Gancitano, S., et al., 1998. Sintesi delle ricerche sulle risorse demersali dello stretto di Sicilia (Mediterraneo centrale) negli anni 1985–1997 svolte nell'ambito della legge 41/82. Biol. Mar. Medit 5 (3), 130–139.

Lewison, R.L., Crowder, L.B., Wallace, B.P., Moore, J.E., Cox, T., Zydelis, R., Bjorkland, R., 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc. Natl. Acad. Sci. 111 (14), 5271–5276.

Liubartseva, S., Coppini, G., Lecci, R., Creti, S., 2016. Regional approach to modeling the transport of floating plastic debris in the Adriatic Sea. Mar. Pollut. Bull. 103 (1–2), 115–127.

Liubartseva, S., Coppini, G., Lecci, R., Clementi, E., 2018. Tracking plastics in the Mediterranean: 2D lagrangian model. Mar. Pollut. Bull. 129 (1), 151–162.

Maes, T., Perry, J., Alliji, K., Clarke, C., Birchenough, S.N., 2019. Shades of grey: marine litter research developments in Europe. Mar. Pollut. Bull. 146, 274–281.

Mangano, M.C., Mieszkowska, N., Helmuth, B., Domingos, T., Sousa, T., Baiamonte, G., Sarà, G., 2020. Moving toward a strategy for addressing climate displacement of marine resources: a proof-of-concept. Front. Mar. Sci. 7, 408.

Mansui, J., Molcard, A., Ourmières, Y., 2015. Modelling the transport and accumulation of floating marine debris in the Mediterranean basin. Mar. Pollut. Bull. 91 (1), 249–257.

Mansui, J., Darmon, G., Ballerini, T., van Canneyt, O., Ourmieres, Y., Miaud, C., 2020. Predicting marine litter accumulation patterns in the Mediterranean basin: spatio-temporal variability and comparison with empirical data. Prog. Oceanogr. 182, 102268.

Marini, L., Consiglio, C., Angradi, A.M., Catalano, B., Sanna, A., Valentini, T., Villetti, G., 1996. Distribution, abundance and seasonality of cetaceans sighted during scheduled ferry crossings in the Central Tyrrhenian Sea: 1989–1992. Ital. J. Zool. 63 (4), 381–388.

Marley, S.A., Kent, C.P.S., Erbe, C., Parnum, I.M., 2017. Effects of vessel traffic and underwater noise on the movement, behaviour and vocalisations of bottlenose dolphins in an urbanised estuary. Sci. Rep. 7 (1), 1–14.

Martin, T.G., Wintle, B.A., Rhodes, J.R., Kuhnert, P.M., Field, S.A., Low-Choy, S.J., et al., 2005. Zero tolerance ecology: improving ecological inference by modelling the source of zero observations. Ecol. Lett. 8 (11), 1235–1246.

Massos, A., Turner, A., 2017. Cadmium, lead and bromine in beached microplastics. Environ. Pollut. 227, 139–145.

Maximenko, N., Hafner, J., Niiler, P., 2012. Pathways of marine debris derived from trajectories of lagrangian drifters. Mar. Pollut. Bull. 65 (1–3), 51–62.

Metzger, B., Oppel, S., Carroll, M., Meirinho, A., Dias, M.P., Barbara, N., Lago, P., 2015. Malta marine IBA inventory report. Malta. Downloaded from. https://birdlifemalta.org/wp-content/uploads/2018/03/LIFE10NATMT090-MSP-A8_mIBA_Report_final.pdf, 15(11), 2018.

Moore, K.T., Barco, S.G., 2013. Handbook for Recognizing, Evaluating, and Documenting Human Interaction in Stranded Cetaceans and Pinnipeds.

Moore, M., Andrews, R., Austin, T., Bailey, J., Costidis, A., George, C., Walsh, M., 2013. Rope trauma, sedation, disentanglement, and monitoring-tag associated lesions in a terminally entangled North Atlantic right whale (Eubalaena glacialis). Mar. Mamm. Sci. 29 (2), E98–E113.

Morato, T., Hoyle, S.D., Allain, V., Nicol, S.J., 2010. Seamounts are hotspots of pelagic biodiversity in the open ocean. Proc. Natl. Acad. Sci. 107 (21), 9707–9711.

Moulins, A., Rosso, M., Ballardini, M., Würtz, M., 2008. Partitioning of the pelagos sanctuary (north-Western Mediterranean Sea) into hotspots and coldspots of cetacean distributions. Marine Biological Association of the United Kingdom. J. Mar. Biol. Assoc. U. K. 88 (6), 1273.

