

Sperm whale ship strikes in the Pelagos Sanctuary and adjacent waters: assessing and mapping collision risks in summer

NATHALIE DI-MÉGLIO^{1,2}, LÉA DAVID^{1,2} AND PASCAL MONESTIEZ³

Contact e-mail: nathalie.di-meglio@wanadoo.fr

ABSTRACT

Collisions with large vessels potentially present a major conservation issue for sperm whales in the Pelagos Sanctuary in the northwestern Mediterranean Sea. The exact numbers and locations of ship strikes remain largely unknown at present. In this study, sightings of sperm whales in summer (June–September) were gathered for the period between 1998 and 2008 from nine French and Italian organisations, together covering an area of more than 68,000 km². Working on a regular grid of 0.1° × 0.1° latitude/longitude cells, approximate surface density of the whales was calculated using kriging methods. A database of shipping lanes of ferries and merchant vessels was assembled, and traffic density was mapped (kilometres travelled per cell). The data was overlaid and multiplied, using ArcGIS, to create a relative density surface map of sperm whales correlated with the relative density of maritime traffic. Several maps of collision risk were drawn up according to the speed class of the vessels. Of living animals that had been photo-identified, 9% had scars attributed to ship strike. Results show that sperm whales are at high risk from merchant vessels along the French and Italian continental coasts and at risk from conventional ferries on the east side of the islands of Corsica and Sardinia. It was calculated that 74 animals could be in a ship strike risk situation during the summer period in the Pelagos Sanctuary. Based on these results, mitigation measures already in place were reviewed and new measures to reduce ship strike risk are suggested.

KEYWORDS: SPERM WHALE; MEDITERRANEAN SEA; SHIP STRIKE; MODELLING; DISTRIBUTION; MARINE PROTECTED AREA

INTRODUCTION

The sperm whale (*Physeter macrocephalus*) is one of eight common species of cetaceans living in the Mediterranean Sea. Genetic analyses suggest that these sperm whales are a semi-isolated subpopulation (Drouot, 2004; Engelhaupt *et al.*, 2009). At least partial residency is confirmed by a recent study (Carpinelli *et al.*, 2014) based on mark-recapture from photography, which shows the absence of any photographic recaptures of sperm whales between the Mediterranean Sea and the North Atlantic Ocean. At present, there are no overall abundance estimates for the Mediterranean subpopulation, but it is believed to contain fewer than 2,500 mature individuals and is considered as ‘endangered’ based on IUCN Red List criteria (Notarbartolo di Sciara and Birkun, 2010; Notarbartolo di Sciara *et al.*, 2013). Recent aerial survey results lead to an estimate of less than 450 individuals for the northwestern Mediterranean Sea (Laran *et al.*, 2017).

In summer, group size of sperm whales in the northern part of the Western Basin is on average 1.3 to 2.6 individuals (Di-Méglio and David, 2008; Drouot *et al.*, 2004; Laran and Gannier, 2006) whereas it is larger at an average of 3.4 individuals in the southern part (Drouot *et al.*, 2004). This difference could possibly indicate a greater dispersion of the animals in the northern part in order to make best possible use of the trophic resources available (Jaquet and Gendron, 2002). However, contrary to the results of Drouot *et al.* (2004) which show that females and calves are more often seen in the southern part (around the Balearic Islands) and solitary males in the northern part, recent encounters with large schools (including calves) have occurred each year in the northern part of the Western Basin (Di-Méglio and David, 2008; Laran and Gannier, 2006; Laran *et al.*, 2010;

Moulins and Würtz, 2005). These sightings were mainly made in the international Pelagos Sanctuary. The sanctuary was created in 2002 by France, Italy and Monaco to support the protection of marine mammals by promoting regional research and management measures. Sperm whales in the region are known to inhabit mainly continental-slope waters and some offshore areas (Laran *et al.*, 2012; Praca *et al.*, 2009). They are particularly abundant in areas such as the Gulf of Lion, the Balearic Sea and the Ligurian-Provençal Sea (Gannier *et al.*, 2002; Laran *et al.*, 2012).

One of the growing threats to the sperm whale in the Mediterranean Sea is ship strike. Collisions between large commercial vessels and large cetaceans can have a considerable impact on these animals (David, 2002; Di-Méglio *et al.*, 2010). Of the 11 species recognised as at risk of collisions worldwide (Jensen and Silber, 2003; Van Waerebeek *et al.*, 2007), the fin whale is most frequently struck, followed by the humpback whale, the right whale, and the sperm whale (Van Waerebeek and Leaper, 2008). The Mediterranean Sea is one of the areas where the most collisions with large cetaceans occur (Laist *et al.*, 2001).

Between 1972 and 2001, Panigada *et al.* (2006) estimated that 27 to 40 fin whales may be killed every year by collisions in the western basin (for a population of about 3,500 individuals); this could be responsible for an annual increase of 19.1% in the mortality of the Mediterranean fin whale. Regarding sperm whales, according to Panigada and Leaper (2010), at least 70% of carcasses stranded on the Greek coast between 1997 and 2007 presented obvious marks of collision with large ships. This is a major problem in Greece, where many social groups of sperm whales are present, rather close to shore (Frantzis *et al.*, 2003).

¹ EcoOcéan Institut, 18 rue des Hospices 34090 Montpellier, France.

² GIS3M, «Le Kalliste» bât. B4, 1 avenue. Clément Monnier 13960 Sausset les Pins, France.

³ INRA, Unité Biostatistique et Processus Spatiaux, Domaine St Paul, Site Agroparc, 84914 Avignon Cedex 9, France.

Several authors (Panigada and Leaper, 2010; Panigada *et al.*, 2006) note that in the Mediterranean Sea ship strikes could seriously threaten the population of sperm whales, which is already considered as 'endangered' by the IUCN (Notarbartolo di Sciara *et al.*, 2012). Indeed, this Mediterranean population, semi-isolated genetically (Drouot *et al.*, 2004; Engelhaupt *et al.*, 2009), appears to have declined over the last half-century (Notarbartolo di Sciara *et al.*, 2012), mainly due to bycatch in pelagic driftnets (Reeves and Notarbartolo di Sciara, 2006) but also to ship strikes (Di-Méglio *et al.*, 2010).

The Mediterranean sea is a high-density maritime traffic area. Every year, 220,000 ships greater than 100 tons cross the Mediterranean basin and approximately 30% of international sea-borne traffic volume originates from or is directed towards the 300 ports in the Mediterranean Sea. These values are expected to grow three or four-fold within the next 20 years (Dobler, 2002). Furthermore, a total of over 9,000 vessels, including ferries, fast ferries and hydrofoils, as well as military, fishing, pleasure and whale watching boats, navigate the waters of the Western Basin daily (SCOT, 2004).

The Pelagos Sanctuary, in particular, seems to be a high-risk area for collisions, because 82% of the lethal collisions known for fin whale in the Mediterranean Sea are listed within or in waters adjacent to the Sanctuary and the mortality rate for fin whales associated with these known collisions is 3.25 times higher there than in the whole basin (Panigada *et al.*, 2006). According to the latest results (Di-Méglio *et al.*, 2010), 60 collisions with fin whales (94%), and 5 with sperm whales (6%) were listed between 1972 and 2009 off the French coast in the Pelagos Sanctuary and adjacent areas. During this period, the average number of large cetaceans (sperm and fin whales) killed in a year was 1.51. In addition, an average of 2.2% of living individuals photo-identified show clear marks of collision and 2.6% probable marks of collision. In 40 known cases of ship strike the type of ship is indicated: 25 (62%) concern different type of ferries; 6 (15%) merchant vessels (container-ship, methane carrier, etc.), 4 (10%) high-speed ships and 5 (12.5%) sailing vessels.

