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Locating ship strike risk hotspots for fin whale (*Balaenoptera physalus*) and sperm whale (*Physeter macrocephalus*) along main shipping lanes in the North-Western Mediterranean Sea

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ABSTRACT

The Pelagos Sanctuary is the only pelagic marine protected area in the Mediterranean Sea, instituted for the conservation of cetaceans. Considering the number and size of commercial and touristic ports located along its coasts, this protected area is highly impacted by human activities, and especially marine traffic. Fin whales and sperm whales are regularly sighted in the Pelagos Sanctuary, and ship strikes with large vessels are one of the main threats affecting these two species. Mapping hotspots of distribution along main shipping lanes could be an effective conservation tool, as they directly allow locating high risk areas. In this work, we used data collected during summer from 2009 to 2019, along main marine traffic corridors in the central region of Pelagos Sanctuary. Ship strike hotspots have been identified, considering the persistence of distribution hotspots over the 11 years period. Hotspots occurrence has then been predicted over the entire Pelagos Sanctuary area applying Generalized Additive Models, allowing for ship strike risk assessment over the marine protected area. Our results highlighted the recurrence of important areas for both species along shipping lanes characterized by high vessel traffic, identifying regions where to address conservation measures.

1. Introduction

Collision with large vessel is known as one of the main human induced threats to cetacean populations worldwide, in the Atlantic Ocean (Vanderlaan and Taggart, 2007; Panigada et al., 2008), in the Pacific Ocean (Williams and O'Hara, 2009; Redfern et al., 2013; Nichol et al., 2017; Keen et al., 2019; Smith et al., 2020) as well as in the Mediterranean Sea (Panigada et al., 2006; Peltier et al., 2019; Foskolos et al., 2020). Many species are known to be affected by ship strikes, and especially large whales: among these, fin whales (*Balaenoptera physalus* Linnaeus, 1758), humpback whales (*Megaptera novaeangliae* Borowski, 1781) and sperm whales (*Physeter macrocephalus* Linnaeus, 1758) are the most frequently involved in collisions (Laist et al., 2001; Winkler et al., 2020). Though all vessels could potentially hit a cetacean, it has been demonstrated that speed and dimension play a crucial role in the probability of a vessel to be involved in ship strike with large whales (Laist et al., 2001; Jensen et al., 2004; Vanderlaan and Taggart, 2007; Cates et al., 2017; Winkler et al., 2020). Particularly, it has been demonstrated that speed greater than 12 knots is enough to cause serious injuries to whales or, in the worst case, death, depending on the severity of the impact and on which body parts are involved (Vanderlaan and Taggart, 2007).

The Pelagos Sanctuary is an international Marine Protected Area (MPA) created in 2002 by France, Italy and Monaco (Notarbartolo-di-Sciara et al., 2008), located in North-Western Mediterranean Sea. This region is characterized by high productivity (D'Ortenzio and Ribera d'Alcalà, 2008), triggered by the complex topography of the area and the influence of currents (Casella et al., 2014). Both deep-water and shelf-slope habitats are present, allowing the recurring presence of different cetacean species, among which the fin whale and the sperm whale (Tepsich et al., 2014; Morgado et al., 2017).

For both species, the main human-induced threat in this area is collision with large ships (Laist et al., 2001; Agardy et al., 2007; David et al., 2011; Campana et al., 2017; Peltier et al., 2019; Ritter and Panigada, 2019; Winkler et al., 2020). Their large body size and their surface behavior, characterized by longer surface time compared with other

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cetaceans, makes these species the ones risking the most to collide with ships. Particularly, fin whales are the cetacean globally more often struck by vessel (Winkler et al., 2020). For the Mediterranean population, it has been estimated that the 16% of individuals found dead from 1972 to 2001 were killed by boats (Panigada et al., 2006). For sperm whales, the risk of collision with vessel is high, placing them at the third place among the species more often struck by vessels (Winkler et al., 2020). Even if they actually spend long time diving at depths (Di-Méglio et al., 2018), while breathing at surface they remain motionless, making themselves more vulnerable (Di-Méglio et al., 2018). Peltier et al. (2019) estimated that between 2005 and 2017, 15.8% of the total strandings of sperm whales along the Western Mediterranean Sea were caused by ship strikes.

According to the last IUCN Red List assessment, the Mediterranean subpopulations of fin whale and sperm whale are respectively listed as "vulnerable" (Panigada and Notarbartolo di Sciara, 2012) and "endangered" (Notarbartolo di Sciara et al., 2012). Both species are known to regularly occur throughout the Mediterranean basin, with the highest density recorded in the Pelagos Sanctuary. Here fin whales and sperm whales are present year-round (Cotté et al., 2009; Arcangeli et al., 2017; Laran et al., 2017), but indeed this area is recognized as an important feeding ground especially during summer (Forcada et al., 1995; Gannier et al., 2002b; Aïssi et al., 2008; Druon et al., 2012; Carpinelli et al., 2014; Geijer et al., 2016). Generally, summer months are also the busiest for Pelagos, in terms of marine traffic, especially for the transit of cruise ships and passenger ferries connecting tourist destinations (David et al., 2011; Campana et al., 2015, 2017; Coomber et al., 2016), resulting in a higher risk of ship strikes.

Risk of collision inside Pelagos has been calculated with different approaches: by combining data on shipping intensity and species sightings rate (David et al., 2011; Di-Méglio et al., 2018), by examining stranded carcasses (Panigada et al., 2006; Peltier et al., 2019) and by using photo-identification methods to assess the rate of injured individuals (Di-Méglio et al., 2018).

In order to address effective conservation measures, mapping the overlap between species distribution and areas of high human use (Pennino et al., 2017) allows the identification of specific higher-risk areas. Species Distribution Models (SDMs) are a widely recognized valuable tool to understand and predict animal distribution (Pearce and Ferrier, 2000; Redfern et al., 2006; Gormley et al., 2013; Santora et al., 2014; Cribb et al., 2015; Becker et al., 2016). Nevertheless, when dealing with large areas and/or highly mobile species, identifying priority areas within species known/predicted distribution is essential. Distribution hotspots can be seen as areas with consistently higher abundance (Santora et al., 2011; Suryan et al., 2012; Yurkowski et al., 2019), or locations where the species occurred at greater frequencies (Moulins et al., 2008). In highly dynamic environments, the persistence of distribution hotspots, which can be defined as the spatio-temporal reoccurrence of areas with high frequencies of species presence (Santora and Veit, 2013), can provide effective indication on priority areas for setting conservation measures.

In this study we aim to assess the risk of ship strike for fin whales and sperm whales in the Pelagos Sanctuary, by locating species distribution hotspots along two main shipping lanes in the north-western Mediterranean Sea. Previous attempts to map risk of collision for fin whale or sperm whale in the area, presented overall maps of the entire area, as a result of the concurrent probability of encountering a whale and the mean traffic in the same area (David et al., 2011; Vaes and Druon, 2013; Di-Méglio et al., 2018). In all cases, whales presence data were collected either by research surveys (David et al., 2011) or modeled (Vaes and Druon, 2013). While such results are of great interest, they are difficult to transfer to maritime companies. By mapping hotspots along routes, the awareness about the collision risk would be better presented to companies navigating along that route. At this end, hotspots maps can be included in training courses and specific recommendations to enhance surveillance by embarking marine mammals' observers (Flynn and Calambokidis, 2019), or by using tools to signal in real time the presence of cetaceans, could be better addressed and consequently more effective.

We applied SDMs in order to map distribution of persistent hotspots over the entire Pelagos Sanctuary, as an effective tool to address persistent ship strike risk over the marine protected area. While the strong interannual variability in species presence in the area (Azzellino et al., 2012; Tepsich et al., 2020), suggest the adoption of dynamic management measures (Ham et al., 2021), these solutions are difficult to apply considering the high use of the Pelagos region for marine traffic. Furthermore, when considering passengers' ferries or cruise ships, which constitute the majority of maritime traffic in the region (Coomber et al., 2016), dynamic management would not be feasible for companies having to respect a strict schedule of trips. The identification of persistent hotspots could represent the first step for fixed management measures.

2. Material and methods

2.1. Study area

The Pelagos Sanctuary can be divided into two areas: the western region, which includes a large abyssal plain (more than 2000 m), while the continental shelf is almost absent, and the eastern part, where the latter is quite extended with many canyons and a seamount region (Moulins et al., 2005; Bo et al., 2020). The western region of the Sanctuary is part of the Ligurian-Provençal Basin, while the eastern region is connected to Tyrrhenian Sea through the Corsica Channel. The main currents that determine the water mass circulation in the basin all year round are the Liguro-Provençal current, flowing anticlockwise along the continental side, and the northeastern current of the Corsican, Sardinian and Balearic Islands side, the West Corsican current (Estrada, 1996) (Fig. 1). The resulting cyclonic gyre creates a permanent thermal front between offshore water and coastal water, which helps to keep the sea surface temperature in the central zone lower than in adjacent basins, as the Tyrrhenian Sea (Astraldi et al., 1995).

Seasonally, coastal upwelling and vertical mixing occurs, caused by the northwesterly wind ('mistral') (Notarbartolo-di-Sciara et al., 2008); this enrichment of nutrients happens between January and April (Bricaud et al., 2002), resulting in the proliferation of zooplankton fauna, such as Meganyctiphanes Norvegica (M. Sars, 1857), an euphausiid crustaceans (krill), known as the main prey of fin whales (Orsi Relini and Cappello, 1992).

2.2. Data collection

Data on fin whale and sperm whale presence and distribution were collected during summer (from the 21st of May to the 30th of September) from 2009 to 2019 on board ferries crossing the northern part of the Pelagos Sanctuary, along the following routes: Savona-Bastia (SB), Savona-Ile Rousse (SI), Savona-Calvi (SC), Nice-Bastia (NB), Nice-Ile Rousse (NI) and Nice-Calvi (NC) (Fig. 1). Surveyed routes fall within the main traffic corridors for passenger ferries in the northern part of the Pelagos Sanctuary. At least three Marine Mammal Observers (MMOs) collected data directly from the ferry command deck: two, placed on the left and on the right side of the bridge, scanned the sea with binoculars 7 × 50, while one was dedicated to data recording. Every 30 min, MMOs changed position in order to avoid fatigue. Survey data included the entire ferry track, sea state condition, wind direction (degrees), wind speed (knots), visibility and cloud cover (0–8). Surveys were conducted following the standard Distance Sampling protocol (Buckland et al., 2001; Tepsich et al., 2020). For each cetacean sighting, linear distance of the cetaceans from the observer as well as the angle between the observed animal and the vessel heading were recorded, together with species, number of individuals, heading of the animal and his behavior.

