Evaluation of the potential of collision between fin whales and maritime traffic in the north-western Mediterranean Sea in summer, and mitigation solutions

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Abstract

Collisions with large vessels present a major conservation issue for the Mediterranean fin whale (*Balaenoptera physalus*), as shown by strandings and body scars on live individuals at sea. However the effect of collisions on this fin whale population and locations of collision events remain poorly known. Using existing knowledge of summer fin whale distribution and data collected regarding main shipping routes, this study aimed to i) assess the spatial distribution of the potential for collisions and ii) discuss mitigation measures. During summer, the sighting densities of fin whales (individuals/hour of effort) calculated from 1993 to 2001, and the levels of shipping density (in km travelled), were computed over a 0.1° X 0.1° regular grid using a GIS. The ship strike potential, expressed as a function of the overlap between fin whale sightings and shipping density, was found to be the highest in the central part of the Ligurian Sea, due to the occurrence in the area by both the animals and shipping traffic, mainly ferries and Very Fast Ferries (VFF). The potential for collision was also found to be high off the Provençal coasts mainly due to ferry and trading vessels, but was lower in the Gulf of Lions. In order to reduce these risks, various solutions with differing levels of implementation and constraints, ranging from dedicated observers to reduction of ship speed and avoidance of areas of high whale concentration, are discussed. This GIS approach combining threat density and animal density can be used to determine areas most at risk for any threat. [JMATE. 2011;4(1):17-28]

Keywords: Baleen whale, strike, commercial vessel, Mediterranean sea, GIS

Introduction

Fin whales (*Balaenoptera physalus*) are regularly encountered in the north-western Mediterranean Sea (Figure 1), and were found to concentrate in this area in summer (16). A nine year dataset on the summer (July-August) distribution of fin whales in the north-western Mediterranean Sea was established (30). High inter annual predictability of areas exhibiting the highest density were identified (13) (Figure 2) revealing that fin whales tended to concentrate in the most productive portions of the Corsican and Ligurian Sea (16, 19, 31, 35), where they feed on euphausids, *Meganyctiphanes norvegica* (32, 40). This key fin whale feeding area is part of a large international marine mammal protected area (approx. 90,000 km²), the PELAGOS Sanctuary (Figure 1) listed among SPAMIs (Specially Protected Area of Mediterranean Importance, Barcelona Convention SPA Protocol).

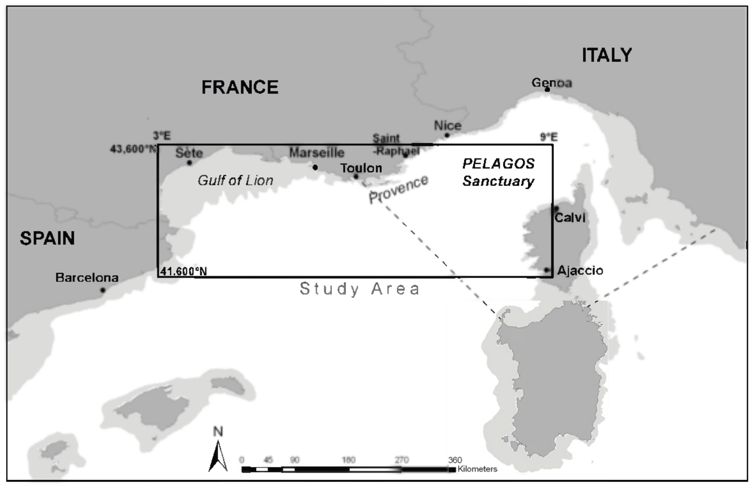

Figure 1- The study area (plain line), the PELAGOS Sanctuary (dashed line) in the western part of the Mediterranean Sea

The conservation status of Mediterranean fin whales remains unclear due to insufficient data on trends in abundance and population-level threats (39). The fin whales found in the Mediterranean Sea are genetically distinct from fin whales found in different coastal waters of the Atlantic and are thought to be year round residents of the Mediterranean (3, 33). Results of regular surveys for quantifying fin whale passages through the Strait of Gibraltar (22, 10, 21), together with stable isotope techniques combined with satellite tagging, reveal limited exchange between the Mediterranean and the Atlantic (2). A recent study based on acoustic detections of fin whales suggests seasonal movements between different regions of the Mediterranean Sea (6). Specifically, an important number of Mediterranean fin whales aggregating in the

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north-western Mediterranean basin during summer migrate through French and Spanish waters towards Southern Mediterranean regions, but do not migrate into the Atlantic Ocean (6). Some fin whales were detected off northern Morocco, crossing the Strait of Gibraltar and wintering in the south-western Mediterranean basin (Alboran Sea) (6).