One of the most important factors contributing to collision risk seems to be the spatial overlapping of zones of presence of cetaceans with zones of intense sea traffic (e.g. Mayol, 2007; NOAA, 2004). In the Pelagos Sanctuary, the principal source of collision is attributed (e.g. Mayol *et al.*, 2008; Panigada *et al.*, 2008) to a combination of a high, constantly increasing density of maritime traffic, (David, 2005; Di-Méglio *et al.*, 2010) and a high abundance of large cetaceans in this area in summer (Reeves and Notarbartolo di Sciara, 2006).

Other factors can also contribute to collision risks and outcomes. For example, mortality rate increases appreciably with the size of the ships (Van Waerebeek and Leaper, 2008). The power of the shock at collision increases under the influence of the slow speed of larger vessels and gaps in visibility increase when the footbridge is placed towards the stern of a large ship (WDCS, 2006). This present study also raises the problem of the slowness of reaction of very large ships in changing course, leading to an inevitable collision if the animal is not detected very early.

The risk of the death of the animal which has been struck also increases significantly with speed (Pace and Silber,

2006; Van Waerebeek and Leaper, 2008; Vanderlaan and Taggart, 2007). Pace and Silber (2006) consider that at 10.5 knots, a big cetacean struck by a ship has a 50% chance of being killed or seriously hurt. This value reaches 90% at 17 knots. Beyond 15 knots, the chance of a lethal outcome quickly approaches 100%. (Vanderlaan and Taggart, 2007). However, Jensen and Silber (2003) explain that even if the speed listed during the collision ranges from 2 to 51 knots, the average is 18.1 knots, and the majority of ships navigate between 13–15 knots. However, Vanderlaan and Taggart (2007) also specify that the probability of encounter increases in inverse proportion to speed, i.e. the slower the speed is the more the probability of encounter increases, notwithstanding the aggravating factor of high speed.

Regarding ship strikes in the Pelagos Sanctuary, several studies have dealt with the fin whale (David *et al.*, 2011; Panigada *et al.*, 2006) but none focuses on sperm whales. Several articles and workshop reports have stressed the need to fill the knowledge gap concerning sperm whales and the threat of collision. Panigada and Leaper (2010) recommend mapping the temporal and geographic distribution and abundance of large cetaceans in relation to similar information on vessel traffic to identify potential high risk areas. In addition, they suggest using the data to develop models to explain and predict fin whale and sperm whale distribution and abundance, and in relation to maritime traffic, and also to refine existing estimates of abundance.

The report of the Joint IWC-ACCOBAMS Workshop on Reducing Risk of Collisions between Vessels and Cetaceans (IWC, 2011) urges the identification of 'high risk areas' for more detailed studies (qualitative general identification or more detailed spatial modelling). The workshop recognised that there are gaps in the data for sperm whale distribution and abundance, and for shipping density. This lack of data prevents a full assessment of the conservation implications of ship strikes for this species. Six priority areas were recommended for collecting data to allow improved risk assessments of ship strikes and among them is the Pelagos Sanctuary. The workshop report also highlights the fact that data on shipping density and movements are of value in identifying potential 'hotspots' (by comparison with cetacean density and movement information), in examining potential mitigation measures (e.g. shipping lanes, exclusion zones, speed limits) and in monitoring compliance with any measures that may be adopted. It concluded that shipping and whale data overlays can be a first step in identifying areas of higher risk of encounters between whales and vessels that may lead to collisions. This is most useful if it can involve large data sets from surveys conducted over different years to account for temporal variations in whale distribution. Modelling using associated environmental parameters may be used to predict relative or absolute cetacean densities in areas or for seasons with low survey effort. For shipping data, variables such as vessel type and speed would be useful to assess variation in risk.

The initial overlay allows for more detailed investigations in those areas identified as having highest probability of encounter. For these areas, risk of collisions and the proportion likely to be fatal may be assessed in more detail, considering factors such as vessel type and speed, seasonal differences, behaviour and age groups of whales. Thus, it

was proposed to fill the knowledge gap by highlighting ‘hotspots’ of collisions between sperm whales and ships in the Pelagos Sanctuary and the adjacent waters in the northwestern Mediterranean Sea. To achieve this aim, sightings data collected in research surveys over 14 years has been gathered and data on all the maritime traffic of different types of large commercial vessels over the vast area studied. The method used by David *et al.* (2011) was then followed by drawing up a distribution map of the sighting rates of sperm whale (kriging) and a distribution map of maritime traffic intensity of large commercial vessels in this sector.

Maritime traffic density is higher in summer as is that of sperm whales. The available sighting data is reliable, sufficiently numerous and available mainly in summer for sperm whales, so the study focussed on the period from June to September. Visual sightings are only partly sufficient as a basis for studying this species, because these animals spend about 50 minutes under water and only 9 minutes at the surface (Drouot, 2003). Given that, the study was undertaken on the basis of the hypothesis that the kriged resulting map, based on visual sightings, could be seen as the ‘minimum’ distribution. The maps resulting from the kriging were overlaid with the one of maritime traffic intensity with the purpose of highlighting respectively the ‘minimum’ zones of high collision risks between sperm whales and commercial maritime traffic.

This paper presents an assessment of the risk of ship strikes for sperm whale in the northwestern Mediterranean Sea, giving some insights concerning the number of animals potentially in the way of a large vessel in summer, the number of photo-identified animals bearing ship strike marks on their body, and mapping area where the risk of ship strike may be the higher. To reduce the risk of future

collisions in the northwestern Mediterranean Sea and more particularly in the Pelagos Sanctuary, the study aimed to review mitigation measures already in place and to make some more recommendations for measures that could be implemented in the future.

MATERIALS AND METHODS

Study area

The study area is in the northern part of the western Mediterranean Sea, between 4°30' and 12°E longitude and 40°30' and 44°30'N latitude. It includes an international marine mammal protected area (approx. 90,000 km²), the Pelagos Sanctuary, listed among the SPAMI (Specially Protected Area of Mediterranean Importance, Barcelona Convention SPA Protocol), and it is surrounded by 3 countries: France, Italy and Monaco (Fig. 1).

The area studied goes from the coast to offshore, with the western and southern part characterised by a small area of continental shelf, a steep slope and in contrast, a northern and eastern part with a more extensive continental shelf with a gentle slope.

Datasets

Sighting data and effort

Data comes from nine different French and Italian research organisations (EcoOcéan Institut, WWF France, Fondation Nicolas Hulot, GECCEM, CRC, CETUS Italie, Genoa Aquarium, Cybelle Planète, Swiss Cetacean Society), all operating in the northwestern Mediterranean Sea (Laran *et al.*, 2012), over a period of 14 years (1994–2008). Data were collected during specific visual surveys carried out in summer (June to September) by expert observers. The surveys used the standardised Line Transect method