Mussi, B., Miragliuolo, A., 2003. I cetacei della costa nord occidentale dell'isola d'Ischia (Canyon di Cuma). Ambiente marino e costiero e territorio delle isole Flegree (Ischia, Procida e Vivara–Golfo di Napoli): risultati di uno studio multidisciplinare. Mem. Accad. Sci. Fis. Mat. Soc. Ital Sci. Lettere e Arti in Napoli 5, 213–232.

Naceur, L.B., Gannier, A., Bradai, M.N., Drouot, V., Bourreau, S., Laran, S., et al., 2004. Recensement du grand dauphin Tursiops truncatus dans les eaux tunisiennes. Bull. Inst. Natn. Scien. Tech. Mer de Salammbô 31, 76.

Neumann, D.R., Orams, M.B., 2003. Feeding behaviours of short-beaked common dolphins, Delphinus delphis, in New Zealand. Aquat. Mamm. 29 (1), 137–149.
Nowacek, S.M., Wells, R.S., Solow, A.R., 2001. Short-term effects of boat traffic on bottlenose dolphins, Tursiops truncatus, in Sarasota Bay, Florida. Mar. Mamm. Sci. 17 (4), 673–688.
Oceana, 2011. Oceana Mednet. MPA Network Proposal for the Mediterranean Sea, 98 pp.
Ohizumi, H., Yoshioka, M., Mori, K., Miyazaki, N., 1998. Stomach contents of common dolphins (Delphinus delphis) in the pelagic western North Pacific. Mar. Mamm. Sci. 14 (4), 835–844.
Pace, D., Mussi, B., Airoldi, S., Alessi, J., Arcangeli, A., Atzori, F., Tringali, M., 2015. Nuove conoscenze sulla presenza e distribuzione della specie minacciata delfino comune Delphinus Delphis nei mari italiani. In: Congresso della Società Italiana di Biologia Marina, Vol. 10, p. 12.
Pace, D.S., Arcangeli, A., Mussi, B., Vivaldi, C., Ledon, C., Lagorio, S., Ardizzone, G., 2018. Habitat suitability modeling in different sperm whale social groups. J. Wildl. Manag. 82 (5), 1062–1073.
Pace, D.S., Giacomini, G., Campana, I., Paraboschi, M., Pellegrino, G., Silvestri, M., Arcangeli, A., 2019. An integrated approach for cetacean knowledge and conservation in the Central Mediterranean Sea using research and social media data sources. Aquat. Conserv. Mar. Freshwat. Ecosyst. 29 (8), 1302–1323.
Palacios, D.M., Baumgartner, M.F., Laidre, K.L., Gregr, E.J., 2013. Beyond correlation: integrating environmentally and behaviourally mediated processes in models of marine mammal distributions. Endanger. Species Res. 22 (3), 191–203.
Palatinus, A., Viršek, M.K., Robic, U., Grego, M., Bajt, O., Šiljic, J., Peterlin, M., 2019. Marine litter in the croatian part of the middle Adriatic Sea: simultaneous assessment of floating and seabed macro and micro litter abundance and composition. Mar. Pollut. Bull. 139, 427–439.
Panigada, S., Di Sciara, G.N., Panigada, M.Z., Airoldi, S., Borsani, J.F., Jahoda, M., 2005. Fin whales (Balaenoptera physalus) summering in the Ligurian Sea: distribution, encounter rate, mean group size and relation to physiographic variables. J. Cetacean Res. Manag. 7 (2), 137.
Panigada, S., Zanardelli, M., MacKenzie, M., Donovan, C., Mélin, F., Hammond, P.S., 2008. Modelling habitat preferences for fin whales and striped dolphins in the pelagos sanctuary (Western Mediterranean Sea) with physiographic and remote sensing variables. Remote Sens. Environ. 112 (8), 3400–3412.
Panigada, S., Lauriano, G., Burt, L., Pierantonio, N., Donovan, G., 2011. Monitoring winter and summer abundance of cetaceans in the pelagos sanctuary (northwestern Mediterranean Sea) through aerial surveys. PLoS One 6 (7), e22878.
Panigada, S., Lauriano, G., Donovan, G., Pierantonio, N., Cañadas, A., Vázquez, J.A., Burt, L., 2017. Estimating cetacean density and abundance in the central and Western Mediterranean Sea through aerial surveys: implications for management. Deep-Sea Res. II Top. Stud. Oceanogr. 141, 41–58.
Panti, C., Baini, M., Lusher, A., Hernandez-Milan, G., Rebolledo, E.L.B., Unger, B., Fossi, M.C., 2019. Marine litter: one of the major threats for marine mammals. outcomes from the european cetacean society workshop. Environ. Pollut. 247, 72–79.