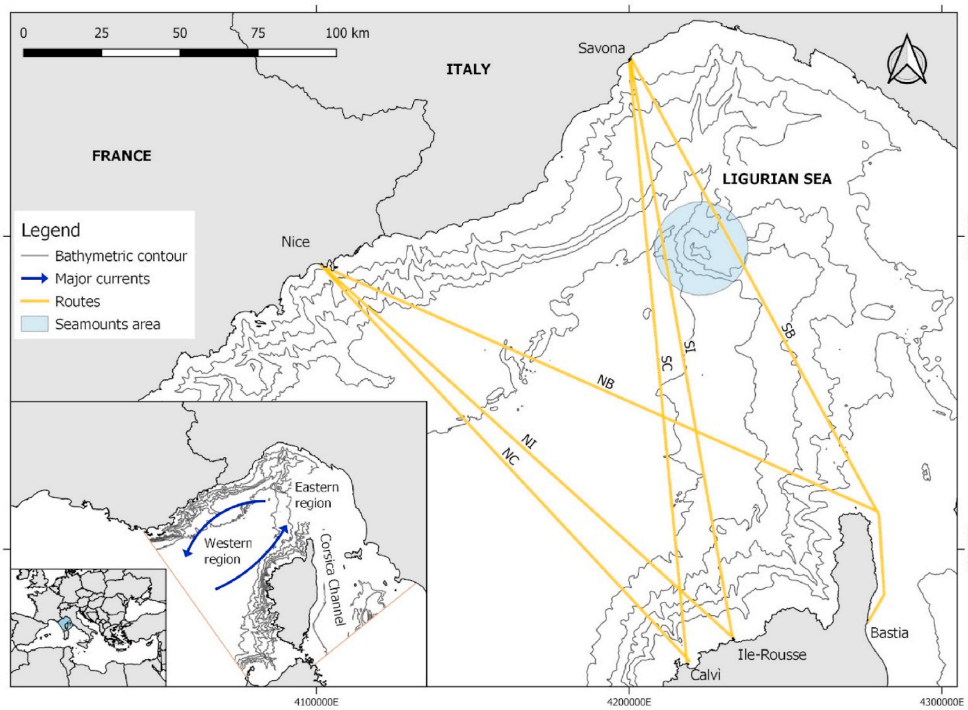

Fig. 1. Map of the study area and monitored routes, namely Savona-Bastia SB, Savona-Ile Rousse SI, Savona-Calvi SC, Nice-Bastia NB, Nice-Ile Rousse NI, Nice-Calvi NC.

2.3. Data elaboration

2.3.1. Field data processing

All data were stored in a PostgreSQL (version 1.22.2; The pg Admin Development Team, 2019) database and then spatially analyzed using QGIS (Version 2.18.15). A 3-step process was developed in order to analyze transect data and build a presence/absence 5 km grid, to be used in the identification of distribution hotspots (Ham et al., 2021). This procedure was applied to each survey (considered as a single trip from port to port) separately, where each survey consisted of a single monitored transect.

First, only tracks "on-effort" (with MMOs actively looking for cetaceans) and conducted under good weather conditions (defined as sea State ≤ 4 for the fin whales and sea state ≤ 3 for the sperm whales) were used in the analysis. A buffer of 2000 m was applied to each monitored track (effort-buffer zone) and to each sighting (sighting-buffer), in order to take into account effective distance of species sightability by observers, as well as species movements (Tepsich et al., 2014; Cominelli et al., 2016).

Secondly, data were gridded into the 1 km European Environmental Agency's (EEA) INSPIRE compliant reference grid and the area covered by each survey was calculated per cell. Survey grids and sighting grids were treated independently. For survey grids, a threshold of 0.2 km^2, equal to 20% of the size of the cell, was applied to identify effectively surveyed cells: all cells not covered by the effort-buffer zone for at least 0.2 km^2 were discarded, while the others were considered as sampled. All sampled cells were then associated to 1 Unit Effort (UE_1). The same threshold was applied for sighting grids, so all cells covered by sighting-buffer $\geq$ 20% of a cell area were retained and given 1 Unit Sighting (US_1).

Finally, a 5 km-grid was created following the INSPIRE compliancy guidelines, ensuring better representativeness for the following analysis (Nichol et al., 2017). Only 1 km cells with at least 1 UE_1 were considered. Each survey has been re-mapped into a 5 km grid: if the number of UE_1 in a 5 km-cell was more or equal to 6 (equal to ¼ of the area of the 5 km cell), or if it contained at least 1 US_1, the cell was considered as surveyed and got 1 UE_5; 5 km-cell containing at least 1 US_1 were assigned 1 US_5. Successively, all the survey grids obtained were aggregated per year and per route (see Fig. 1 for considered routes) and the total number of UE_5 and US_5 was computed. For each year_route 5 km grid then, cells with UE_5 equal to one or US_5 less than or equal to one were removed. The final SPUE (Sightings Per Unit Effort) per year (y) and per route (r) was calculated for each cell i, dividing the US of the cell during that year, by the number of UE for the cell during that year, and normalized by the highest SPUE value recorded along that route during that year:

$$SPUE_{i(r,y)} = \frac{\frac{\sum US_{5i(r,y)}}{\sum UE_{5i(r,y)}}}{SPUE_{\max(r,y)}}$$

To obtain the final yearly 5 km grid of the study area, for the cells where different routes overlapped (e.g. areas in the proximity of Bastia and Nice harbors which are common to different routes), only the most representative cell was kept, considering the most surveyed cell over the year.

A resume of the entire protocol followed to process raw data to create the yearly grids is represented in the Supplementary Material.

2.3.2. Environmental variables

Both physiographic (static) and oceanographic (dynamic) variables were used for modelling the occurrence of distribution hotspots, according to the known habitat preferences of the two species in the area (Table 1).

Bathymetric data has been obtained from the General Bathymetric Chart of the Oceans (GEBCO, 2019) which has a resolution of 30 arc-seconds (~1 km). Bathymetric data were mapped in the 5 km grid and mean value was used as depth of the cell; range of the bathymetry within the 5 km cell, as a proxy for sea bottom topography complexity.

Seafloor geomorphic structures have been demonstrated to be better descriptors than seafloor depth in modelling the distribution of marine mammals (Azzellino et al., 2012; Tepsich et al., 2014; Claro et al., 2020). Considering the geomorphology of the area, four different features were

Table 1
Summary of the physiographic and oceanographic variables used in the SDM.

	Variables	Code	Units	Spatial resolution
Seafloor geomorphic features	Distance to continental shelf	Dcsh	km	1 km
	Distance to continental slope	Dcs	km	1 km
	Distance to the seamount	Dsm	km	1 km
	Distance to the submarine canyon	Dcanyon	km	1 km
Bathymetric features	Bathymetry	Bath_mean	m	30 arc-seconds (~1 km)
	Bathymetric range	Bath_range	m	30 arc-seconds (~1 km)
Sea Surface Temperature	Climatological summer (Jun–Sept) mean	SST_mn	°C	4 km
	Climatological summer (Jun–Sept) standard deviation	SST_sd	°C	4 km
Chlorophyll *a* concentration	Climatological bloom concentration	Bloom_cl	mg/m^3	1 km

considered: the continental shelf (identified as the region ranging from coastline to the 200 m depth contour) (Gannier et al., 2012), the continental slope (identified as the region form the 200 m depth contour which identifies the shelf-break, to the 2000m depth contour), the seamount located in the northern part of the study area (Bo et al., 2020) and the submarine canyons (see Tepsich et al., 2014 for details on submarine canyons identification) (Fig. 1). The Euclidean distance from the edge of each feature to the centre of each 5 km-cell was computed in QGIS.

Concerning dynamic variables, two oceanographic variables are known to influence species presence and distribution: sea surface chlorophyll concentration and sea surface temperature (Gregr and Trites, 2001; Laran and Gannier, 2008; Pirotta et al., 2011, 2020; Druon et al., 2012; Morgado et al., 2017; Panigada et al., 2017; Prieto et al., 2017; Becker et al., 2020). Both parameters were considered at the climatological scale (considered the 10-years period covered by data collection). Particularly, for sea surface chlorophyll concentration, the concentration during the spring bloom is known to have major influence on the distribution pattern of the species (Laran and Gannier, 2008; Morgado et al., 2017). At this end, monthly maps from January to April, identified as the blooming period (Bricaud et al., 2002) of surface *Chl* concentration, were obtained from the online database of the European Union Copernicus Marine Environment Monitoring Service. Yearly bloom maps were then built summing the *Chl* mean of the 4 considered months. The 10-years climatological bloom map was built, as the average of the yearly blooms' maps from 2009 to 2018. Bloom maps were built using the original resolution of the dataset and then mapped into the 5 km grid, and mean value for each 5 km cell was computed.

Sea Surface Temperature (SST) data were obtained by PO.DAAC, with a 4 km resolution. Mean Summer sea surface temperature and standard deviation were computed considering the four summer months, from June to September for each year. The climatological mean and standard deviation maps of SST were then built using the average of the maps obtained, for the 10-years period considered for Sea surface Chlorophyll. Final maps were remapped into the 5 km grid, and mean value for both variables for each cell was computed.