Dedicated line-transect survey yielded estimates of 3,583 Fin whales (95% C.I. 2,130 – 6,027) over a large portion of the western Mediterranean Sea in 1991 (16), and 901 (95% C.I. 591-1,374) in the Corsican-Ligurian-Provençal basin in 1992 (15). Further line-transect survey effort in the same area in 1996 (17) provided a similar estimate as Forcada et al. (15), while Panigada et al. (35) reported a decreasing trend in fin whales encounter rate from 1995 to 1999.

Ship strikes represent the main fatal threat for fin whales on a global scale (25, 8) and this risk of collision is particularly high for the western Mediterranean Sea (47, 23). This risk was found to increase with ship speeds, with the majority of the lethal wounds inflicted by ships travelling at speed higher than 13 knots (25, 45). Within the frame of ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and contiguous Atlantic area), IWC (International Whaling Commission), IUCN (International Union for Conservation of Nature) and PELAGOS Sanctuary experts recommended sustained efforts to document mortality from ship strikes, taking into account the information available on the distribution of fin whales and the logistical and financial constraints for shipping companies to propose mitigation solutions (47, 23). Different constraints and costs are associated with the range of mitigation measures generally proposed, knowing that none of them alone are likely to be effective or suitable to reduce ship strikes, since each mitigation measure is efficient in particular situations or could have undesired side-effects.

Panigada et al. (36) reviewed the ship collision records, from 1972 to 2001, for fin whales in the Mediterranean Sea: 46 carcasses out of 287 examined (16.0%) exhibited ship-strikes injuries most likely to be responsible for their death. Moreover, among 383 photo-identified living whales, 9 (2.4%) had marks attributed to ship collision (36) and these authors estimated that the annual fatal collision rate increased from the 1970s to the 1990s leading to the potential annual death of 16 animals in the north-western Mediterranean Sea (likely to be underestimated due to undetected cases of collisions). This is among the highest reported ship-strike mortality rate for baleen whales worldwide (47). Ferries and trading vessels were identified as vessels the most frequently associated with fatal collision events for fin whales (25, 36).

82.2% of fatal strike events were reported within or adjacent to the PELAGOS Sanctuary, and lethal collisions were more frequent between April and September (36). This pattern may reflect the combined effect of the seasonal increase of passenger vessel traffic in the area during spring and summer and the highest density of fin whales concentrating in the north-western Mediterranean Sea (16, 18, 30, 7). In summer, intense ferry traffic between the continent, Corsica and Sardinia transports large numbers of tourists. Merchant shipping is also intense between the largest Mediterranean harbours of Barcelona, Marseilles and Genoa (28, 42, 12). Vessels such as ferries and Very Fast Ferries (VFF) can be damaged during these events and sometimes human injuries occur, with such events negatively impacting the public image of shipping companies. Floating carcasses are another issue as they represent a marine hazard to shipping and marine authorities have to remove them.

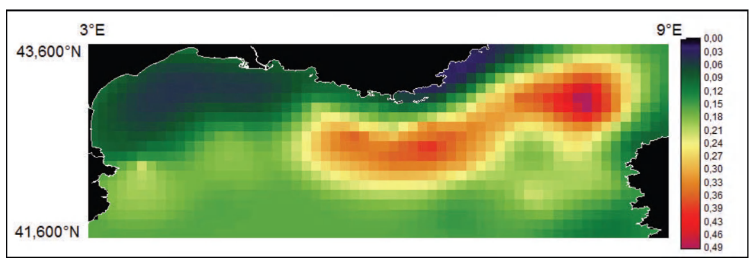

Figure 2 - Distribution of fin whales in the north-western Mediterranean Sea for July-August over 9 years (1993-2001), expressed as a mean number of sightings per hour of effort, in 0.1° x 0.1° cells. Kriging map (figure modified from (30)).

The regular increases of reported collision cases and the likelihood of unreported strikes, suggest that this threat is underestimated for fin whales. But the areas where collisions are most probable remain undetermined, which may slow down the implementation of mitigation measures. Using the known summer distribution of fin whales (Figure 2 modified from Monestiez et al. (30)), the aim of this study was to assess the spatial distribution of the potential for collision between fin whales and large commercial vessels. These results allow us to propose and discuss mitigation measures best suited to reduce this collision potential, and moreover to delimit more precisely the zones where they should be implemented. The approach we use could be used in all part of the world where similar threats occur in order to highlight the area and/or time where collision potential is highest and to model mitigation solutions.