Papale, E., Ceraulo, M., Giardino, G., Buffa, G., Filiciotto, F., Grammauta, R., et al., 2016. Association patterns and population dynamics of bottlenose dolphins in the strait of Sicily (Central Mediterranean Sea): implication for management. Popul. Ecol. 59 (1), 55–64.
Patruno, R., 2008. Prevention of marine pollution from ships in the Mediterranean region: economic, legal and technical aspects. Geogr. Fis. Din. Quat. 31, 211–214.
Phillips, S.J., Dudík, M., Elith, J., Graham, C.H., Lehmann, A., Leathwick, J., et al., 2009. Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. Ecol. Appl. 19 (1), 181–197.
Pirotta, E., Vighi, M., Brotons, J.M., Dillane, E., Cerdà, M., Rendell, L., 2020. Stable isotopes suggest fine-scale sexual segregation in an isolated, endangered sperm whale population. Mar. Ecol. Prog. Ser. 654, 209–218.
Praca, E., Gannier, A., Das, K., Laran, S., 2009. Modelling the habitat suitability of cetaceans: example of the sperm whale in the northwestern Mediterranean Sea. Deep-Sea Res. I Oceanogr. Res. Pap. 56 (4), 648–657.
Pulcini, M., Pace, D.S., La Manna, G., Triossi, F., Fortuna, C.M., 2014. Distribution and abundance estimates of bottlenose dolphins (Tursiops truncatus) around Lampedusa Island (Sicily Channel, Italy): implications for their management. J. Mar. Biol. Assoc. U. K. 94 (6), 1175–1184.
Pyle, P., Carver, M., Etherington, L., 2008. Methodology for debris monitoring during at sea observation programs in West Coast National Marine Sanctuaries, 8 pp. In: Final report to NOAA Marine Debris Program (. http://cordellbank.noaa.gov/science/debris_protocols_08.pdf.
Roman, L., Lowenstine, L., Parsley, L.M., Wilcox, C., Hardesty, B.D., Gilardi, K., Hindell, M., 2019. Is plastic ingestion in birds as toxic as we think? Insights from a plastic feeding experiment. Sci. Total Environ. 665, 660–667.
Roman, L., Schuyler, Q., Wilcox, C., Hardesty, B.D., 2021. Plastic pollution is killing marine megafauna, but how do we prioritize policies to reduce mortality? Conserv. Lett. 14 (2), e12781.
Salerno, M., Berlino, M., Mangano, M.C., Sarà, G., 2021. Microplastics and the functional traits of fishes: a global meta-analysis. Glob. Chang. Biol. 27 (12), 2645–2655.
Santana, M.F.M., Moreira, F.T., Turra, A., 2017. Trophic transference of microplastics under a low exposure scenario: insights on the likelihood of particle cascading along marine food-webs. Mar. Pollut. Bull. 121 (1–2), 154–159.
Santoro, R., Sperone, E., Tringali, M.L., Pellegrino, G., Giglio, G., Tripepi, S., Arcangeli, A., 2015. Summer distribution, relative abundance and encounter rates of cetaceans in the Mediterranean waters off southern Italy (western Ionian Sea and southern Tyrrhenian Sea). Mediterr. Mar. Sci. 16 (3), 613–620.
Santos, M.B., Pierce, G.J., Reid, R.J., Patterson, I.A.P., Ross, H.M., Mente, E., 2001. Stomach contents of bottlenose dolphins (Tursiops truncatus) in Scottish waters. J. Mar. Biol. Assoc. U. K. 81 (5), 873–878.
Santos, R.G., Andrades, R., Boldrini, M.A., Martins, A.S., 2015. Debris ingestion by juvenile marine turtles: an underestimated problem. Mar. Pollut. Bull. 93 (1–2), 37–43.
Sarà, G., Porporato, E.M.D., Mangano, M.C., Mieszkowska, N., 2018. Multiple stressors facilitate the spread of a non-indigenous bivalve in the Mediterranean Sea. J. Biogeogr. 45, 1090–1103.
Sbrocco, E.J., Barber, P.H., 2013. MARSPEC: ocean climate layers for marine spatial ecology: ecological archives E094–086. Ecology 94 (4), 979.
Schmidt, N., Thibault, D., Galgani, F., Paluselli, A., Sempéré, R., 2018. Occurrence of microplastics in surface waters of the Gulf of lion (NW Mediterranean Sea). Prog. Oceanogr. 163, 214–220.
di Sciara, G.N., 2002. Cetacean species occurring in the Mediterranean and Black Seas. In: State of Knowledge and Conservation Strategies.
di Sciara, G.N., Birkun, A., 2010. Conserving Whales, Dolphins and Porpoises in the Mediterranean and Black Seas.