2.4. Data analysis

2.4.1. Yearly hotspots and 11-years persistence

In order to identify hotspots for species presence on a yearly basis, the overall mean and standard deviation of SPUEs of presence cells ($SPUE_{norm} > 0$) was calculated for each year separately. If the SPUE value of a 5 km-cell exceeded the yearly mean by 1 standard deviation (>1 SD), it was considered an "Hotspot" (H) for the considered year; if it fell between 0 and 1 SD it was classified as "Regular" (R); otherwise, if the difference value was less than 0 it was considered as an "Occasional" (O) presence cell.

$$(H)\ SPUE_{i,y} - \overline{SPUE_y} > 1\ SD_y$$

$$(R)\ 0 < SPUE_{i,y} - \overline{SPUE_y} < 1\ SD_y$$

$$(O)\ SPUE_{i,y} - \overline{SPUE_y} < 0$$

These classes were used in order to inspect the yearly occurrence of hotspots for the two considered species along the shipping lanes surveyed.

To assess spatio-temporal persistence of yearly hotspots over the entire considered period, an Hotspot Index (HI) was computed for each cell, in order to take into account the number of times each cell was considered as H, R or O over the 11 years period. The HI was computed as:

$$HI_i = \frac{NH + 0.50*NR + 0.25*NO}{N}$$

where NH is the number of times cell *i* was considered as "Hotspot", NR as "Regular", NO as "Occasional", and N is the number of times the cell was sampled over 11 years. The regular presence was considered to have half of the importance (0.50) of the hotspots cell, while the occasional cells was given a quarter (0.25). The obtained index HI, varies between zero, indicating persistent absence, and one, indicating cells with persistent species presence.

2.5. Modelling

Generalized additive models (GAMs) (Hastie and Tibshirani, 1986) were used to predict the persistent hotspots occurrence over the entire Pelagos area, using 2009–2019 persistence index (HI) and the above-mentioned environmental variables. GAMS are frequently used to explain cetacean distribution (Redfern et al., 2006; Santora et al., 2014; Correia et al., 2015; García et al., 2018; Schleimer et al., 2019; Becker et al., 2020).

Correlation between environmental variables to be used in the model was tested, and for variables highly correlated (Pearson correlation > 0.7) one of them was not included in the model. GAMs were build using the package *mgcv* (Wood, 2011) in the software R, version 4.0.0 (R development Core, 2020). For each species models were fitted using a tweedie distribution family with a log link function. The maximum number of splines was set to 5 to avoid overfitting. Backward selection was used to obtain the best models, based on their Akaike's information criterion (AIC) and the p-values: in the first model, all the variables not correlated were considered; successively, the least significant variable (p value > 0.05) was discarded, and a second model was run again. If the result showed lower AIC, the selection continued, otherwise, the variable was inserted back and the next least significant variable was removed. This process was repeated until the obtaining of the best-fitted model determined by the lowest AIC (Correia et al., 2015). The best models were successively plotted and if the smoothing spline possessed an estimated degree of freedom close to 1 and the corresponding plot showed a linear behavior, the variable was considered as linear. To map distribution of persistent hotspots over the entire Pelagos Sanctuary, we applied the *predict.gam* function to the best model, for each species.

3. Results

In total 592 transects for fin whales (BP) and 587 for sperm whales (PM) were conducted under good weather conditions during summer from 2009 to 2019, totaling 1240 fin whale and 136 sperm whale sightings. Details on yearly total survey effort and sightings collected is presented in Table 2. Overall, 2049 5 km-cells for the fin whale and 1979 for the sperm whale were considered as sampled in 11 years of monitoring using the filters mentioned in the methods. Among the considered traffic lanes, the Savona-Bastia and the Nice-Calvi/Nice-Ile Rousse were regularly surveyed all along the study period, while the Savona-Calvi/Savona-Ile Rousse was surveyed from 2013 to 2015 and the Nice-Bastia from 2017 to 2019.

3.1. Localization of hotspots

Table 3 shows yearly frequency of the three classes (H, R, O), for each species during each year of data collection. In 2013 the highest number of R cells was recorded for both species, while the lowest numbers were recorded in 2009, 2014 and 2019 for the fin whale and in 2010, 2018 and 2019 for the sperm whale. The highest number of hotspots was recorded in 2013 for the fin whale and in 2014 for the sperm whale.

Concerning the fin whale, a strong interannual variability is confirmed, with years showing few and restricted areas of presence of the species compared to years when the species is more widespread over the route (Fig. 2). The interannual variability is more evident along the SB route, where years with no regular cells are present (e.g. 2009 and 2016). Lower variability is present along the NC/NI route, where the species is regularly present and numerous hotspots are recorded. 2014 emerges as a negative record year, as previously evidenced in the area for this species (Cominelli et al., 2016; Morgado et al., 2017; Tepsich et al., 2020).

The sperm whale is generally less present, being almost absent in 2018, and regularly sighted during the other years, yet in small and well-defined areas (Fig. 3). Species presence along all the considered routes is scattered with hotspots located closer to the coast as well as in the deepest portion of the basin. Interestingly, hotspots, regular and occasional presence cells are found right outside main ports, such as Savona (2012, 2013 and 2015), Nice (2012, 2014 and 2017). Hotspot Index, indicating Persistent presence for fin whale along shipping lanes is shown in Fig. 4.

The highest values, corresponding to areas with high persistence of hotspots along the considered period, are located in the central-western part of the study area and particularly along two shipping routes: the NC/NI and the SC/SI. These two routes cross the center of the study area where the depth is greater than 2000 m, known to be the preferred habitat for the species. (Moulins et al., 2005; Panigada et al., 2005; Aïssi et al., 2008; Laran and Gannier, 2008). Similarly, the highest values of HI along the NB route, are found in the central part, which covers the same area of the abovementioned routes. The SB route shows an overall lower persistence for species presence, with a well localized highest HI area over the seamount region. Occasional presence of hotspots is also shown in correspondence of the Nice and Bastia ports. In this latter case, it must be stressed how the area outside the port of Bastia, is not a preferred habitat for the species, being over the continental shelf at depths less than 100 m.

Table 2
Summary of all the surveys from 2009 to 2019, from 21.05 to 30.09, with conditions: sea state ≤4 for fin whale, ≤ 3 for sperm whale, and only "on-effort" part taken in account. BP = fin whale; PM = sperm whale.

	No. of surveys		No. of sightings		Surveyed 5 km-cells	
	BP	PM	BP	PM	BP	PM
2009	58	56	26	10	149	148
2010	72	72	151	10	166	163
2011	65	65	90	8	146	143
2012	62	61	223	31	152	141
2013	74	74	329	13	241	222
2014	60	60	17	12	222	219
2015	59	59	175	17	256	249
2016	45	45	49	11	167	159
2017	38	36	76	14	172	164
2018	25	25	59	2	195	194
2019	34	34	45	8	183	177
Total	*592*	*587*	*1240*	*136*	*2049*	*1979*

Table 3
Summary of the yearly frequency of Occasional, Regular and Hotspot cells throughout the 11-years period. BP = fin whale; PM = sperm whale.

Years	No. of cells where SPUE = 0		No. of Occasional presence cells (NO)		No. of Regular presence cells (NR)		No. of Hotspot cells (NH)	
	Bp	Pm	Bp	Pm	Bp	Pm	Bp	Pm
2009	115	128	20	11	9	6	5	3
2010	64	146	72	14	13	1	17	2
2011	86	126	43	12	11	3	6	2
2012	42	90	69	39	28	7	13	5
2013	72	190	97	17	45	10	27	5
2014	187	195	20	12	9	2	6	10
2015	111	219	92	20	38	4	15	6
2016	105	140	34	12	20	2	8	5
2017	84	136	57	14	18	10	13	4
2018	125	191	39	2	16	0	15	1
2019	103	157	55	14	7	0	18	6

Fig. 5 represents HI for sperm whale over the study period.

A well-defined area confirming the importance of the seamount region, is evidenced along the SB route. Along this corridor, moreover, lower but still important HI areas are evidenced in correspondence of the Savona port and of the north-eastern part of Corsica, in relatively shallow areas. No highest HI areas are found along the NC/NI corridor nor along the NB one. The SC/SI lane shows two high HI cells in the southern part of the route.

3.2. Modelling

Distance from continental shelf was excluded by the models as correlated with 5 out of 8 considered variables. The climatological bloom concentration resulted highly correlated with the climatological mean SST (0.79), the distance from the continental slope (0.72) and the bathymetry (0.75). This variable was excluded by the model, together with the climatological mean SST, which was still correlated with the bathymetry (0.78) and the distance from the slope (0.76). A summary of the selection of the variables and of the models is presented in the Supplementary Material.

The results of the best fitted models are showed in Table 4. The deviance explained by the final model is 32.2% for the fin whale and 4.85% for the sperm whale, respectively. The parameters bathymetry and distance to the continental shelf proved to be very significant for both species. Distance from sea mount and Sea surface temperature standard deviation were retained by the final model for fin whale.

Fig. 6 and Fig. 7 represent GAM−predicted smooth splines of the persistence of fin whale and sperm whale presence respectively, as a function of the explanatory variables.

As it can be seen from the plots, the behavior of all retained parameters was linear. Areas with higher persistence values for fin whales are characterized by greater depths, long distances from the edge of the continental slope, proximity to the seamount and higher variability of the sea surface temperature during summer. For sperm whale, only static variables were included in the final model, highlighting higher persistence for species presence in both areas characterized by greater depths and areas closer to the continental shelf. Nevertheless, considering the lower deviance explained by this model, these results should be interpreted with caution. For the same reason, no further analysis has been implemented for the sperm whale.

Prediction of persistence of fin whale over the entire Pelagos Sanctuary is shown in Fig. 8.