Material and Methods

Datasets

Good quality data on fin whale distribution exist only for summer months. The 9-year summer distribution map of fin whales (1993-2001) was based on the map from Monestiez et al. (30). This study took place in the north-western Mediterranean Sea (3.0-9.0°E, 41.6-43.6°N) and encompassed a large part of the PELAGOS Marine Mammal Sanctuary. Fin whale density was extracted for 1,040 cells of 0.1°x 0.1° (i.e. 90 km²/cell).

The shipping traffic data set was established for ferries according to the timetables provided by the companies through the Internet or in schedule booklets. The trajectories were drawn according to the route ferries have to follow to link departure and arrival harbours. Two categories were distinguished: 1) car-ferries, large passenger ships travelling at speeds lower than 25 knots (46.4 km/h) and 2) Very Fast Ferries or VFF (high-speed car-ferries) and also fast ferries: large boats travelling at speeds higher than 25 knots (beyond 46.4 km/h). Our data set was established for the July - August 2001 period.

The data for trading vessels (vessel size ranging form 70 to 320 m long), were provided by the Lloyd's Intelligence Maritime Unit to the S.C.O.T. Society which conducted a study ordered by the French Ministry of Equipment, Transport, Housing, Tourism and the Sea. It is quite an exhaustive data set of all categories of merchant vessels (bulk carrier, tanker, port-container) travelling in the western Mediterranean Sea. We were allowed to extract from their data set all information needed to assess the distribution of commercial traffic in July - August 2001 period for the north-western Mediterranean Sea.

Data analysis

a) Shipping intensity

The vector map of the ship's trajectories was converted into a raster map with a cell resolution of 0.1° x0.1° in order to match the scale chosen to map the fin whale abundance. Using GIS (ARCVIEW 3.2 and IDRISI 32) for each cell, we calculated 1) the distance covered by the trajectory within that cell and 2) the number of ships following that route during July and August. By combining these two data sets we were able to map the shipping intensity expressed as a number of km travelled in a cell for each ship category.

b) Potential of collision

"Potential of collision" was estimated by combining data on fin whales density and shipping intensity at a 0.1°x0.1° scale using GIS (ARCVIEW 3.2 and IDRISI 32). Data on these two independent events were previously normalized and the resulting values were also normalized in order to obtain an indicator of the potential of collision ranging from low (0) to high (1).

c) Estimation of collision frequency

Tregenza et al. (43) proposed a simple model to evaluate the collision frequency "collision.exe" (http://www.chelonia.co.uk/collision_prediction.htm) based on the estimation of the number of whales that a ship can find in its path each year:

$$N = (W + 0{,}64L) \times D/1000 \times T \times P \times Y$$

With :

W = Hull width in m
L = Length of whale in m
D = Length of ferry transect in km
T = Percentage of whale time near surface
P = Mean number of whales per sq km
Y = ferry transect per year

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

$$D \times R = \int^{1}_{k} (d1 \times r1 + d2 \times r2 \ldots + dk \times rk)$$

To model 2D collision risk 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) ferries do not avoid whales.
5) the ferry transect has an overall density of whales that is the same as some overlapping area from which a survey has given the density estimate.

d) Mitigation by reduction of shipping speed

We propose a range of solutions based on a progressive reduction speed according to the density of the whales. We had to select spatial limits for the different speed limitations. So the quartile of the sighting density of fin whales (30) were use in order to defined three thresholds as three areas: the first one encompassed cells where the fin whale sighting density represented three quarters (75%) of the maximum density (i.e. > 0.122 sighting/hour, for a maximum of 0.49), the second encompassed cells with density half of the maximum (> 0.24 sighting/hour), and the third encompassed cells with the highest quartile (25%) of the maximum of density (> 0.37 sighting/hour). According to Laist et al. (25), the ship speed limit should be set at 10 knots in order to limit the severity and the number of strikes.

e) Modelling of least costly routes

As fuel represents an important part of shipping costs, assessment of the best compromise between the shortest ship trajectories of the vessels in order to avoid the highest density areas of fin whales sightings was modelled. This model of "least costly routes" in terms of strike risk, used an accumulated friction surface (whales sighting densities) using a push-broom algorithm. This means that the trajectory of the vessel from one point (harbour of departure) to another (harbour of arrival) is calculated to be the shortest, taking into account the constraint to avoid the area where the whale densities are the highest.

