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Mediterranean fin whales at risk from fatal ship strikes

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Abstract

This paper reviews and analyzes ship collision records for the relatively isolated population of fin whales in the Mediterranean Sea from 1972 to 2001. Out of 287 carcasses, 46 individuals (16.0%) were certainly killed by boats. The minimum mean annual fatal collision rate increased from 1 to 1.7 whales/year from the 1970s to the 1990s. Fatal strike events (82.2%) were reported in or adjacent to the Pelagos Sanctuary, characterized by high levels of traffic and whale concentrations. Among 383 photo-identified whales, 9 (2.4%) had marks that were attributed to a ship impact. The reported rates are unusually high for baleen whales. The high likelihood of unreported fatal strikes combined with other anthropogenic threats suggests an urgent need for a comprehensive, basin-wide conservation strategy, including ship strike mitigation requirements, like real-time monitoring of whale presence and distribution to re-locate ferry routes to areas of lower cetacean density, and reducing ship speed in high cetacean density areas.
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1. Introduction

Fin whales (*Balaenoptera physalus*) are common in the Mediterranean Sea, where they tend to concentrate in localized, highly productive areas for feeding purposes (Orsi Relini et al., 1994; Zanardelli et al., 1999; Notarbartolo di Sciara et al., 2003). One such aggregation area for fin whales is the Pelagos Sanctuary for Marine Mammals (Fig. 1); oceanographic features of this MPA support high levels of prey biomass (Jacques, 1990; Astraldi et al., 1995) and a large number of cetaceans (Notarbartolo di Sciara et al., 1993; Gannier, 2002).

Genetic evidence suggests that the Mediterranean Sea population, estimated in the western basin at around 3500 (Forcada et al., 1996), is resident and characterized by only very limited gene flow with the North Atlantic population (Bérubé et al., 1998; Palsbøll et al., 2004). This small and ecologically isolated population faces several threats, where widespread environmental degradation has taken place in recent years; acoustic pollution, presence of detrimental manmade compounds in the marine food web, increased human disturbance, interaction with fisheries, depletion of living resources and loss of biodiversity, are among the main problems that affect Mediterranean fin whales (Notarbartolo di Sciara and Gordon, 1997).

Ship strikes with odontocetes and mysticetes are regularly reported from all over the world's oceans, with evidence of ships collision described for 11 species of large whales, of which the fin whale is most commonly recorded as being hit by ships worldwide (Laist et al., 2001).

Every year, 220000 ships of more than 100 tons cross the Mediterranean basin (Anonymous, 1999; SCOT, 2004). Furthermore, a total of 2000 vessels, including

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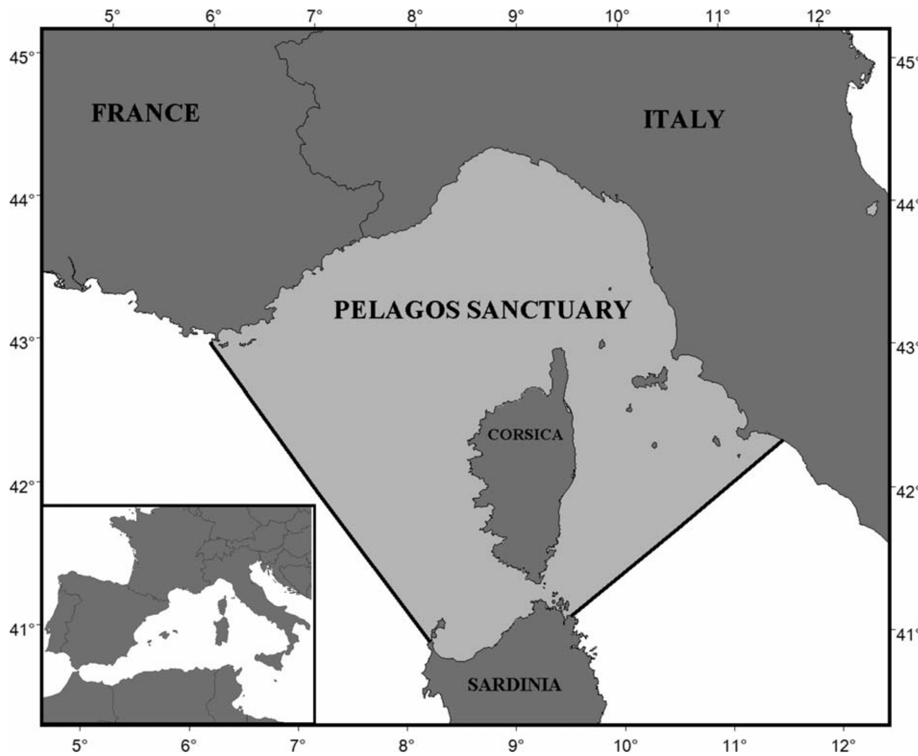