The model correctly identifies the known distribution for the species,

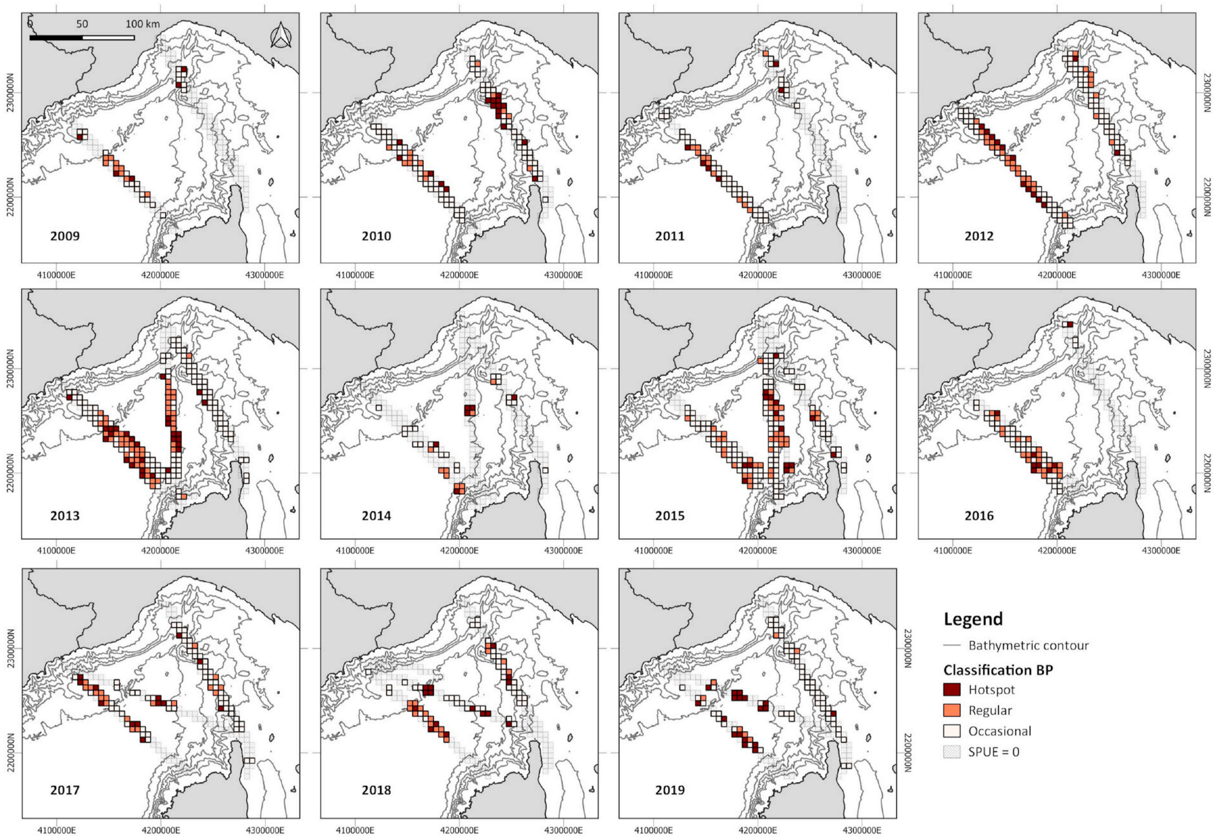

Fig. 2. Hotspot maps of fin whale (BP) across the routes from 2009 to 2019.

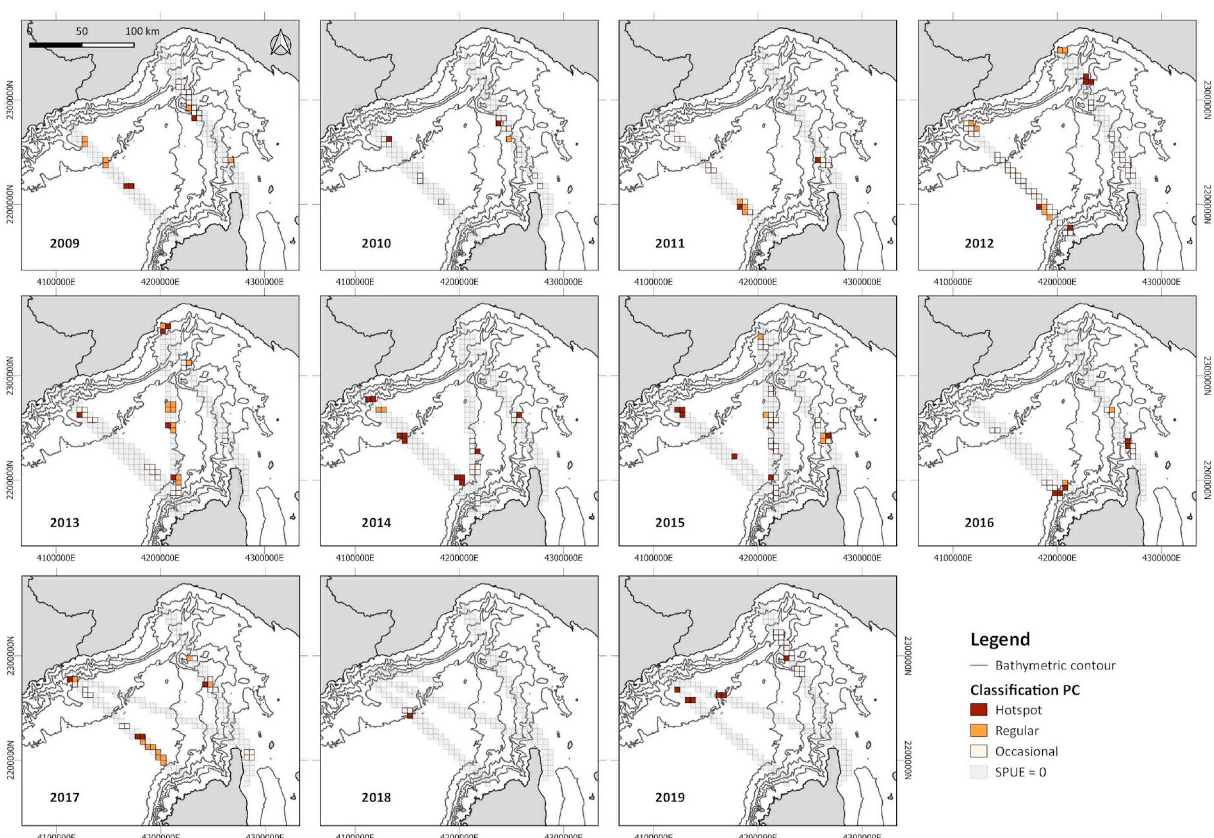

Fig. 3. Hotspot maps of sperm whale (PM) across the routes from 2009 to 2019

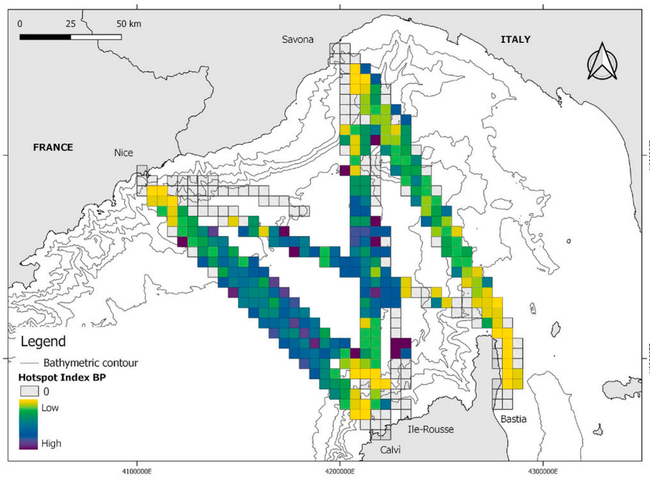

Fig. 4. Persistence map of fin whale (BP) across the routes sampled in 11 years. Values of 0 correspond to absence during the whole period. "Low" and "High" correspond to the lowest and maximum Hotspot Index for the fin whale.

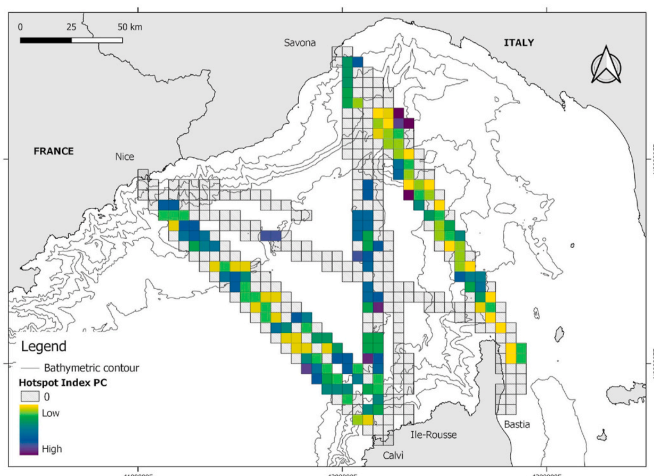

Fig. 5. Persistence map of sperm whale (PM) across the routes sampled in 11 years. Values of 0 correspond to absence during the whole period. "Low" and "High" correspond to the lowest and maximum Hotspot Index for the sperm whale.

Table 4
Summary of best-fitted models. Significance codes: $p < 0.001$ '***', $p < 0.01$ '**', $p < 0.05$ '*'. Bath_mean = bathymetric mean value of the 5 km-cell; dcs = distance from the edge of the continental slope; dsm = distance from the edge of the seamount; SST_sd = climatological SST standard deviation.

FIN WHALE	Estimate	SE	t	p
Intercept	−8.4608338	1.4139994	−5.984	4.97e-09 ***
Bath_mean	−0.0005673	0.0001063	−5.338	1.60e-07 ***
dcs	0.0179927	0.0040437	4.450	1.13e-05 ***
dsm	−0.0047347	0.0015755	−3.005	0.00283 **
SST_sd	3.3701590	0.8369889	4.027	6.81e-05 ***
Deviance explained	*32.2%*			
SPERM WHALE	Estimate	SE	t	p
Intercept	−4.1392600	0.3113253	−13.296	<2e-16 ***
Bath_mean	−0.0007246	0.0001709	−4.240	2.8e-05 ***
dcs	−0.0197318	0.0085275	−2.314	0.0212 *
Deviance explained	*4.85%*			

identifying the western-central area of Pelagos as the main area for the species, and excluding the eastern and shallower area. Here, nevertheless, an area with low persistence is identified off eastern Corsica, confirming what had been shown by other studies in that area (Arcangeli et al., 2013). Highest persistence values are reached in the deepest portion of the basin at the extreme western boundary of the protected area.