di Sciara, G.N., Venturino, M.C., Zanardelli, M., Bearzi, G., Borsani, F.J., Cavalloni, B., 1993. Cetaceans in the Central Mediterranean Sea: distribution and sighting frequencies. Ital. J. Zool. 60 (1), 131–138.
Shank, T.M., 2010. Seamounts: deep-ocean laboratories of faunal connectivity, evolution, and endemism. Oceanography 23 (1), 108–122.
Sheavly, S.B., Register, K.M., 2007. Marine debris & plastics: environmental concerns, sources, impacts and solutions. J. Polym. Environ. 15 (4), 301–305.
Silva, M.A., Sequeira, M., 1996. Preliminary results on the diet of common dolphins (Delphinus delphis) off the Portuguese coast. Eur. Res. Cetaceans 10, 253–259.
Simmonds, M., Nunny, L., 2002. Cetacean Habitat Loss and Degradation in the Mediterranean Sea. Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies. A Report to the ACCOBAMS Secretariat, Monaco.
Smith, J., 2010. The Ecology of Cuvier's Beaked Whale, Ziphius cavirostris (Cetacea: Ziphiidae), in the Bay of Biscay. University of Southampton, Southampton, UK. Ph.D. thesis.
Soto-Navarro, J., Jordá, G., Deudero, S., Alomar, C., Amores, Á., Compa, M., 2020. 3D hotspots of marine litter in the Mediterranean: a modeling study. Mar. Pollut. Bull. 155, 111159.
Soto-Navarro, J., Jordá, G., Compa, M., Alomar, C., Fossi, M.C., Deudero, S., 2021. Impact of the marine litter pollution on the Mediterranean biodiversity: a risk assessment study with focus on the marine protected areas. Mar. Pollut. Bull. 165, 112169.
Suaria, G., Aliani, S., 2014. Floating debris in the Mediterranean Sea. Mar. Pollut. Bull. 86 (1–2), 494–504.
Suaria, G., Avio, C.G., Mineo, A., Lattin, G.L., Magaldi, M.G., Belmonte, G., Aliani, S., 2016. The Mediterranean plastic soup: synthetic polymers in Mediterranean surface waters. Sci. Rep. 6 (1), 1–10.
Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., Huvet, A., 2016. Oyster reproduction is affected by exposure to polystyrene microplastics. Proc. Natl. Acad. Sci. 113 (9), 2430–2435.
Tepsich, P., Schettino, I., Atzori, F., Azzolin, M., Campana, I., Carosso, L., Arcangeli, A., 2020. Trends in summer presence of fin whales in the Western Mediterranean Sea region: new insights from a long-term monitoring program. PeerJ 8, e10544.
Thiel, M., Hinojosa, I., Vásquez, N., Macaya, E., 2003. Floating marine debris in coastal waters of the SE-Pacific (Chile). Mar. Pollut. Bull. 46 (2), 224–231.
Thuiller, W., Georges, D., Engler, R., Breiner, F., Georges, M.D., Thuiller, C.W., 2016. Package 'biomod2'. Species distribution modeling within an ensemble forecasting framework. Software.
Turvey, S.T., Pitman, R.L., Taylor, B.L., Barlow, J., Akamatsu, T., Barrett, L.A., Wei, Z., 2007. First human-caused extinction of a cetacean species? Biol. Lett. 3 (5), 537–540.
Vassallo, P., Paoli, C., Alessi, J., Mandich, A., Wurtz, M., Fiori, C., 2018. Seamounts as hot-spots of large pelagic aggregations. Mediterr. Mar. Sci. 19 (3), 444–458.
Verborgh, P., Gauffier, P., Esteban, R., Giménez, J., Cañadas, A., Salazar-Sierra, J.M., de Stephanis, R., 2016. Conservation status of long-finned pilot whales, Globicephala melas, in the Mediterranean Sea. Adv. Mar. Biol. 75, 173–203.
Vetter, E.W., Smith, C.R., De Leo, F.C., 2010. Hawaiian hotspots: enhanced megafaunal abundance and diversity in submarine canyons on the oceanic islands of Hawaii. Mar. Ecol. 31 (1), 183–199.
Wilcox, C., Van Sebille, E., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proc. Natl. Acad. Sci. 112 (38), 11899–11904.
Wilcox, C., Puckridge, M., Schuyler, Q.A., Townsend, K., Hardesty, B.D., 2018. A quantitative analysis linking sea turtle mortality and plastic debris ingestion. Sci. Rep. 8 (1), 1–11.
Woods, J.S., Rødder, G., Verones, F., 2019. An effect factor approach for quantifying the entanglement impact on marine species of macroplastic debris within life cycle impact assessment. Ecol. Indic. 99, 61–66.
Zambianchi, E., Trani, M., Falco, P., 2017. Lagrangian transport of marine litter in the Mediterranean Sea. Front. Environ. Sci. 5, 5.