Results

Shipping distribution

Our database for Ferries and VFF accumulated over the 2001 summer season contains over 11,000 one-way trips from fifteen companies with 57 distinct destinations. The extracted data set from the SCOT data base for trading vessels contained 5,002 passages over 478 different trajectories.

All data were combined to map the shipping traffic intensity and revealed that 90.5% of the cells (941 cells out of 1,040) were crossed by at least one ship through the summer. Some cells exhibited very high shipping intensity (up to 16 crossing per day, Figure 3, Figure 4). Ferries, VFF and trading vessels represented 48.5%, 12.8% and 38.7% of the summer shipping traffic respectively. Distinctive trends appear according to ship category: trading vessel traffic is widespread over the whole study area (93.1% of the cells), whereas the traffic of ferries and particularly of VFF is rather intense over a more restricted area (53.2% and 12% of the cells respectively). A prevailing southwest/northeast axis appears, and secondly a north-south axis, resulting mainly from the main cargo lines. In the Ligurian Sea, most of the traffic connects the continental harbours to those of both islands of Corsica and Sardinia.

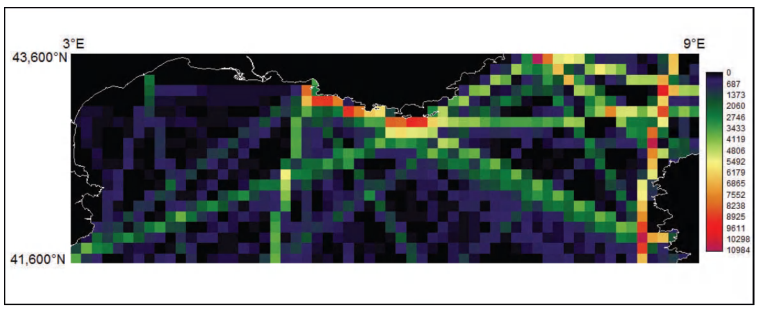

Figure 3 - Shipping traffic intensity of all large vessels combined (ferry, Very Fast Ferry and trading vessel), expressed in km covered, in 0.1° x 0.1° cells

Hence the highest shipping intensity is found in the Ligurian Sea (Figure 3) and high intensity of traffic is also observed 1) in the vicinity of Marseille and Nice harbours, 2) in locations where shipping routes cross each other and 3) along the coastline between Marseille and Toulon and along the western coast of Corsica.

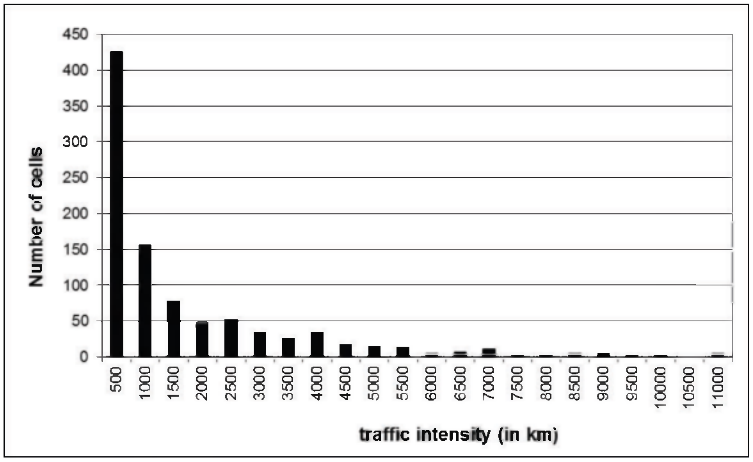

Figure 4 - Frequency of traffic intensity of large vessels in summer in the north-western Mediterranean Sea, in km per 0.1° x 0.1° cells

Areas of high potential of collision between fin whales and large vessels

Most of the summer fin whale's habitat is exposed to collision (Figure 5). Only 14.8% of the fin whales habitat (i.e. the study area excluding the shelf of the Gulf of Lion) has a 0 potential estimation, and this rises up to nearly 32% if the Gulf of Lion is included (Figure 6). The highest potential of collision was mainly found in the Ligurian Sea and secondly off the Provençal coast (offshore Marseille to Saint-Raphaël) (Figure 5).