4. Discussion

Ferries are widely used as platforms for collecting valuable data on cetaceans (Kiszka et al., 2007; Arcangeli et al., 2012; Morgado et al., 2017; Matear et al., 2019; Robbins et al., 2020; Tepsich et al., 2020), as well as on other marine megafauna (Zampollo et al., 2018; Arcangeli et al., 2019). In this study, the use of such platforms allowed us to collect data on species presence directly along some of the main shipping lanes crossing the Pelagos Sanctuary area. The identification of hotspots areas and above all of areas showing persistent presence of the species over the study period, can be directly translated into an effective assessment of risk of collision with large vessels. In order to deal with the sampling biases arising by the use of ferries, we developed a novel method, based on a strict filtering process aimed to effectively reduce the effect of under-sampling of cells only seldom crossed by the surveys, as well as the over-sampling of the more often surveyed ones. The final presence grids obtained on a yearly basis allowed the identification of yearly occasional, regular and hotspots areas within the traffic corridors.

The majority of traffic in the Pelagos Sanctuary is due to passenger vessels, whereas the proportion of cargo and tanker ships transits are lower compared to the rest of Mediterranean Sea (Coomber et al., 2016). At the same time, the regular routes of ferries constitute a series of maritime corridors between the continent and the islands of Corsica and Sardinia, forming a dense network of traffic within the whole Pelagos Sanctuary (Di-Méglio et al., 2018). Cargo and tanker traffic follows separate corridors, extending the risk of ship strike for both species over more areas. At this end the model we developed aim to map persistent areas of species presence also along corridors not specifically sampled during this study. This represents a first step to identify possible risk corridors, where to address specific investigation.

Our results showed a strong variability in the distribution and quantity of hotspots for both species among the years (Figs. 2 and 3). Fin whale occurrence in the area is known to be affected by a strong interannual variability (Azzellino et al., 2017; Laran et al., 2017; Tepsich et al., 2020), with consequences not only in the number of individuals present (Panigada et al., 2011; Laran et al., 2017) but also the main aggregation areas (Cominelli et al., 2016; Morgado et al., 2017). The species is known to prefer habitat characterized by depths exceeding 2000 m; while the SB corridor is entirely laying over the steep slope and continental shelf areas, the SI/SC, NI/NC and NB corridors all cross a large portion of bathyal plan. As expected then, species cannot be considered as regular along the SB lanes. Still occasional, regular as well as some hotspots are present every year during the summertime. These areas are even more important considering that they are located in areas of intense shipping densities, such as in the canyon outside Savona harbor (hotspots in 2012 and 2016) and the continental shelf area in front of Bastia (occasional in 2013, 2014, 2015, 2017 and 2019). Increasing awareness among ferries and commercial ships crews about species presence along this corridor and especially in relatively unexpected areas, could be a first measure to reduce ship strikes risk. Along the western corridor and namely the NC/NI routes, species presence is regular, with yearly hotspots consistent with species known habitat preferences. Also here, some occasional, regular and hotspots cells are found in correspondence of the Nice (2011, 2012 and 2018) and Calvi/Ile Rousse harbors (in 2013 and 2015).

Concerning the sperm whale, little is known about the interannual variability of species presence in the area, consequently this is one of the few studies showing the distribution pattern of this species over a longer

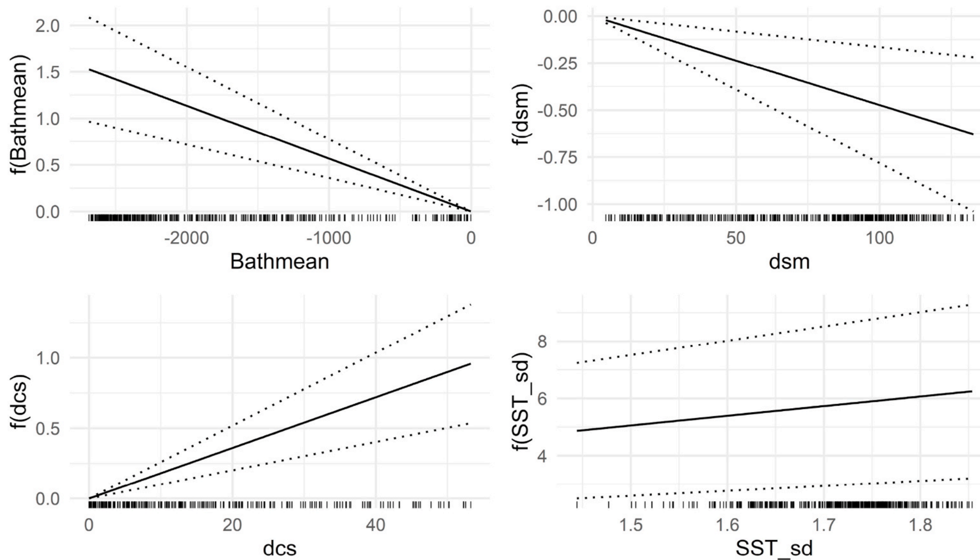

Fig. 6. Model function plots of the final GAM of fin whale (BP). y-axis represents the fitted function. x-axis is in the units of the environmental variable being represented. Bath_mean = bathymetric mean value of the 5 km cell; dcs = distance from the edge of the continental slope; dsm = distance from the edge of the seamount; SST_sd = climatological SST standard deviation.

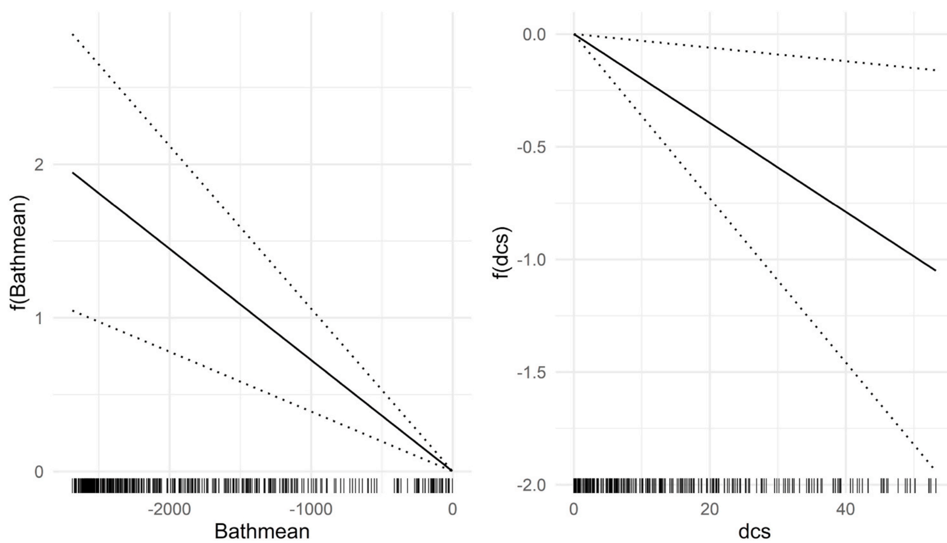

Fig. 7. Model function plots of the final GAM of sperm whale (PM). y-axis represents the fitted function. x-axis is in the units of the environmental variable being represented. Bath_mean = bathymetric mean value of the 5 km cell; dcs = distance from the edge of the continental slope.

timeseries (11 years). Indeed, for this species the perception bias caused by longer diving time affects our ability to catch species presence, especially when using platforms of opportunity, and only visual methods. Nevertheless, species regular as well as hotspots cells in correspondence of the Savona (2012, 2013 and 2015) and Nice (2012, 2014 and 2017) ports indicate the need for direct conservation measures in these areas.

For both species, the highlighted variability stresses the importance of long-term dataset for an effective analysis of presence and distribution. Moreover, it underlines the possible limits of the application of static traffic management schemes, which would not suit the highly dynamic situation evidenced. Nevertheless, dynamic management of maritime traffic is difficult to achieve, and more accurate research should be done to better identify temporal and spatial scales of such variability. In this work we propose the identification of static persistent areas needing priority actions, as an intermediate and complementary action with the dynamic measures. For both species, urgent conservation actions are needed, considering the impact of ship strikes and the conservation status of Mediterranean populations.

Along the SB shipping lanes, the seamount area and surroundings, including the Genoa canyon system, emerges as an important area for both species. This area is also known to be a biodiversity hotspot and already impacted by human activities (Bo et al., 2020). The persistent presence of both species in correspondence of two of the main commercial and touristic ports of Pelagos (Savona and Bastia), where the highest traffic densities are present, points out the presence of important risk areas. Considering that this area is also interested by the other two big traffic corridors for passengers and cargos, one connecting Savona and Genoa to the western part of the basin towards the Atlantic, and the one connecting Genoa with the southern Mediterranean area (Coomber et al., 2016), these shall be identified as a ship strike risk hotspots for Pelagos (Panigada et al., 2006; Di-Méglio et al., 2018). While some measures have already been implemented in the Savona area, such as the installation of a real time automated passive acoustic monitoring

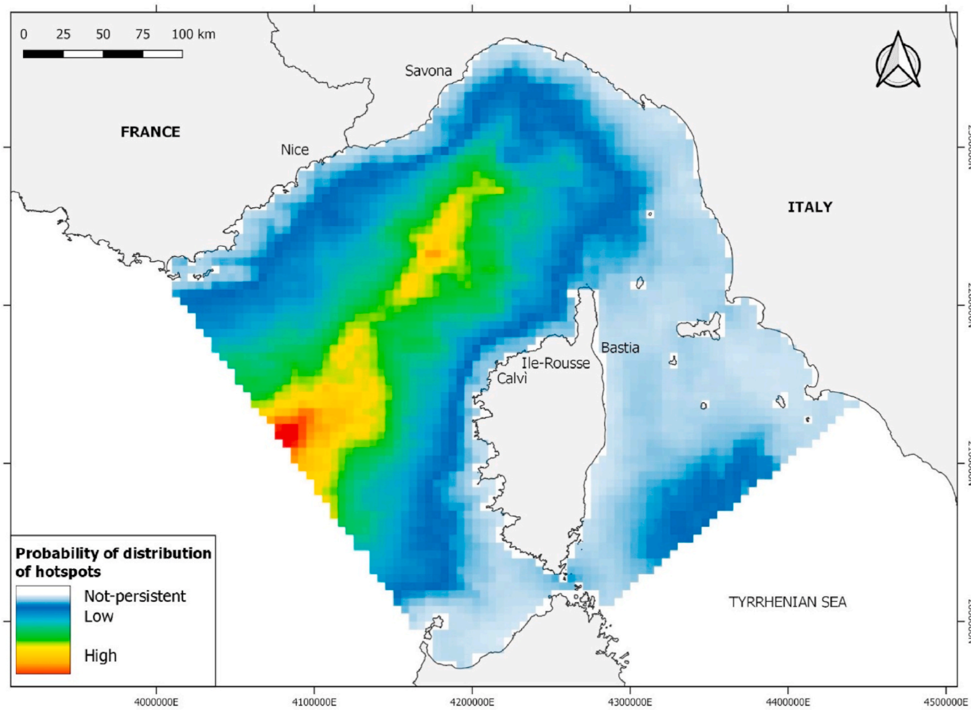

Fig. 8. Map of the probability of distribution of hotspots obtained with the best-model of the fin whale.

system for sperm whale (Sanguineti et al., 2021), no measures have been implemented in the Bastia area. Moreover, a multi-species approach is needed in the area, which demonstrated to be important for the fin whale as well.