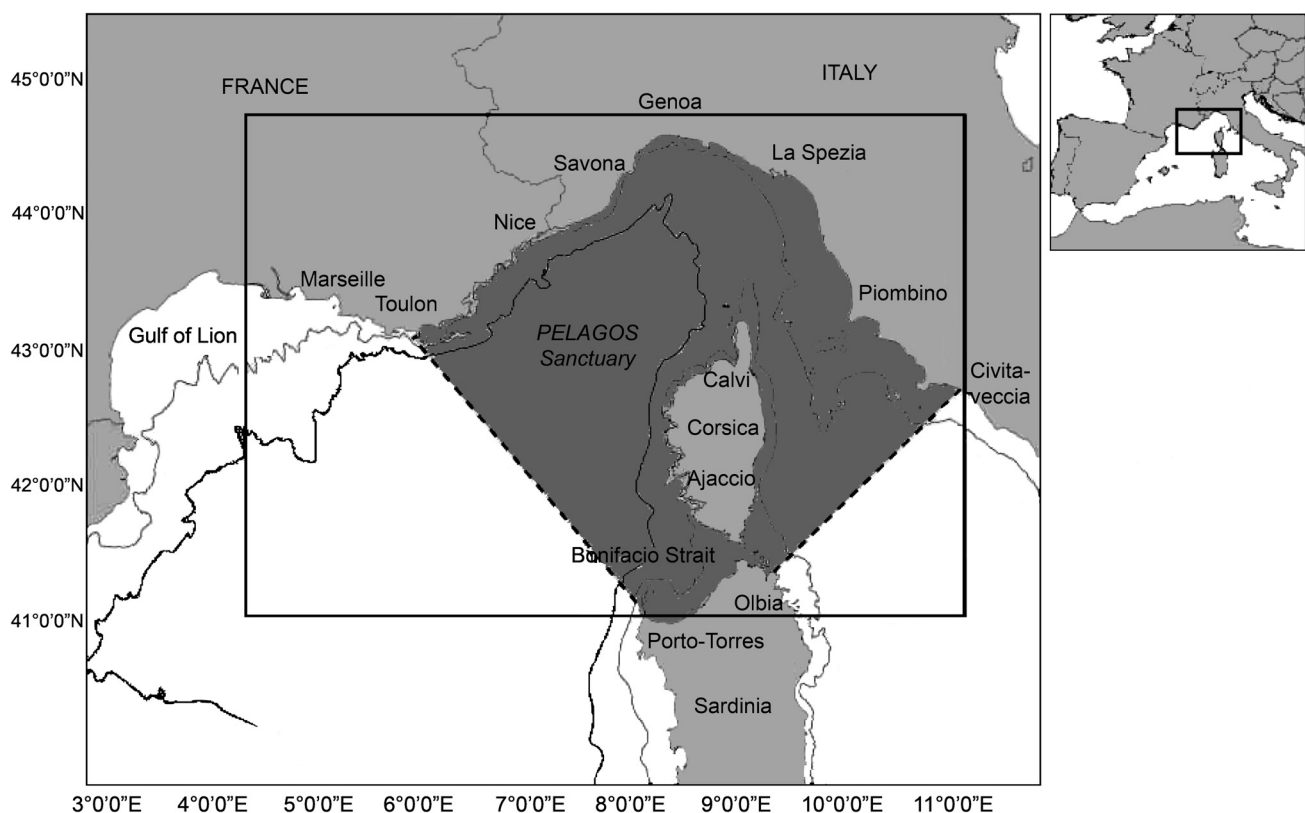


Fig. 1. Study area, the Pelagos Sanctuary and its neighbourhoods.

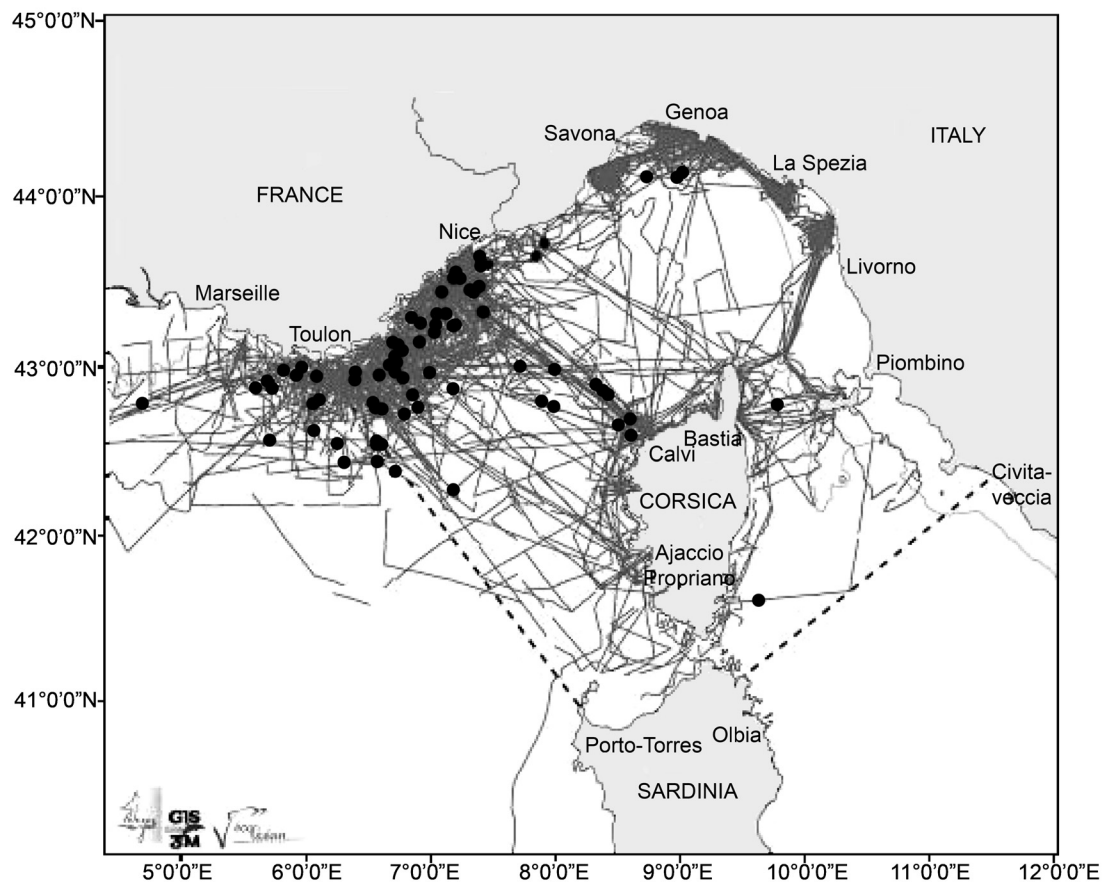


Fig. 2. Survey tracks and distribution of the sightings of sperm whale (*Physeter macrocephalus*) in summer (June to September 1994 to 2008) in the northwestern Mediterranean Sea. • = sperm whale sighting.

(Buckland *et al.*, 2001): three observers scan the water surface in an angle of 180° in front of them with naked eyes, whereas the boat follows a route with constant speed (around 6 knots) and heading. The data are analysed only if they were collected in sea states ≤ 3 Beaufort. Platforms used were sailing vessels or motor boats, with an eye height above the sea surface from 2.5 to 4 metres. The parameters collected during a sighting were: species, number of individuals, geographic coordinates (GPS), time and date, sighting conditions (mainly sea state).

The datasets examined contained a combined total of 83 sperm whale sightings (117 individuals) for the 95,039km covered in survey effort (Fig. 2).

Shipping

The data for merchant vessels were provided by the Lloyd's Intelligence Maritime Unit (LMIU) to the SCOT Society which conducted a study commissioned by the French Ministry of Transport. This is an extensive dataset of all categories of merchant vessel travelling in the western Mediterranean Sea. These maritime traffic patterns barely changed between 2002 and 2010 (LMIU, 2008). It was therefore considered that these data were representative of current marine traffic patterns in this study area.

Commercial traffic distribution from June to September 2002 for the northwestern Mediterranean Sea were extracted and theoretical tracks were estimated using harbours of departure and arrival.

This study's dataset 'Ferry' was established for the June–September 2010 period. Due to ferry traffic expansion

between 2002 and 2010, the most recent data for this type of vessel was chosen as a basis for considering conservation and mitigation measures to be implemented.

The dataset was established for ferries according to the timetables provided by the companies on the Internet or in schedule booklets. The trajectories were drawn according to the ferries route between departure and arrival harbours. Two categories were distinguished: (1) Conventional Ferries (CF), large passenger ships travelling slower than 25 knots; and (2) Fast Ferries (FF), large passenger ships and RORO fast ferries travelling faster than 25 knots.