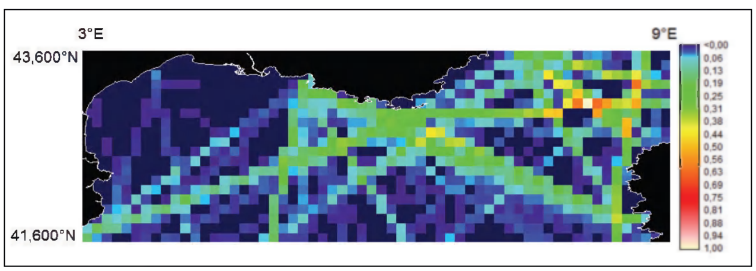

Figure 5 - Overall potential for collision between fin whales and the three categories of large vessels (ferry, Very Fast Ferry and trading vessel) in summer in the north-western Mediterranean Sea. Indicator: from 0 (low potential for collision in blue) to 1 (high potential for collision in white).

The potential of collision varies geographically according to ship category, increasing eastward for ferry and VFF, due to higher tourist traffic between the European mainland, Corsica and Sardinia.

Estimation of collision frequency

When applying the model proposed by Tregenza et al. (43) to the study area and according to fin whales density estimates (0.097 individuals/km^2 in the PELAGOS Sanctuary, which represent a population of 715 individuals (CV=31.2%) from Gannier (20)), we estimated that up to 210 fin whales could be in the path of large vessels for one summer (3.4 fin whales per day; Table 1). The collision rate associated with ferry and trading vessel was higher per km covered compared to VFF due to their slimmer hull width.

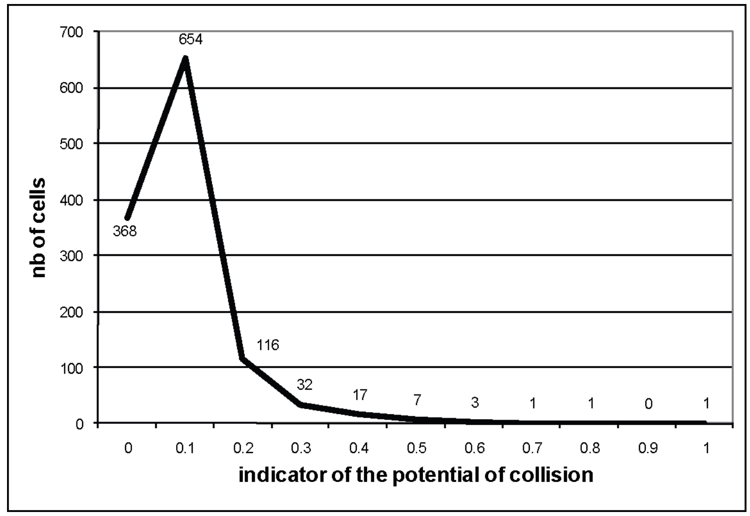

Figure 6 - Frequency of the indicator of the potential of collision between fin whales and all large vessels in summer in the north-western Mediterranean Sea, from 0 (low potential) to 1 (high potential) per 0.1° x 0.1° cells. (Data corresponding to Figure 5).

	Total large vessels	Ferry	VFF	Trading vessel
Number of km travelled by vessels	**2,201,200**	1,238,600	354,200	608,400
Length of a whale in meters	**20**	20	20	20
Percentage of whale time near surface [(1)]	**30**	30	30	30
Hull width in meters	**20**	20	13	20
Mean number of whales per sq.km [(2)]	**0.0097**	0.0097	0.0097	0.0097
Number of fin whale found on trajectory/ summer	**210.1**	118.2	26.6	58.1
Number of fin whale found on trajectory/day	**3.4**	1.9	0.4	0.9

[(1)] from Jahoda and Notarbartolo di Sciara (1993) (31) and [(2)] from Gannier (2006) (20).

Table 1 - Variables used and results of the estimation on the number of fin whales that traditional ferry, Very Fast Ferry and trading vessel are likely to find on their trajectories in the PELAGOS Sanctuary in summer (July-August)