Along the NC/NI corridor species persistent presence is generally higher; at the same time, this corridor is specific for passenger ferries (Coomber et al., 2016) and traffic density is lower than in the other corridors. Specific conservation measures, addressing companies navigating in the area could directly help in minimizing ship strike risk. As an example, training courses on ship strike risk for crews or the presence on board of marine mammal observers (Flynn and Calambokidis, 2019). These considerations well apply also to the SC/SI and NB corridors, with the exception of the northern part of the SC/SI corridor which lays in the high-risk area previously evidenced.

Results obtained by both models, well agree with the known habitat preferences already evidenced for both species in the area. Specifically, bathymetric features were extremely significant in predicting species persistent areas with preference for the deepest portion of the basin (Moulins et al., 2008; Panigada et al., 2008; Aïssi et al., 2015; Morgado et al., 2017). Despite the lower power of the sperm whale model, our results still catch the known bimodal distribution for the species, highlighting the importance of both deeper areas as well as the areas of the steep slope closer to the continental shelf (Gordon et al., 2000; Gannier et al., 2002a; Tepsich et al., 2014). For the fin whale, the model is also capable of identifying an area outside coverage of our surveys, specifically the area eastern of northern Sardinia. There, a cyclonic gyre known as the Bonifacio gyre (Artale et al., 1994) generates an intermittent bloom region, as evidenced by D'Ortenzio and Ribera d'Alcalà (2008), resulting in an area where fin whales are present, according to a strong interannual variability (Arcangeli et al., 2013). Oceanographic features did not result significant, exception for the climatological SST standard deviation for the fin whale, which indicates a preference for more dynamic areas. The lower power of oceanographic/dynamic variables is probably due to the aggregated values used in the analysis, which then do not allow to catch differences arising from intra-seasonal and interannual variability in oceanographic conditions. Nevertheless, the prediction is in line with results obtained applying satellite telemetry data (Cotte et al., 2011; Panigada et al., 2017), and habitat model which consider dynamic variables at smaller spatial and temporal scales (Panigada et al., 2005; Laran and Gannier, 2008; Druon et al., 2012; Laran et al., 2012).

Our aim in modelling persistent areas was to provide a tool for an early assessment of risk collision areas, looking at the main traffic corridors present in the Pelagos Sanctuary. Our results highlight persistent areas for the species where, when crossed by traffic corridor, specific conservation actions, should be implemented. The western area is more interested by traffic from mainland France to Corsica. The French decree of the March 8, 2017 (Décret, 2017) requires the mandatory use of systems to signal in real time the presence of cetaceans in the PELAGOS sanctuary. This is the only conservation action currently in act in the area and only by vessels flying the French flag. Though main traffic along those routes is probably due to French maritime companies, that area is also crossed by corridors (passengers and commercials) connecting the Italian port of Genoa and Savona to southern Mediterranean. Some Italian companies have decided to voluntarily equip their vessels with a system to signal cetacean presence and this conservation measure has been recently integrated in the Marine Strategy Directive Framework by Italy (DPCM 10 ottobre, 2017). Given the importance of the area for both species the use of such systems should be advisable for all vessels navigating in the area, regardless the nationality.

Our study enhances the necessity of an integrated risk assessment strategy, based on long term dataset and which should take into account a multi species approach as well as the integration of static and dynamic measures.

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.ocecoaman.2021.105820.

References

Agardy, T., Aguilar, N., Cañadas, A., Engel, M., Frantzis, A., Hatch, L., Hoyt, E., et al., 2007. A Global Scientific Workshop on Spatio-Temporal Management of Noise. Management: 22–25. http://www.cetaceanhabitat.org/pdf_bin/dokumentedesmeeres_report_eng_final_amended_v2.pdf.

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. J. Mar. Biol. Assoc. U. K. 88, 1253–1261. https://www.cambridge.org/core/product/identifier/S0025315408000891/type/journal_article.

Aïssi, M., Arcangeli, A., Crosti, R., Daly Yahia, M.N., Loussaief, B., Moulins, A., Pellegrino, G., et al., 2015. Cetacean occurrence and spatial distribution in the central Mediterranean Sea using ferries as platform of observation. Russ. J. Mar. Biol. 41, 343–350.

Arcangeli, A., Tepsich, P., Crosti, R., 2012. A Fixed Line Transect Network to Monitor Cetacean Diversity in Central-Western Mediterranean Sea A Fixed Line Transect Network to Monitor Cetacean Diversity in Central-Western Mediterranean Sea.

Arcangeli, A., Marini, L., Crosti, R., 2013. Changes in cetacean presence, relative abundance and distribution over 20 years along a trans-regional fixed line transect in the Central Tyrrhenian Sea. Mar. Ecol. 34, 112–121.

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. Freshw. Ecosyst. 27, 995–1010.

Arcangeli, A., Maffucci, F., Atzori, F., Azzolin, M., Campana, I., Carosso, L., Crosti, R., et al., 2019. Turtles on the trash track: loggerhead turtles exposed to floating plastic in the Mediterranean Sea. Endanger. Species Res. 40, 107–121. https://www.int-res.com/abstracts/esr/v40/p107-121/.

Artale, V., Astraldi, M., Buffoni, G., Gasparini, G.P., 1994. Seasonal variability of gyre-scale circulation in the northern Tyrrhenian Sea. J. Geophys. Res. 99.

Astraldi, M., Bianchi, C.N., Gasparini, G. Pietro, Morri, C., 1995. Climatic fluctuations, current variability and marine species distribution : a case study in the Ligurian Sea (north-west Mediterranean). Oceanologica Acta, pp. 139–149. https://www.semanticscholar.org/paper/Climatic-fluctuations%2C-current-variability-and-%3A-a-Astraldi-Bianchi/cb511d10e3ba2620774c0d7d9c811ad0949fe4b3/figure/0.

Azzellino, A., Panigada, S., Lanfredi, C., Zanardelli, M., Airoldi, S., Notarbartolo di Sciara, G., 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. https://doi.org/10.1016/j.ocecoaman.2012.05.024. Elsevier Ltd.

Azzellino, A., Airoldi, S., Lanfredi, C., Podestà, M., Zanardelli, M., 2017. Cetacean response to environmental and anthropogenic drivers of change: results of a 25-year distribution study in the northwestern Mediterranean Sea. Deep Sea Res. Part II Top. Stud. Oceanogr. 146, 104–117. https://linkinghub.elsevier.com/retrieve/pii/S0967064517300383.

Becker, E.A., Forney, K.A., Fiedler, P.C., Barlow, J., Chivers, S.J., Edwards, C.A., Moore, A.M., et al., 2016. Moving towards dynamic ocean management: how well do modeled ocean products predict species distributions? Rem. Sens. 8, 149. https://www.mdpi.com/2072-4292/8/2/149.

Becker, E.A., Carretta, J.V., Forney, K.A., Barlow, J., Brodie, S., Hoopes, R., Jacox, M.G., et al., 2020. Performance evaluation of cetacean species distribution models developed using generalized additive models and boosted regression trees. In: Ecology and Evolution: Ece3, vol. 6316. https://onlinelibrary.wiley.com/doi/abs/10.1002/ece3.6316.

Bo, M., Coppari, M., Betti, F., Massa, F., Gay, G., Cattaneo-Vietti, R., Bavestrello, G., 2020. Unveiling the deep biodiversity of the janua seamount (Ligurian sea): first mediterranean sighting of the rare Atlantic bamboo coral chelidonisis aurantiaca studer, 1890. Deep-Sea Research Part I: Oceanographic Research Papers, 156: 103186. Elsevier Ltd. https://doi.org/10.1016/j.dsr.2019.103186.

Bricaud, A., Bosc, E., Antoine, D., 2002. Algal biomass and sea surface temperature in the Mediterranean Basin: intercomparison of data from various satellite sensors, and implications for primary production estimates. Rem. Sens. Environ. 81, 163–178. http://www.sciencedirect.com/science/article/pii/S0034425701003352.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction To Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press.

Campana, I., Crosti, R., Angeletti, D., Carosso, L., David, L., Di-Méglio, N., Moulins, A., et al., 2015. Cetacean response to summer maritime traffic in the Western Mediterranean Sea. Mar. Environ. Res. 109, 1–8. https://linkinghub.elsevier.com/retrieve/pii/S0141113615000768.

Campana, I., Angeletti, D., Crosti, R., Luperini, C., Ruvolo, A., Alessandrini, A., Arcangeli, A., 2017. Seasonal characterisation of maritime traffic and the relationship with cetacean presence in the Western Mediterranean Sea. Mar. Pollut. Bull. 115, 282–291. Elsevier Ltd. https://linkinghub.elsevier.com/retrieve/pii/S0025326X1630995X.

Carpinelli, E., Gauffier, P., Verborgh, P., Airoldi, S., David, L., Di-Méglio, N., Cañadas, A., et al., 2014. Assessing sperm whale (Physeter macrocephalus) movements within the western Mediterranean Sea through photo-identification. Aquat. Conserv. Mar. Freshw. Ecosyst. 24, 23–30.