Catalogue of photo-identification

As several studies show (Di-Méglio *et al.*, 2010; Panigada *et al.*, 2006), most of the known collisions in the northwestern Mediterranean Sea (respectively 91.7% and 87.5%) with large cetaceans are with merchant vessels. In order to achieve a more accurate estimate of the number of collisions between sperm whales and merchant vessels in the northwestern Mediterranean Sea, several photo-identification catalogues were analysed: the *EcoOcéan Institut* catalogue from 1995 to 2009, comprising 35 individuals and the GIS3M (*Groupement d'Intérêt Scientifique pour les Mammifères Marins de Méditerranée et leur environnement*) catalogue from 2006 to 2009, comprising 20 individuals. Animals that had survived collisions and showed obvious marks of collisions were listed. As not all the sperm whales in this zone were photographed, it is evident that this method underestimates the number of sperm whales having undergone a collision. However, the investigation provides

a minimum number which can serve as a basis for comparison with data on the frequency of collision obtained by other methods (e.g. strandings and necropsy, known cases of sperm whale collisions, etc.).

Data analysis

Kriging model

The interpolation is based on the spatial auto-correlation principle according to which spatially close objects tend to possess similar characteristics (Baillargeon, 2005; Webster and Oliver, 2007): the unknown values for one variable are estimated from the surrounding points. The data are the sightings collected in sightings effort, and the indices are expressed in number of individuals per kilometre of effort. The kriging model and the method of estimation of the spatial structure applied here are described in detail in Monestiez *et al.* (2006). This method enables the estimation of the number of sightings of cetaceans per kilometre in less known zones, especially with a variance much lower than that associated with the other methods of kriging. Technically, by means of the software *R*, the distances of all the segments of transect were summed, in each cell of a regular grid of 0.1° of latitude by 0.1° of longitude, that is on a surface about 90 km^2 . In the same way, the sperm whale sightings are summed per cell. A sighting rate was summed (number of sighting. km^{-1}) per cell. *R* programming of estimators as given in Monestiez *et al.* (2006) is then used to estimate the variogram, and the interpolation of expectations of sighting rate of sperm whales per kilometre in the whole study area as well as the variances. This modelling was done with data collected in survey effort between 1994 and 2008.

Shipping intensity

The vector map of the ships' trajectories was converted into a raster map with a cell resolution of $0.1^\circ \times 0.1^\circ$ in order to match the spatial scale chosen for the kriging. Using GIS (ArcVIEW 9.2) for each cell, calculations were made for: (1) the distance covered by the trajectory within that cell; and (2) the number of ships following that route during June to September. By combining these two datasets it was possible to map the shipping intensity expressed as number of kilometres travelled in a cell for each ship category.

Collision potential

The 'Collision Potential' was estimated by combining data on shipping intensity and sperm whales sighting rate (kriging model) at a $0.1^\circ \times 0.1^\circ$ scale using GIS (ArcVIEW 9.2). Data on these two independent events were previously normalised and the resulting values were also normalised with the aim of obtaining an indicator of the potential for collision ranging from low (0) to high (1).

Collision rate

Estimation of collision rate (Tregenza *et al.*, 2000) is a simple 2-dimensional model of maximum possible collision rates (see <http://www.chelonia.co.uk/html/collisions.html>) based on the estimation of the number of whales that a ship can find in its path each year:

$$N = (W + 0.64 \cdot L) \cdot D \cdot T \cdot P \cdot \frac{Y}{10}$$

With, W = Hull width in km, L = Length of whale in km, D = Length of ferry transect in km, T = Percentage of whale time near surface, P = Mean number of whales per km^2 , Y = ferry transect per year.

These calculations were refined by considering the distance travelled (D) and the number of passages (R) for each ship (from 1 to n) according to:

$$D \cdot R = \sum_1^n d_n \cdot r_n$$

To model 2D collision rate, five assumptions are made:

- (1) the vulnerable parts of the whale can be represented as a line of the same length as the whale;
- (2) the whale's orientation relative to the direction of travel of the ferry is random;
- (3) the whale does not tend to move into or out of the ferry's path, actively or passively;
- (4) the ferry does not avoid whales; and
- (5) the ferry transect has an overall density of whales that is the same as some overlapping areas from which a survey has given a density estimate.

For this calculation, only data for July and August was used in order to match the period where the estimation of sperm whale density has been made in the literature.

RESULTS

Shipping traffic

Analyses concerning maritime traffic were performed from two databases. The database for Ferries (conventional ferry and fast ferry) over the 2010 summer season contains 12,267 one-way trips (or 6,152,800 kilometres) from 12 companies to 31 different destinations. The extracted dataset from the SCOT database for trading vessels contained 9,172 vessels: this represents a total of 3,776,600km of theoretical trajectories.

All data were combined to map the shipping traffic intensity of all commercial vessels and this revealed that 81.8% of the cells (1,799 cells out of 2,200) were crossed by at least one ship during the summer. Some cells exhibited very high shipping intensity (Fig. 3).

Marine traffic of large commercial vessels in the northwestern Mediterranean Sea in 2002 (Fig. 4) is mainly, in summer, passenger ships connecting the mainland and Corsica, Sardinia islands, which represent approximately 67% of vessels travelling in the summer and 86% of kilometers travelled in this area. The dataset further revealed that 49% of all commercial vessels operating in the study area are conventional ferries, 18% are fast ferries, and 33% are other types of merchant vessels.

Overall, it has therefore been found that almost all the study area is crossed by large commercial vessels. While this traffic is spatially extensive and low in intensity over most of the basin, it is intensive around some major destinations: the exchanges of freight between European countries are on an axis south-west/north-west, and exchanges between Europe and Africa are on a north-south axis. Due to the configuration of the northwestern basin, the most intensive

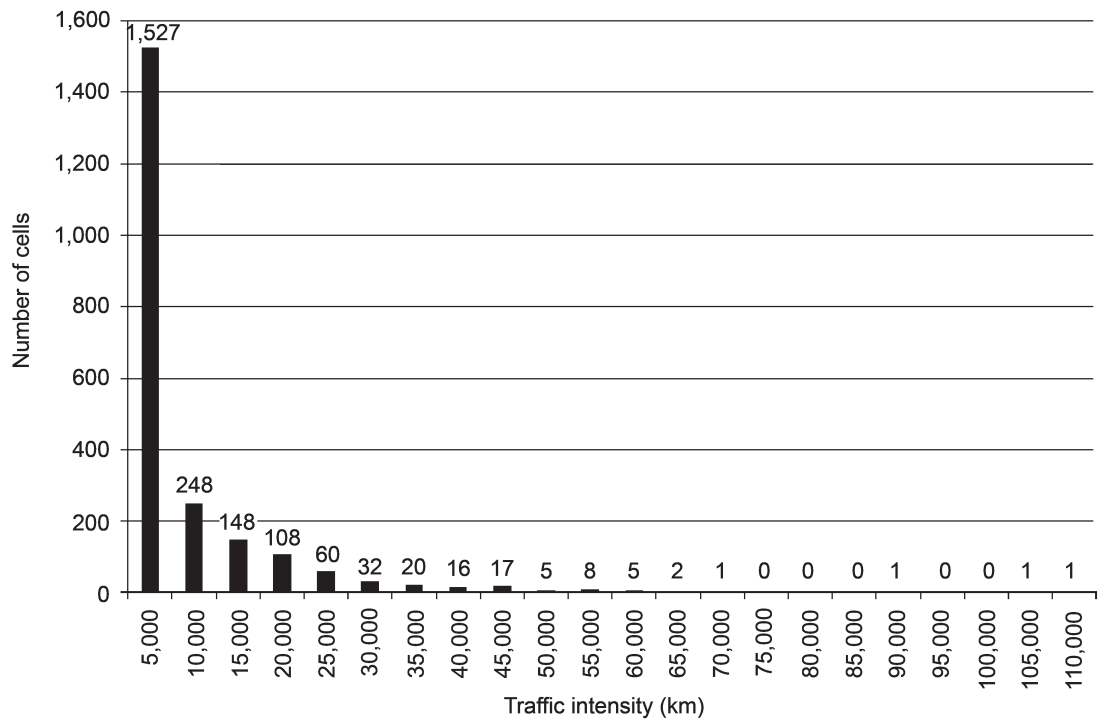


Fig. 3. Frequency of traffic intensity of large vessels in summer in the northwestern Mediterranean Sea, in km per $0.1^\circ \times 0.1^\circ$ cells.