Modelling least costly routes and areas of ship speed reduction

According to the quartiles of sighting densities of fin whale we draw areas (Figure 7) of potential ship speed reduction: area 1 (inside the yellow line, from the offshore Gulf of Lion through the west coast of Corsica) where the sighting densities of fin whales is 75% of the maximum density (i.e. > 0.122 sighting/hour, for a maximum of 0.49), area 2 (inside the red line, off the Provençal coast) encompassed cells with density 50% of the maximum (> 0.24 sighting/hour), and two small areas 3 (inside the pink line) encompassed cells with the highest quartile (25%) of the maximum of density (> 0.37 sighting/hour). The area where the reduction of speed is most needed are (a) the centre of the Ligurian Sea and offshore Toulon (corresponding to areas 3), (b) an area encompassing a large part of the habitat of the fin whale (offshore from Marseille to Corsica) (inside red line). On the other hand, the areas that do not need speed limitation are coastal ones (from coast to yellow line). The least costly routes, from the main harbours (Barcelone, Marseille, Toulon, Nice, Bastia, Calvi, Ajaccio, Propriano…) avoiding areas of high fin whales densities are also shown in Figure 7. This would result in a mean increase of the distance travelled of 19.3 ± 10.6 km per trip.

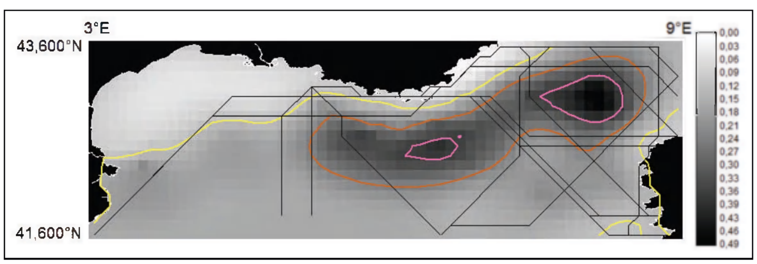

Figure 7 - Potential areas for reduction of ship speed to 10 knots in summer in the north-western Mediterranean Sea based on the quartiles of sighting densities of fin whale (see text). And modelling results computing least costly routes in term of collision for ferries and trading vessels (in black lines) in order to avoid high sighting densities of fin whale areas (Figure 2 in background, expressed in number of sightings per hour in 0.1° x 0.1° cells).

Discussion

Concerning the maritime traffic data, the Automatic Identification System (AIS) which is mandatory since January 2005 aboard all vessels over 300 gross tons, should provide valuable information. It is a VHF broadcast system that sends information at regular intervals including the identity of vessel, position, course and speed to other vessels or onshore receivers. But because AIS is a VHF system, transmissions are generally limited to line of sight and the range of transmission depends greatly on atmospheric conditions (23, 41). So some offshore sea areas may not have a constant coverage leading to inconsistent data and underestimation of maritime traffic. In the future, the network of receivers and the archiving systems of AIS data for the Mediterranean Sea will certainly be improved in order to be a reliable, regular and available source of information. Nevertheless, our map of maritime traffic and the "hotspots" of intensity of traffic are coherent with the maps provided by AIS data collection (41, 14, www.marinetraffic.com/ais).

Keeping in mind that the potential of collision is a theoretical maximum calculated in the absence of any reaction either of the ship or the animal (which fortunately is not the case), this study shows a rather eloquent map of shipping traffic intensity which when compared to the summer occurrence of fin whales reveals that fin whales are threatened by collision nearly everywhere in their summer habitat. This threat is particularly high firstly within the central part of the Ligurian Sea and secondly off the coast of Provence (from Marseille to Saint-Raphaël). The threat is lower in the Gulf of Lion, a widespread shelf rarely visited by fin whales and with low maritime traffic. It is also low in the southern part of the study area, but this could be due to reduced fin whale observation effort increasing with distance from the coast. Also maritime traffic is less than in the northern part of the study area. Calculation of the collision frequency is overall very high, ranging from 0.4 whale/day for a VFF to 1.9 w/d for a ferry (Table 1). On the other hand, if the frequency of collision for the summer for each type of ferry is divided by the number of respective vessel usually in action, i.e. 10 VFF and 45 traditional ferries, it would become identical for both types of vessel: 2.6 whales/vessel. Indeed, there are fewer VFF but they travel fast so they accumulate a larger distance covered due to their higher speed, whilst the ferries are more numerous but are slower. However the frequency of collision is lower (0.012 whale/vessel) for the trading vessels because they travel less across high density fin whales areas compared to the other ship categories. As a consequence of these results, mitigation measures and involvement of shipping companies are likely to vary according to ship category.