Casella, E., Tepsich, P., Couvelard, X., Caldeira, R.M.A., Schroeder, K., 2014. Ecosystem dynamics in the Liguro-Provençal Basin: the role of eddies in the biological production. Mediterr. Mar. Sci. 15, 274–286 (Hellenic Centre for Marine Research).

Cates, K., Brownell, R., Silber, G., Ritter, F., Cates, K., Demaster, D.P., Brownell, R.L., et al., 2017. Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations: 2017-2020. Accessed 22 February 2021. https://www.researchgate.net/publication/332539367.

Claro, B., Pérez-Jorge, S., Frey, S., 2020. Seafloor geomorphic features as an alternative approach into modelling the distribution of cetaceans. Ecol. Inf. 58, 101092. https://linkinghub.elsevier.com/retrieve/pii/S157495412030042X.

Cominelli, S., Moulins, A., Rosso, M., Tepsich, P., 2016. Fin whale seasonal trends in the Pelagos sanctuary, Mediterranean Sea. J. Wildl. Manag. 80, 490–499. https://doi.org/10.1002/jwmg.1027.

Coomber, F.G., D'Incà, M., Rosso, M., Tepsich, P., Notarbartolo di Sciara, G., 2016. Description of the vessel traffic within the north Pelagos sanctuary: inputs for marine spatial planning and management implications within an existing international marine protected area. Mar. Pol. 69, 102–113. https://linkinghub.elsevier.com/retrieve/pii/S0308597X16301853.

Correia, A.M., Tepsich, P., Rosso, M., Caldeira, R., Sousa-Pinto, I., 2015. Cetacean occurrence and spatial distribution: habitat modelling for offshore waters in the Portuguese EEZ (NE Atlantic). J. Mar. Syst. 143, 73–85. https://doi.org/10.1016/j.jmarsys.2014.10.016. Elsevier B.V.

Cotte, C., d'Ovidio, F., Chaigneau, A., Lèvy, M., Taupier-Letage, I., Mate, B., Guinet, C., 2011. Scale-dependent interactions of Mediterranean whales with marine dynamics. Limnol. Oceanogr. 56, 219–232. http://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lo.2011.56.1.0219.

Cotté, C., Guinet, C., Taupier-Letage, I., Mate, B., Petiau, E., 2009. Scale-dependent habitat use by a large free-ranging predator, the Mediterranean fin whale. Deep Sea Res. Oceanogr. Res. Pap. 56, 801–811. https://linkinghub.elsevier.com/retrieve/pii/S0967063708002501.

Cribb, N., Miller, C., Seuront, L., 2015. Towards a standardized approach of cetacean habitat: past Achievements and future directions. Open J. Mar. Sci. 5, 335–357. https://doi.org/10.4236/ojms.2015.53028.

D'Ortenzio, F., Ribera d'Alcalà, M., 2008. On the trophic regimes of the Mediterranean Sea: a satellite analysis. Biogeosci. Discuss. 5, 2959–2983.

David, L., Alleaume, S., Guinet, C., 2011. Evaluation of the potential of collision between fin whales and maritime traffic in the north-western Mediterranean Sea in summer, and mitigation solutions, 4, 17–28.

Décret n° 2017-300 du 8 mars 2017 relatif aux dispositifs de partage des positions visant à éviter les collisions des navires avec les cétacés dans les aires marines protégées Pelagos (Méditerranée) et Agoa (Antilles).

Di-Méglio, N., David, L., Monestiez, P., 2018. Sperm whale ship strikes in the Pelagos Sanctuary and adjacent waters: assessing and mapping collision risks in summer. J. Cetacean Res. Manag. 18, 13.

DPCM 10 ottobre, 2017. Implementazione di soluzioni tecniche (metodologiche e strumentali) per la riduzione delle collisioni con i cetacei" nell'ambito del Programma Nazionale di Misure della Strategia Marina.

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

Estrada, M., 1996. Primary production in the northwestern Mediterranean. Sci. Mar. 60, 55–64.

Flynn, K.R., Calambokidis, J., 2019. Lessons from placing an observer on commercial cargo ships off the U.S. West Coast: utility as an observation platform and insight into ship strike vulnerability. Frontiers in Marine Science 6, 501. Frontiers Media S. A. https://www.frontiersin.org/article/10.3389/fmars.2019.00501/full.

Forcada, J., Notarbartolo Di Sciara, G., Fabbri, F., 1995. Abundance of fin whales and striped dolphins summering in the Corso-Ligurian Basin. Mammalia 59. https://www.degruyter.com/view/j/mamm.1995.59.issue-1/mamm.1995.59.1.127/mamm.1995.59.1.127.xml.

Foskolos, I., Koutouzi, N., Polychronidis, L., Alexiadou, P., Frantzis, A., 2020. A taste for squid: the diet of sperm whales stranded in Greece, Eastern Mediterranean. In: Deep Sea Research Part I: Oceanographic Research Papers, vol. 155. Elsevier Ltd, p. 103164. https://doi.org/10.1016/j.dsr.2019.103164.

Gannier, A., Drouot, V., Goold, J., 2002a. Distribution and relative abundance of sperm whales in the Mediterranean Sea. Mar. Ecol. Prog. Ser. 243, 281–293. http://www.int-res.com/abstracts/meps/v243/p281-293/.

Gannier, A., Drouot, V., Goold, J., 2002b. Distribution and relative abundance of sperm whales in the Mediterranean Sea. Mar. Ecol. Prog. Ser. 243, 281–293. Inter-Research. http://www.int-res.com/abstracts/meps/v243/p281-293/.

Gannier, A., Petiau, E., Dulau, V., Rendell, L., 2012. Foraging dives of sperm whales in the north-western Mediterranean Sea. J. Mar. Biol. Assoc. U. K. 92, 1799–1808. htt