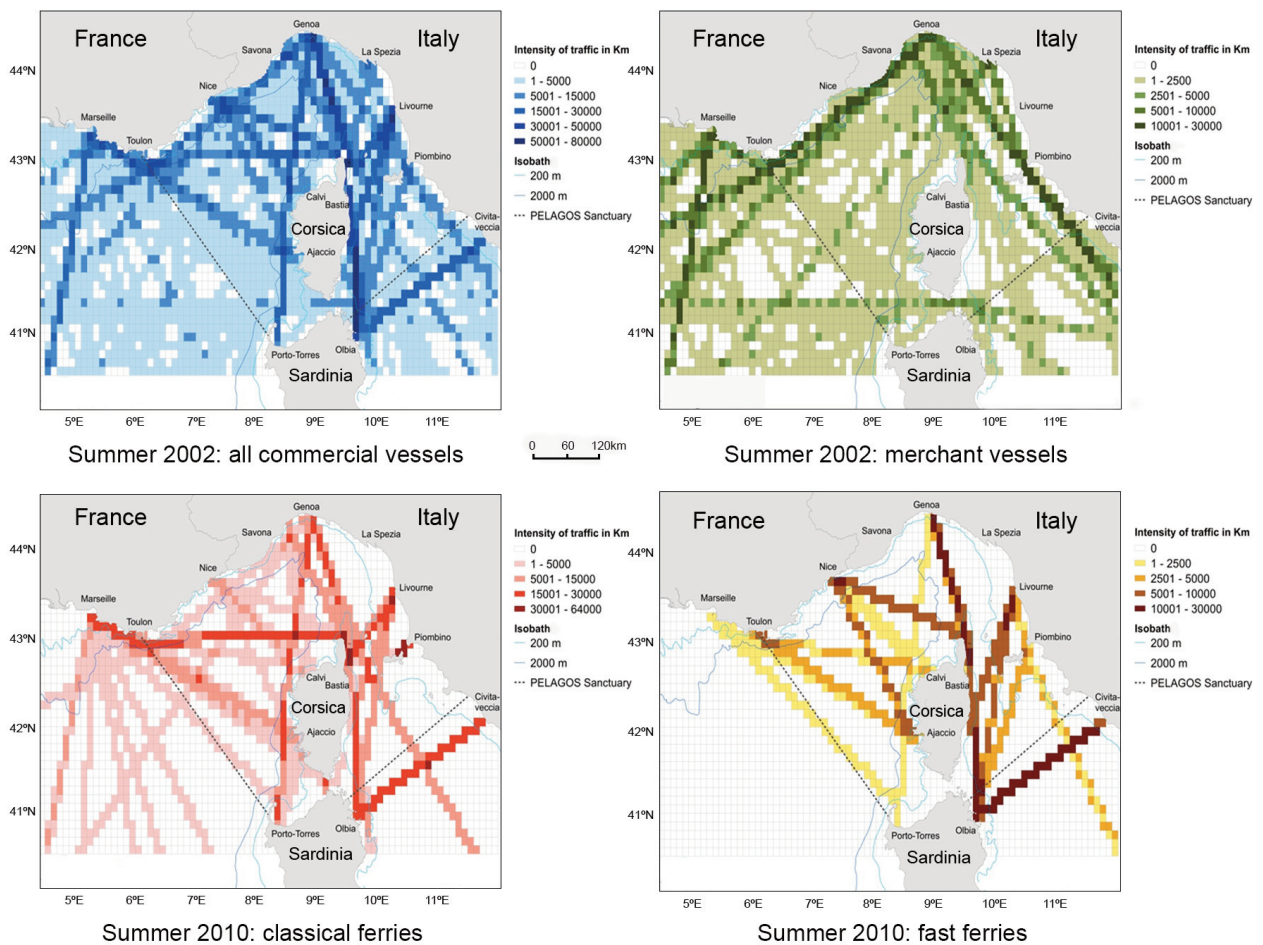


Fig. 4. Distribution of the summer intensity (in km) of traffic for large commercial vessels: calculated from the theoretical routes in 2002 for merchant ships and in 2010 for classical and fast ferries.

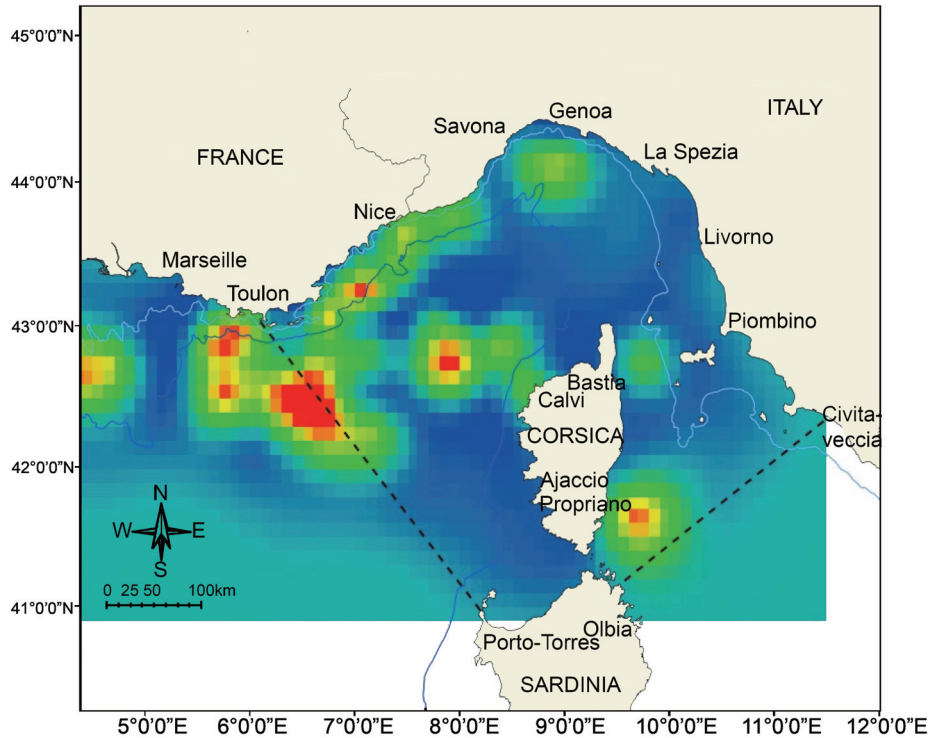


Fig. 5. Map of kriging values (prediction of the number of sightings of sperm whales per kilometer of prospecting effort) during summer period, cumulated from 1994 to 2008. Expected sighting rate (no. sightings per km), High (red, 0.005), Low (blue, 0).

cargo traffic follows the Provençal coast or passes through the Corsican Channel (east of Corsica). The north of the Pelagos Sanctuary is a highly frequented sector. The Strait of Bonifacio is also the site of intensive vessel traffic. In parallel, the regular and predefined routes of ferries constitute a series of maritime bridges between the continent and the islands of Corsica and Sardinia, forming a dense network of traffic within the Pelagos Sanctuary.

Kriging

Sperm whale distribution, even extrapolated (Fig. 5), presents a ‘scattered’ spatial structure. Nevertheless, the map shows the affinity of the species for a zone close to the coast, from Genoa to La Ciotat (20km west of Toulon), corresponding to the continental slope. In the Gulf of Genoa and the Gulf of Lions, highest densities are partly located

over the great submarine canyons cutting across the slope. Following that, sectors of high density appear further offshore to the south of Toulon (6°50'E and 42°30'N) or in the centre of the Ligurian Sea (in 8°E, 42°50'N). The map of the variances (Fig. 6) associated with the results of the kriging supports the validity of the results. Here the variance is merely due to the heterogeneity of the distribution of the survey effort in the area. So, the variance is low where the survey effort is high and inversely where the effort is low.