Vessels travel speed was pointed out as one of the most important parameters involved in collision (25, 45). Panigada et al. (36) highlighted that VFF caused 12.5% of fatal ship strikes in the entire dataset, but since their introduction in 1996, they have been involved in 42.9% of the accidents. On the other hand, Panigada et al. (36) did not find a significant difference in the annual numbers of fatal strikes before and after fast ferries were introduced in the north-western Mediterranean Sea. The situation is different in the area of the Canary Islands where only 7 collisions were reported over a 13-year period previous to the introduction of fast ferries while 30 collision events were reported over a 6-year period after VFF were introduced (11). According to our calculations the probabilities of potential collisions are lower for these vessels compared to classical ferries. Nevertheless, speed is not the only factor which could play a role in collisions: manoeuvrability is also very important. For example, the minimum detection distance needed to allow the pilot to react and avoid the animal depends on both speed and manoeuvrability. We gathered manoeuvrability and speed characteristics for two Very Fast Ferries and four classical ferries (Cdt Capoulade *pers.comm*) from the SNCM company crossing from the south of France to Corsica. We calculated that to give the pilot 10 seconds to react, the distances of detection should range between 198 - 246 m for classical ferries and 298 - 325 m for VFF.

According to the elements previously mentioned, it appears that in order to reduce the potential of collision, solutions have to address several points: increasing awareness and detection of animals, reduction of vessel speed and the avoidance of areas of high potential of collision. At various locations, different solutions have been proposed, tested, and recommended: detection and avoidance manoeuvres, repulsion, protection and training, in parallel with reporting and research (9, 12, 36, 47).

According to our results we discuss and improve the implementation of three possible mitigation measures, already put forward by other authors (9, 12, 29, 38, 47), and which are associated with increasing constraints to the Mediterranean Fin whale case.

(1) The use of observers.

The first approach is an "instantaneous and direct" measure which aims at detecting the whale while underway and reporting the sighting: specially trained observer and additional detecting tools (sonar or night vision devices) need to be aboard (8, 5, 36). This measure is useful since our results show that the fin whale is threatened by collision over its whole habitat. The observer can be a “Marine Mammal Observer” or a person from the shipping company who has been trained for that purpose. Existing experiments (system REPCET in 29) reveal that trained navigational personnel detect animals more easily and more effectively than those who were not trained. A few days are enough to train the personnel, and investment in such training is undoubtedly worthwhile for a shipping company. The specialized trained observer remains an effective solution during daylight and in good, or even moderately good weather conditions. Apart from these conditions, there is little alternative. As these solutions are suitable only in daylight and good weather conditions and as numerous collisions occur during the night, vessels travelling fast should either reduce their speed or only travel during daylight hours.

(2) Reduction of vessel speed

The second approach is areas of ship speed reduction, which tends to increase the reaction time of the two protagonists and reduces the importance of injuries. The literature already showed and stressed the importance of such a measure in order to mitigate collision (4, 8, 9, 12, 25, 36, 38, 44, 47) and our results make it finally possible to delimit the zones most favourable for its implementation.

Within the range of possible measures, a cost-benefit analysis of mitigation measures has to be made. Considering the current cost of the fuel, a reduced speed to 13 knots could theoretically mean lower costs. On the other hand, the duration of travelling is increased but this relationship varies according to the vessel category. For example a rough calculation shows that a VFF usually travelling at 33 knots from Nice to Calvi in slightly more than 3 hours nowadays and consuming 14.2 tons of fuel, would increase slightly its fuel consumption when reducing its speed whilst crossing areas of speed limitation shown in figure 7: by about 3 % if the speed limits concerns the area 3 only, 5.4% for speed limitation in area 2 and 8.2% for area 1 (Capoulade *pers. comm.*). However the time spent at sea would increase by 38% for a speed limitation in area 3 only, 71% for area 2 and 108% (5h 55min against 2h 51min nowadays) for area 1. The impossibility to travel more than two times a day could be of great concern. On the other hand, a classical ferry for the same trajectory would consume less fuel (between 14% and 39% according to the extension of the area of speed limitation) and increase between 21 to 60% its time at sea (6h 15min against 3h 55min). This might not be a problem when making one Provence-Corsica round trip per 24 hours. So, if any speed limitation would be implemented, VFF would no longer be interested in that part of the sea because their full speed capacity will be less used and their travel time would be only about 20 to 49 minutes less than a classical ferry. But whether or not a speed reduction means lower costs depends very much upon the design of the vessel and engine. The most efficient cruising speed for a vessel is not necessarily a slower speed and this needs to be examined on a vessel-by-vessel basis.

Some vessels could also choose to increase their speed outside the limited areas, although these accelerations may again not be profitable according to the characteristics of engine and optimal speed of the considered vessels.