ps://www.cambridge.org/core/product/identifier/S0025315412001087/type/journal_article.
García, L.G., Pierce, G.J., Autret, E., Torres-Palenzuela, J.M., 2018. Multi-scale habitat preference analyses for azorean blue whales. PloS One 13, 1–25.
Geijer, C.K.A., Sciara, G. N. di, Panigada, S., 2016. Mysticete migration revisited: are Mediterranean fin whales an anomaly? Mamm Rev. 46, 284–296. http://onlinelibrary.wiley.com/doi/abs/10.1111/mam.12069.
Gordon, J.C.D., Matthews, J.N., Panigada, S., Gannier, A., Borsani, J.F., Notarbartolo di Sciara, G., 2000. Distribution and relative abundance of striped dolphins, and distribution of sperm whales in the Ligurian Sea cetacean sanctuary: results from a collaboration using acoustic monitoring techniques. J. Cetacean Res. Manag. 2, 27–36. http://www.disciara.net/downloads/Gordon_etal_2000.pdf.
Gormley, K.S.G., Porter, J.S., Bell, M.C., Hull, A.D., Sanderson, W.G., 2013. Predictive habitat modelling as a tool to assess the change in distribution and extent of an OSPAR priority habitat under an increased ocean temperature scenario: consequences for marine protected area networks and management. PloS One 8, e68263. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0068263.
Gregr, E.J., Trites, A.W., 2001. Predictions of critical habitat for five whale species in the waters of coastal British Columbia. Can. J. Fish. Aquat. Sci. 58, 1265–1285. http://www.nrcresearchpress.com/doi/10.1139/f01-078.
Ham, G.S., Lahaye, E., Rosso, M., Moulins, A., Hines, E., Tepsich, P., 2021. Predicting summer fin whale distribution in the Pelagos Sanctuary (northwestern Mediterranean Sea) to identify dynamic whale-vessel collision risk areas. Aquat. Conserv. Mar. Freshw. Ecosyst. 1–21.
Hastie, T., Tibshirani, R., 1986. Generalized additive models. Stat. Sci. 1, 297–310. Institute of Mathematical Statistics. http://projecteuclid.org/euclid.ss/1177013604.
Jensen, A.S., Silber, G.K., Calambokidis, C.J., Campbell, C., Cordaro, J., Deiter, R., Ewald, C., et al., 2004. Large Whale Ship Strike Database. Accessed 15 February 2021. http://www.nmfs.noaa.gov/pr/overview/publicat.html.
Keen, E.M., Scales, K.L., Rone, B.K., Hazen, E.L., Falcone, E.A., Schorr, G.S., 2019. Night and day: diel differences in ship strike risk for fin whales (balaenoptera physalus) in the California current system. Frontiers in Marine Science 6. https://www.frontiersin.org/articles/10.3389/fmars.2019.00730/full.
Kiszka, J., Macleod, K., Van Canneyt, O., Walker, D., Ridoux, V., 2007. Distribution, encounter rates, and habitat characteristics of toothed cetaceans in the Bay of Biscay and adjacent waters from platform-of-opportunity data. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 64, 1033–1043. Oxford University Press. https://academic.oup.com/icesjms/article/64/5/1033/641915.
Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., Podesta, M., 2001. Collisions between ships and whales. Mar. Mamm. Sci. 17, 35–75. http://onlinelibrary.wiley.com/doi/abs/10.1111/j.1748-7692.2001.tb00980.x.
Laran, S., Gannier, A., 2008. Spatial and temporal prediction of fin whale distribution in the northwestern Mediterranean Sea. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 65, 1260–1269. https://academic.oup.com/icesjms/article-lookup/doi/10.1093/icesjms/fsn086.
Laran, S., Delacourtie, F., Fulvio, T.D.I., David, L., Di-Meglio, N., Monestiez, P., 2012. Synthèse sur la distribution des cétacés dans le Sanctuaire PELAGOS et les eaux adjacentes, mise en relation avec leur environnement. Scientific Reports of Port-Cros national Park 26, 119–147.
Laran, S., Pettex, E., Authier, M., Blanck, A., David, L., Dorémus, G., Falchetto, H., et al., 2017. Seasonal distribution and abundance of cetaceans within French waters- Part I: the North-Western Mediterranean, including the Pelagos sanctuary. Deep Sea Res. Part II Top. Stud. Oceanogr. 141, 20–30. Elsevier Ltd. https://linkinghub.elsevier.com/retrieve/pii/S096706451630409X.
Matear, L., Robbins, J.R., Hale, M., Potts, J., 2019. Cetacean biodiversity in the Bay of Biscay: suggestions for environmental protection derived from citizen science data. Mar. Pol. 109, 103672 (Elsevier Ltd).
Morgado, C., Martins, A., Rosso, M., Moulins, A., Tepsich, P., 2017. Fin whale presence and distribution in the Pelagos sanctuary: temporal and spatial variability along 2 fixed-line transects monitored in 2009-2013. International Journal of Marine and Environmental Sciences 1, 1–14.
Moulins, A., Rosso, M., Würtz, M., Provenzale, A., 2005. Cetacean habitat in the Ligurian sea. 15th Meeting of the Italian Society of Ecology.
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. J. Mar. Biol. Assoc. U. K. 88, 1273–1281.
Nichol, L., Wright, B., O'Hara, P., Ford, J., 2017. Risk of lethal vessel strikes to humpback and fin whales off the west coast of Vancouver Island, Canada. Endanger. Species Res. 32, 373–390. http://www.int-res.com/abstracts/esr/v32/p373-390/.
Notarbartolo-di-Sciara, G., Agardy, T., Hyrenbach, D., Scovazzi, T., Van Klaveren, P., 2008. The Pelagos sanctuary for mediterranean marine mammals. Aquat. Conserv. Mar. Freshw. Ecosyst. 18, 367–391. https://doi.org/10.1002/aqc.855.
Orsi Relini, L., Cappello, M., 1992. The fin whale and other large pelagic filters as samplers of Meganyctiphanes norvegica. Rapport des Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée 33, 263.
Panigada, S., Notarbartolo di Sciara, G., Zanardelli Panigada, M., 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, 10. https://cetaceanalliance.org/download/literature/Panigada_etal_2005.pdf.
Panigada, S., Pesante, G., Zanardelli, M., Capoulade, F., Gannier, A., Weinrich, M.T., 2006. Mediterranean fin whales at risk from fatal ship strikes. Mar. Pollut. Bull. 52, 1287–1298. https://linkinghub.elsevier.com/retrieve/pii/S0025326X06001238.
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. Rem. Sens. Environ. 112, 3400–3412. http://www.sciencedirect.com/science/article/pii/S0034425708001375.
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, e22878. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0022878.
Panigada, S., Donovan, G.P., Druon, J.-N., Lauriano, G., Pierantonio, N., Pirotta, E., Zanardelli, M., et al., 2017. Satellite tagging of Mediterranean fin whales: working towards the identification of critical habitats and the focussing of mitigation measures. Sci. Rep. 7. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5469747/.
Pearce, J., Ferrier, S., 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecol. Model. 133, 225–245. http://www.sciencedirect.com/science/article/pii/S0304380000003227.
Peltier, H., Beaufils, A., Cesarini, C., Dabin, W., Dars, C., Demaret, F., Dhermain, F., et al., 2019. Monitoring of marine mammal strandings along French coasts reveals the importance of ship strikes on large cetaceans: a challenge for the European marine strategy framework directive. Frontiers in Marine Science 6, 486. https://www.frontiersin.org/article/10.3389/fmars.2019.00486/full.
Pennino, M.G., Arcangeli, A., Prado Fonseca, V., Campana, I., Pierce, G.J., Rotta, A., Bellido, J.M., 2017. A spatially explicit risk assessment approach: cetaceans and marine traffic in the Pelagos Sanctuary (Mediterranean Sea). PloS One 12, e0179686. https://dx.plos.org/10.1371/journal.pone.0179686.
Pirotta, E., Matthiopoulos, J., MacKenzie, M., Scott-Hayward, L., Rendell, L., 2011. Modelling sperm whale habitat preference: a novel approach combining transect and follow data. Mar. Ecol. Prog. Ser. 436, 257–272. http://www.int-res.com/abstracts/meps/v436/p257-272/.
Pirotta, E., Brotons, J.M., Cerdà, M., Bakkers, S., Rendell, L.E., 2020. Multi-scale analysis reveals changing distribution patterns and the influence of social structure on the habitat use of an endangered marine predator, the sperm whale Physeter macrocephalus in the Western Mediterranean Sea. Deep Sea Res. Oceanogr. Res. Pap. 155, 103169. https://linkinghub.elsevier.com/retrieve/pii/S0967063719303152.
Prieto, R., Tobeña, M., Silva, M.A., 2017. Habitat preferences of baleen whales in a mid-latitude habitat. Deep Sea Res. Part II Top. Stud. Oceanogr. 141, 155–167. https://doi.org/10.1016/j.dsr2.2016.07.015. Elsevier Ltd.
Redfern, J., Ferguson, M., Becker, E., Hyrenbach, D., Good, C., Barlow, J., Kaschner, K., et al., 2006. Techniques for cetacean-habitat modeling. Mar. Ecol. Prog. Ser. 310, 271–295. https://www.researchgate.net/publication/223145282_Techniques_for_cetacean-habitat_modeling.
Redfern, J.V., McKenna, M.F., Moore, T.J., Calambokidis, J., Deangelis, M.L., Becker, E. A., Barlow, J., et al., 2013. Assessing the risk of ships striking large whales in marine spatial planning. Conserv. Biol. 27, 292–302.
Ritter, F., Panigada, S., 2019. Collisions of vessels with cetaceans-the underestimated threat. World Seas: an Environmental Evaluation Volume III: Ecological Issues and Environmental Impacts. Elsevier, pp. 531–547.
Robbins, J.R., Babey, L., Embling, C.B., 2020. Citizen science in the marine environment: estimating common dolphin densities in the north-east Atlantic. PeerJ, 2020: e8335. PeerJ Inc. https://peerj.com/articles/8335.
Sanguineti, M., Alessi, J., Brunoldi, M., Cannarile, G., Cavalleri, O., Cerruti, R., Falzoi, N., et al., 2021. An automated passive acoustic monitoring system for real time sperm whale (Physeter macrocephalus) threat prevention in the Mediterranean Sea. Appl. Acoust. 172, 107650 (Elsevier Ltd).
Santora, J., Veit, R., 2013. Spatio-temporal persistence of top predator hotspots near the Antarctic Peninsula. Mar. Ecol. Prog. Ser. 487, 287–304. http://www.int-res.com/abstracts/meps/v487/p287-304/.
Santora, J.A., Sydeman, W.J., Schroeder, I.D., Wells, B.K., Field, J.C., 2011. Mesoscale structure and oceanographic determinants of krill hotspots in the California Current: implications for trophic transfer and conservation. Prog. Oceanogr. 91, 397–409. http://www.sciencedirect.com/science/article/pii/S0079661111000371.
Santora, J.A., Schroeder, I.D., Loeb, V.J., 2014. Spatial assessment of fin whale hotspots and their association with krill within an important Antarctic feeding and fishing ground. Mar. Biol. 161, 2293–2305. http://link.springer.com/10.1007/s00227-014-2506-7.
Schleimer, A., Ramp, C., Plourde, S., Lehoux, C., Sears, R., Hammond, P., 2019. Spatio-temporal patterns in fin whale Balaenoptera physalus habitat use in the northern Gulf of St. Lawrence. Mar. Ecol. Prog. Ser. 623, 221–234. https://www.int-res.com/abstracts/meps/v623/p221-234/.
Smith, J.N., Kelly, N., Childerhouse, S., Redfern, J.V., Moore, T.J., Peel, D., 2020. Quantifying ship strike risk to breeding whales in a multiple-use marine park: the great barrier reef. Frontiers in Marine Science 7. https://www.frontiersin.org/articles/10.3389/fmars.2020.00067/full?utm_source=S-TWT&utm_medium=SNET&utm_campaign=ECO_FMARS_XXXXXXXX_auto-dlvrit.
Suryan, R., Santora, J., Sydeman, W., 2012. New approach for using remotely sensed chlorophyll a to identify seabird hotspots. Mar. Ecol. Prog. Ser. 451. http://www.int-res.com/abstracts/meps/v451/p213-225/.
Tepsich, P., Rosso, M., Halpin, P., Moulins, A., 2014. Habitat preferences of two deep-diving cetacean species in the northern Ligurian Sea. Mar. Ecol. Prog. Ser. 508, 247–260. http://www.int-res.com/abstracts/meps/v508/p247-260/.
Tepsich, P., Schettino, I., Atzori, F., Azzolin, M., Campana, I., Carosso, L., Cominelli, S., et al., 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. https://doi.org/10.7717/peerj.10544. PeerJ Inc.
Vaes, T., Druon, J.N., 2013. Mapping of Potential Risk of Ship Strike with Fin Whales in the Western Mediterranean Sea: A Scientific and Technical Review Using the Potential Habitat of Fin Whales and the Effective Vessel Density, p. 28.

Vanderlaan, A.S.M., Taggart, C.T., 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Mar. Mamm. Sci. 23, 144–156.

Williams, R., O'Hara, P., 2009. Modelling ship strike risk to fin, humpback and killer whales in British Columbia, Canada. J. Cetacean Res. Manag. 11, 1–8.

Winkler, C., Panigada, S., Murphy, S., Ritter, F., 2020. Global numbers of ship strikes: an assessment of collisions between vessels and cetaceans using available data in the IWC ship strike database, 34. IWC Scientific Committee.

Wood, S.N., 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J. Roy. Stat. Soc. B 73, 3–36. https://doi.org/10.1111/j.1467-9868.2010.00749.x.

Yurkowski, D.J., Auger-Méthé, M., Mallory, M.L., Wong, S.N.P., Gilchrist, G., Derocher, A.E., Richardson, E., et al., 2019. Abundance and species diversity hotspots of tracked marine predators across the North American Arctic. Divers. Distrib. 25, 328–345. https://doi.org/10.1111/ddi.12860.

Zampollo, A., Azzolin, M., Arcangeli, A., Buoninsegni, J., Paraboschi, M., Crosti, R., Mancino, C., et al., 2018. Employing ferry as platform of observation for monitoring Loggerhead sea turtle (Caretta caretta) distribution in the Adriatic-Ionian Region. In: 2018 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea), pp. 140–144. IEEE. https://ieeexplore.ieee.org/document/8657883/.