Collision potential

Concerning the results represented by the collision risk area map, this study mainly focuses on the high-risk areas (dark blue and purple). Next to them are low risk areas (light blue). The risk ‘zero’ does not occur in these areas because only one whale and one vessel are enough to make a collision.

The superimposition of the kriging map of sperm whale sighting rate and the map of traffic intensity of large commercial vessels gives a map showing high and low collision risk areas. High risk areas are located over all the continental slope between Genoa and Toulon (Fig. 7). The risk increases around the main harbours (Genoa, Toulon and Bastia) and spreads offshore to the south of the Hyères archipelago and to the northwest of Calvi. A sensitive zone is apparent to the southeast of Corsica where a high collision risk was noted.

In more detail, differences appear in the various maps drawn by categories of large vessels (Fig. 7). Thus, the conventional ferries could impact sperm whales mainly around the harbours they enter (Fig. 7), and in the central zone and along the east coast of Corsica. The fast ferries have a more restricted impact, concentrated around harbours

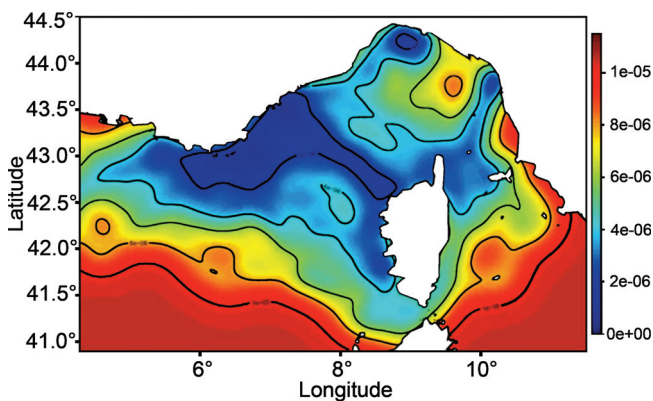


Fig. 6. Map of the kriging variances (square of the mean error of the number of sperm whale sighting per km of prospecting effort), years 1994 to 2008 cumulated. Small variances are represented in dark blue until turquoise and high variances are represented in yellow and red.

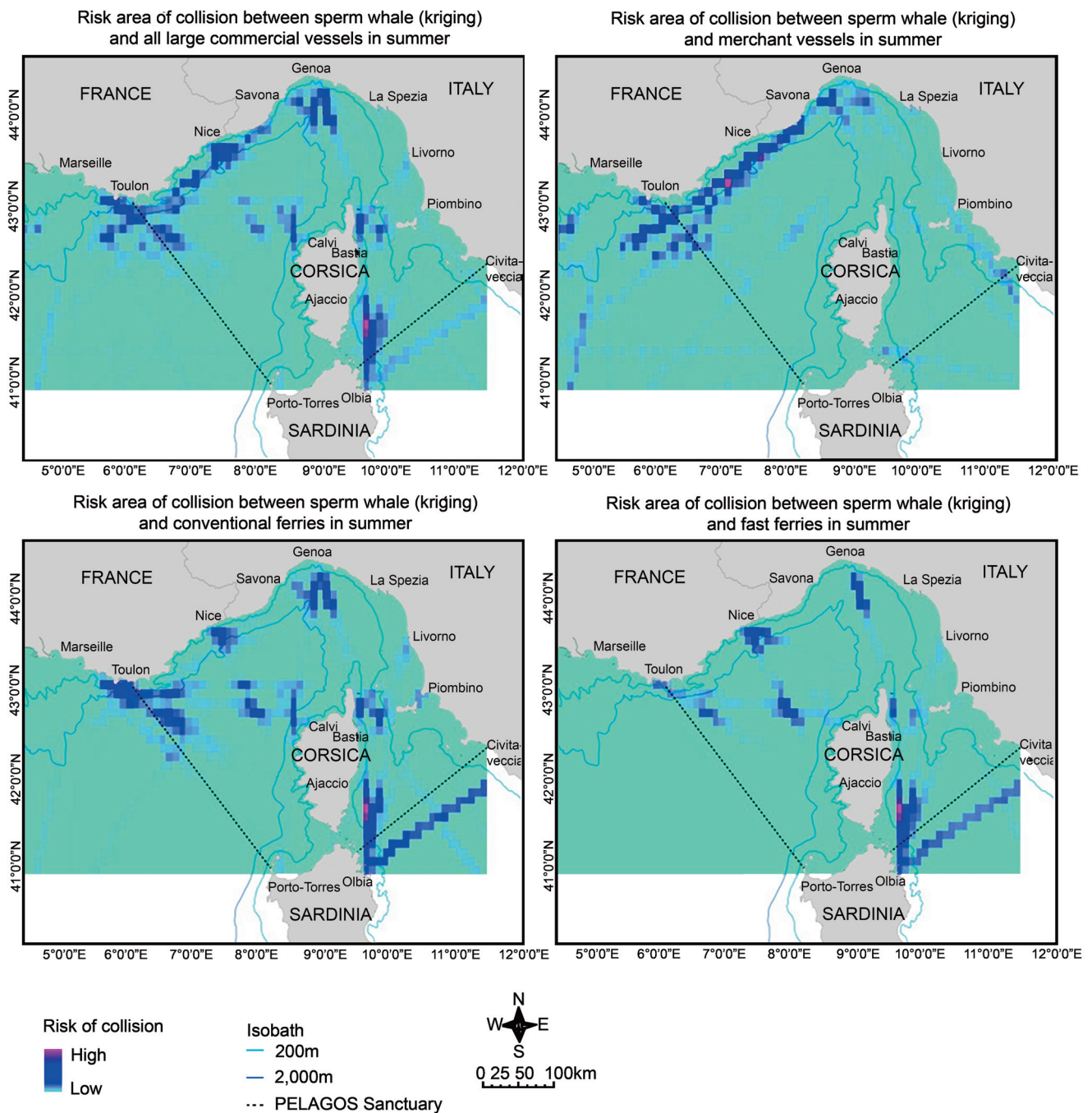


Fig. 7. Summer distribution of the high-risk areas of collision between sperm whales (kriging data) and the large commercial vessels (all categories, merchant vessels, conventional ferries, fast ferries).

receiving this type of ship as well as in a small sector in the centre of the Ligurian Sea and to the southeast of Corsica (Fig. 7). Finally, the collisions between sperm whales and merchant vessels have a strong probability of occurrence on the continental slope between Genoa and Toulon (Fig. 7), and to a lesser extent between Genoa and Civitavecchia. Places more remote from the coast would also favour collisions, off the Hyères archipelago (islands located to the south-east of Toulon) and in the Gulf of Genoa.

Marks on photo-identified sperm whales

Analysis of the photo-identification catalogues show that 5 out of 55 sperm whales had distinct marks that have been attributed to a ship strike. This represents 9.1% of photo-identified animals.

Collision rate

From the literature and the data obtained in this study, it has been estimated that 74 sperm whales (Table 1) were potentially in front of the bows of a large commercial vessel in the Pelagos Sanctuary in height of summer (in July and August). Overall, the conventional ferries constitute the biggest threat (57.8%), then merchant ships (26.1%) and finally fast ferries (15.9%).

DISCUSSION

Sperm whale distribution

The kriged map of predicted sperm whale sightings, based on visual data made over 11 years, is in accordance with information already known about this species in the region: this species is mostly encountered over the continental slope,

Table 1

Parameters and estimation of the number of sperm whales that large commercial vessels could encounter on their passage in the PELAGOS Sanctuary in height of summer (July and August).

	Conventional ferry (2010)	Fast ferry (2010)	Merchant vessel (2002)	Total large commercial vessel
D/1000*R	2,480	915	1,126	4,521
L*	12	12	12	–
T*	16	16	16	–
W	20	13	20	–
P*	0.0039	0.0039	0.0039	–
Nb sperm whale/summer	42.8	11.8	19.4	74
Nb sperm whale/day	0.7	0.2	0.3	1.2

*L and T according to Drouot (2003), P according to Laran *et al.* (2010).