(3) Constraining maritime traffic

The third approach seeks to limit the spatial overlap between the distribution of fin whales and ships (4) during the critical summer period, one of the best options to mitigate collision issue where it is possible according to Weinrich et al. (47). But the design of least costly routes is probably not the optimal solution for our large and offshore area where the distribution of whales shows inter-annual variability. It is better to think in terms of "avoiding areas" of high fin whale density by ships. For the shipping companies, the fuel and time costs associated with the new trajectories will increase proportionally to the increase of the travelled distance, but this has to be evaluated precisely for each route and vessel type.

Considering our results, the area to be avoided could fit the area that encompassed the "hot spots" of the highest density of fin whale (Figure 7, limit 3). But for a greater conservation aim, it should be extended to the area which encompassed 50% of sighting density (Figure 7, limit 2): that means a bigger part of the most frequented habitat of fin whales, a higher number of fin whales, and also an extended area where inter-annual distribution of the hotspot could occur. For practical reasons, the contour of the area should be drawn with straight lines (parallel and straight lines with simple geographical coordinates).

Another difficulty in implementing the solutions of speed limitations and "no ship zone" is the fact that the areas concerned are within international waters. Such measures could be limited to particularly risky vessel types: ferry, VFF, trading vessel at least. Since France, Italy and Monaco ratified the Sanctuary, measurements could certainly apply to their national ships but such measures would need to be implemented for vessels of other nations through IMO. Speed limitation measures were taken recently by the Spanish government in the Strait of Gibraltar to minimize collision potentials.

Panigada et al. (36) and also Mayol et al. (29) suggest a real time reporting of whale sightings for all vessels travelling in the concerned area. This approach has been applied by the Canadian authorities in the Bay of Fundy to protect right whales (46). But fin whales are seen in the whole area (Figure 2) and a previous study in our area shows that fin whales encountered whilst travelling in one direction were not re-sighted on the way back a few hours later (1). The REPCET system (29) takes this mobility in account and calculates in the course of time an Area of Potential Presence (APP) of the animal, starting from the initial geographical positioning of the observation and knowledge of fin whale behaviour. On the other hand, such a system could perhaps be useful around harbours where high densities of vessels occur. The semaphores of the Navy could also warn vessels of the presence of whales from land in certain places.

Another approach relies on habitat selection models in order to forecast large areas and periods of concentration of whales, according to remote sensing data of key environmental factors such as: currents, temperatures, chlorophyll-a, and production of primary and secondary biomass. (13, 26, 27, 37, 7). The map of the potential of collision could be drawn from such data on a near "real-time" year basis, and the implementation of restricted areas and periods could then be adapted.

Conclusion and Perspectives

Collisions are a global threat for cetaceans, but for environmental managers and stakeholders it is important, for obvious reasons of implementation, to accurately determine where and when to act and set up conservation measures. Our study shows the areas where the fin whales are the most exposed.

The next step should be to assess properly the economical cost associated with the solutions proposed in this study for each ship category and this assessment should be conducted in close collaboration with the shipping companies. The implication of ship owners, shipping companies, enforcement officials, and vessel crew, via education on "high-use" areas by species and season and potential of collision (killing animals, damaging vessels, injuring passengers, harbour costs for a carcass strike on the bow, bad publicity for the shipping company), is also the best way to ensure viable conservation measures.

Moreover, one of the hypotheses as to why collision occurs is that animals are involved in a particular behaviour and don't pay attention to their near environment. This subject requires additional study to better understand the reaction (or not) of fin whales to an approaching vessel when involved in different behaviours like resting or feeding. Because some collisions occur at night, research should also include this poorly known period of the animal's life. More radio-tracking or Time-Depth-Recording studies could help in improving our knowledge concerning whale behaviour and movement at the surface and in the water column on day/night cycles (34, 24).

Lastly, evaluating collision potentials for the fin whale and presenting suitable solutions is one step. Making these solutions feasible is another step. Such solutions should not threaten other species. Fin whales are not the only animal being hit: sperm whales (*Physeter macrocephalus*) are also often hit by ships in the Mediterranean Sea (38, 11). Moreover, our study highlighted offshore areas as the highest at risk for collision and coastal ones less at risk, leading to a potential inshore pathway for great vessels. But sperm whales are often seen in coastal areas (slope) as well as offshore. So a similar study should be conducted to evaluate the high collision potential areas for sperm whales before implementing solutions to mitigate collision threats for fin whales.

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