Table 2

Data on collisions for sperm whales in the north-western Mediterranean Sea.

Density ¹ in the PELAGOS Sanctuary (ind.km)	Frequency of ship strike with sperm whale (ind.day ⁻¹)	Number of known collisions ²	% of stranded animal caused by collision (Mediterranean French coast) ³	% of living animals with marks of ship strike ⁴
0.0039	1.2	5	6	9.1

¹According to Laran *et al.* (2010). ²From Di-Méglio *et al.* (2010). ³F. Dhermain, GECM (pers. comm.). ⁴F. Capoulade, GIS3M and EcoOcéan Institut.

mainly off a continental coast with steep slopes and canyons (Azzellino *et al.*, 2008; David and Di-Méglio, 2012; Gannier *et al.*, 2002), but also in some hotspots in more offshore areas (Gannier and Praca, 2006). This study has also provided a new map which shows the variance of prediction. The results are also in line with recent studies, based on acoustic data (Aïssi *et al.*, 2014) or long term but heterogeneous sources of data (Fiori *et al.*, 2014). Habitat studies (Fiori *et al.*, 2014; Tepsich *et al.*, 2014) show that sperm whales are more often detected off the French continental coast, in the Genoa canyon, but are also present on the continental slope of Corsica and in the Tyrrhenian Sea (Aïssi *et al.*, 2014; Azzellino *et al.*, 2012; Drouot, 2003; Fiori *et al.*, 2014; Praca and Gannier, 2008; Tepsich *et al.*, 2010; Tepsich *et al.*, 2014). In the same way, the recent results of Tepsich *et al.* (2010) and Tepsich *et al.* (2014) show the presence of many sperm whales in the area south of Genoa, an area where not many sightings were previously made. Moreover, the results of Aïssi *et al.*, (2014), based on acoustic data, highlight the French continental slope and mostly the Tyrrhenian Sea as a potential habitat of high abundance for this species. Due to the high level of maritime traffic in that area, ship strike could be an important issue there as well. Only the model of Fiori *et al.* (2014) highlight some other offshore hotspots that were also found in this study's results. Because their results are mainly either habitat modelling or prediction maps based on acoustic data, and because they agreed on the same areas of high presence as ours, which is based on visual data, this confirms that this study's map is likely a 'low hypothesis' of presence.

Collision with sperm whale

This study's results made an updated assessment of how important ship strikes might be for sperm whales, through using different approaches: photo-identification on living animals, known ship strikes, theoretical encounter between a vessel and a sperm whale. These results are summarised in Table 2. We found in this study that 9.1% of the 55 whales photo-identified (1992–2009) in the northwestern

Mediterranean showed marks caused by collisions (Table 2), confirming that sperm whales are regularly affected by ship strikes. Not all whales that are hit are killed, but the low rate of injuries seen on living whales (between 6 to 9%) suggests that non-lethal collisions are relatively infrequent. Similarly, Pesante *et al.* (2002) found that 6% of 51 sperm whales photo-identified (39 in Greece and 22 in Italy) show wounds or scars that could clearly be attributed to ship strikes. This is a similar case for North Atlantic right whales, where scars from vessel collisions on photo-identified live whales reaches 7% according to Laist *et al.* (2001). It is also of interest to compare the actual recorded collisions in the stranding database. Thus, in the French Mediterranean stranding database, ca. 33 sperm whales stranded from 1972 to 2012 and 2 were attributed to a collision, which represents 6% (Groupe d'Etude des Cétacés de Méditerranée GECM, pers. comm.). Similarly, more than 6% of the 111 sperm whales stranded in Italy (1986–1999) and Greece (1982–2001) died after being struck by a ship (Pesante *et al.*, 2002).

In the modelling of collision rates by Tregenza (2000; model available for download at http://www.chelonia.co.uk/collision_prediction.htm), it was clearly found that the number of collisions risked by sperm whales per year (one per day in July–August, totalling 74 individuals) is far less than those that really occur (see numbers from stranded and living individuals above). Errors in estimating L, T, W and P could be significant, as could errors in the assumptions. The model works on the hypothesis that the whale does not tend to move into or out of the ferry's path and nor does the ship move away from the whale. At sea, both can happen, reducing the number of strikes. A noisy or slower vessel could be more easily detected and then avoided by a whale, so the orientation and the length of the animal exposed to the ship is different from random. The length of a whale exposed to the hull does not always correspond to its total length (e.g. depending on its orientation, the tail may less at risk). This very simple model does however give us a theoretical 'maximum' number of potential collisions or represents a basis for prediction of possible 'near miss event'. The results

presented here suggest that either (1) many whales die and are unrecorded; or (2) many whales can avoid collisions.

Of 65 known cases of ship strike in the northwestern Mediterranean Sea, only 5 were sperm whales, all others were fin whales (Di-Méglio *et al.*, 2010). The number of collisions reported with sperm whales could however be underestimated because: (1) the population of sperm whale is low (a few hundreds, Rendell *et al.*, 2014); (2) the carcasses of sperm whales are rarely washed up on the coast; (3) the animals, because of their morphology, are not caught on the bow bulb of ships as is the case for the fin whale; (4) the identification of the struck animal can be erroneous in favour of the fin whale; and (5) both catalogues analysed are of small size (20 and 35 photo-identified individuals). This low number of collisions could also be because the sperm whale spends little time at the surface (16%). However, when breathing, animals stay almost without moving for 9 minutes on average at the surface, which makes them very vulnerable to ship strikes. They may also be so preoccupied with feeding, socialising, courtship and mating, or some other activity, that they become oblivious to the presence of vessels (David, 2002).

These results are of concern because they highlight that ship strikes in the northwestern Mediterranean Sea could involve more sperm whales than previously thought. The results are probably only the tip of the iceberg. With future predicted increases in maritime traffic (Dobler, 2002), it will probably get worse. Based on the abundance calculated by Rendell *et al.* (2014) of only 400 animals in the northwestern Mediterranean Sea, the threat of ship strikes affects an important proportion of the population.

Regarding the type of vessel involved in collisions with sperm whales, little information is available. According to the database collected by F. Capoulade (in Di-Méglio *et al.*, 2010), it seems that in one case it was a yacht and, in another case, a large commercial vessel. Sperm whales are also known to be threatened by hydrofoils and other passenger craft including high-speed ferries in the Strait of Gibraltar (De Stephanis and Urquiola, 2006) or in the Canary Islands (Carillo and Ritter, 2008). No more information is available.

After assessment, the results highlight the geographical areas where collision could be the most probable. The determination of high risk areas is essential because these constitute the zones of overlap between hotspots of distribution of the targeted cetaceans and high density of maritime traffic. However, these zones can be defined only from generalised and 'typical' situations because they do not consider fluctuations in the distribution of large cetaceans for which 'atypical' years can occur (Beaubrun *et al.*, 1999; Di-Méglio and David, 2008). Furthermore, ships can occasionally change their route because of bad meteorological conditions (Di-Méglio *et al.*, 2010). These changes would shift the potential impact to other collision areas. Thus, this work is based on the scenario for the great majority of cases and is representative of what was generally observed in the Pelagos Sanctuary. Furthermore, it is evident that zero risk does not exist, because only one animal and one boat are enough to result in a collision. This approach gives interesting results: the whole slope between Genoa and Marseille and along the coast of Corsica and some hotspots further offshore (south of the Hyères Archipelago and

northwest of Calvi in Corsica) are high risk collision areas for sperm whales.

In addition, the region southeast of Corsica down to the northeast of Sardinia appears to be a potential high collision risk zone. Although whales are indeed encountered in these sectors (Drouot, 2003), they are rarely seen in the north of the Tyrrhenian Sea (Arcangelli *et al.*, 2009; Arcangelli *et al.*, 2010; Gannier *et al.*, 2002). However, recent work by Aissi *et al.* (2014) highlighted the Tyrrhenian Sea as an important, even major, habitat for sperm whales (even the north part). It is certain that the danger exists for the rare (or not so rare) whales occurring in that area in view of the exceptionally high intensity of traffic crossing through the Corsican channel. The recent results of Tepsich *et al.* (2010) and Tepsich *et al.* (2014) from the area south of Genoa, show the presence of many sperm whales in an area where not many sightings were made. It therefore appears that the collision risk zone for this sector could be extended further to the south.

Measures to reduce the risk of ship strikes

This study's results, highlighting summer high collision risk areas, provide a good basis for considering action to help managers to define areas to focus on for risk-mitigation solutions. Bearing in mind that Notarbartolo di Sciarra (2014) concludes that among all threats, the problem of collisions between sperm whales and vessels is clearly challenging. Limiting maritime traffic to defined shipping lanes and limiting speed in areas characterised by high densities of sperm whales and urging captains to navigate with particular caution (following the suggestions by Laist *et al.*, 2001) would significantly reduce the risk of ship strikes (Vanderlaan and Taggart, 2009). A combination of different technical, governance and awareness-raising measures that are partly implemented and tested in the Pelagos Sanctuary as a pilot site, were reviewed. Some other measures were suggested that could be implemented within the pilot area.

Ongoing actions

Recent international workshops and reviews have recommended various measures worldwide to mitigate ship strikes (Panigada and Leaper, 2010). In parallel, within the framework of the 'Grenelle de la Mer' programme led by the French Ministry of the Environment, several workgroups have studied the issue and suggested solutions. Various measures have been proposed regarding ship strikes with marine mammals (République Française, 2010) and some of them are already in operation in France, as follows.

- Requesting experts provide a critical analysis of specifications on the ergonomics of ships' bridges to optimise the visual detection of offshore obstacles such as cetaceans (Mayol *et al.*, 2007), for the fast ships at least.
- Encouraging cooperation between the various stakeholders (including local authorities), to place observers aboard merchant ships (passenger and/or cargo) which regularly cross sensitive zones frequented permanently or occasionally by cetaceans. Most of the studies on collisions (ACCOBAMS, 2005; Carillo and Ritter, 2008; David *et al.*, 2011; Panigada *et al.*, 2006; Ritter, 2007) recommend posting an observer dedicated to the detection of whales on the bridge as an inexpensive, easy to

implement and effective approach (Mayol *et al.*, 2007; Weinrich and Pecarcik, 2007). Such a measure also enhances the image of companies which adopt such an approach. In daytime, a dedicated observer focuses on detecting animals to avoid collisions, whereas at night technological systems would take over, using thermal infrared technology. The implementation of the ‘Fix Line Transect’ method aboard ferries for monitoring marine mammals (FLT Med Monitoring Network), which began in 2007 on one line is now spreading over 11 lines across mainly the occidental basin of the Mediterranean Sea (6 of them crossing the Pelagos Sanctuary) (Campana *et al.*, 2015). For a few days per month Marine Mammals Observers observe from the ferry’s bridge, with direct links to the crew members who can act to avoid collisions if necessary.

- Encouraging the development of real time early warning systems of the position of cetaceans in order to limit collision risk and take avoidance action. A Real Time Plotting of Cetacean (REPCET) system is already in place in the Pelagos Sanctuary (Mayol *et al.*, 2008). This system requires the participation of the maximum number of ships to be efficient. The latest call for tenders from France concerning the transport of passengers from the mainland to Corsica includes a mandatory request concerning a ‘system of reducing collisions with cetaceans’.
- Training of crews and future merchant navy personnel in the field of biodiversity and cetaceans. The training already provided at the school for merchant navy officers in Marseille (Souffleurs d’Ecume) should be systematically offered in all such schools and further developed.
- Supporting within the International Maritime Organisation (IMO) the project for the creation of a Particularly Sensitive Sea Area (PSSA) within the Pelagos Sanctuary (OMI, 2009); the creation of a PSSA allows the application of measures concerning sea traffic (implementation of real time alarm or surveillance, speed limits, Traffic Separation Scheme, etc.).
- Developing the database on ship strikes from the IWC (Panigada and Leaper, 2010) through the regular inventory of collisions and associated information (place, time, context, type of ship, etc.). Also, developing and encouraging coordination at regional scale for providing information on the large cetaceans found dead (e.g. performance of necropsy to determine the cause of the death).

All those measures are partly implemented or undertaken. Two points should be followed further: (1) launching studies to assess the measures to mitigate ship strike and (2) assessing the fact that most of these measures will be based on a ‘voluntary’ not mandatory commitments. It is already known that a voluntary speed limit in place in the Gibraltar Strait has been proven to be rather ineffective and not widely followed by mariners (Gauffier *et al.*, 2010). The introduction of mandatory measures is envisaged in the near future.

In the Pelagos Sanctuary two large cetacean species are threatened by collision with large vessels, and it is already known that their habitat is complementary: the fin whale

being mostly offshore beyond the 2,000m isobath while the sperm whale only frequents the continental slope. This means that before embarking on the long process of implementing measures to mitigate collision risks, a detailed comparison of the high-risk areas for both species could help in choosing the best places and measures for both species to avoid increasing the risk for one species, while decreasing it for the other.

In the same way, it could also be of interest to conduct further research on the species’ habitat use patterns in order to better understand the significance of ship strike risks in the study area relative to other areas within the population’s range. From Gibraltar to Greece, via France and Italy, sperm whales are threatened by ship strikes, as known by recent strandings and photo-identification studies (IWC, 2011). It is known that whale social groups are found around the Balearic Islands (Drouot *et al.*, 2004) and the island of Crete (Frantzis *et al.*, 2003), so it might be of use to quantify the number of potential ‘close calls’ or ‘near miss’ and the areas and level of risk of ship strikes (Richardson *et al.*, 2011). This could provide a basis for defining the most important regions for sperm whales and those where this species is the most threatened by ship collision within the whole Mediterranean distribution range of this species.

CONCLUSION

This study is of value to managers of MPAs as a basis for defining high risk areas and the types of vessel which potentially impact sperm whales, and for determining possible risk-mitigation solutions. It is proposed that by relaying the recommendations and possible solutions contained in this study on a worldwide basis to groups of experts, a combination of different technical measures could be developed to be implemented and tested in the Pelagos Sanctuary as an experimental zone.

The ship strike issue in the Pelagos Sanctuary is complex: this is a vast area, shared by three countries, where the problem of collisions concerns at least three categories of commercial vessels and two species of large cetaceans (i.e. fin whale and sperm whale). Thus, it is necessary for administrators to envisage voluntary measures as well as more binding ones. The main next step will be to assess the effectiveness of such measures, as well as the efficiency of the ‘voluntary-based’ process.

Habitat use patterns in the area still require further research with the aim of providing e.g. occurrence information for the non-summer months. Satellite tracking studies could also help to more accurately determine areas of use in both summer and non-summer seasons.

The development of studies on ship strikes increasingly brings to light the role of leisure boats (e.g. Ritter, 2009), which are responsible for between 3% and 8.3% of known collisions with large cetaceans in the Mediterranean Sea (Di-Méglio *et al.*, 2010; Panigada *et al.*, 2006). Similarly, it is important to integrate all naval vessels and to involve navies in the measures adopted. It may also be worthwhile to study the relative frequency of maritime traffic during daylight and at night.

Concerning spatial scale, since the measures to be implemented are on a large scale and will take very long to

implement, the overall potential evolution of the 'hotspot' collision zones by 2030 or later should be considered, to be based on predictive maps of the likely patterns of development of maritime traffic and their overlap with large cetacean habitats.

This type of study could be carried out in other sensitive ship strike risk areas in the Mediterranean Sea for which habitat suitability maps for cetaceans exist and maritime traffic intensity is recorded, as well as for the entire western basin for both fin whale and sperm whale.

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