Fig. 1. Borders of the Pelagos Sanctuary for Marine Mammals. The location of the area in the Mediterranean Sea is shown in the inset.

ferries, fast ferries and hydrofoils, as well as military, fishing, pleasure and whale-watching boats, navigate these waters daily (Anonymous, 1999). This vessel traffic is highest during the summer months in areas where whales often aggregate (Notarbartolo di Sciara and Gordon, 1997; Zanardelli et al., 1999; Gannier, 2002).

The objective of this paper was to collect all the records documenting ship strikes between fin whales and different types of vessels in the Mediterranean Sea in order to assess the extent of ship collisions with Mediterranean fin whales, to assess necessary conservation measures, and to suggest further research activities aimed at reducing the potential for vessel collisions and to maintain mortality rates for the Mediterranean population at sustainable levels.

2. Materials and methods

2.1. Stranding data (dead whales)

Data regarding deceased individuals were initially extracted from existing stranding databases. In the Mediterranean Sea there are three cetacean stranding networks with accurate and complete datasets: Centro Studi Cetacei (CSC) in Italy, Groupe d'Etudes des Cétacés en Méditerranée (GECEM) and Centre for Research on Marine Mammals (CRMM) both in France. Data were extracted from the Italian and French stranding networks covering years 1986–2001 and 1972–2001, respectively. The National Archive of Cetacean Strandings and Sightings in Greece (1991–2001) was also reviewed. We also looked for historical and anecdotal records, such as early stranding records, newspaper articles, ferry companies' archives, Harbor Offices reports, and reports from marine biologists and ship captains.

For all the gathered records we verified the source and checked the contents in order to assess the possible causes of death. A dead animal was considered as being killed by a vessel when: (a) it was reported in a reliable stranding report; (b) it presented fractured heavy bones (Laist et al., 2001) and/or (c) the body presented large wounds or parallel and evenly spaced slashes derived by a ship hull or propeller (Lockyer and Morris, 1990; Bloom and Jager, 1994; Wells and Scott, 1997; Moore et al., 2004).

Accounts from unreliable sources and unclear reports were excluded from the confirmed struck fin whales (Table 1). Moreover, records of specimens possibly struck when already dead were rejected. The presence of hematomas (indicating a functioning circulatory system) was used to confirm that the whale was hit when alive, as were injuries located in the upper part of the body in otherwise intact animals (since dead whales generally float belly up (Laist et al., 2001)). All the reports not positively included among those confirmed were considered as doubtful collisions (Table 1).

For each ship strike we recorded the date, location, source, and, when available, the animal's sex and length, the type and position of injury, and the type of vessel involved (Table 1). To investigate whether some locations were more affected than others, we summarized collision locations and analyzed them by geographical areas.

Table 1
Detailed available information on dead carcasses, sure records are listed first followed by unsure ones

Date	Locality	Country	Sex	Length (m)	Injury type	Source	Vessel type	Notes
09/01/1897	Capo Spartivento, Reggio Calabria	Italy			Collision at sea	Parona (1908)	Yacht	'Kevente', blood in the water
1967	Calvi, Corsica	France			Collision at sea	F.C., this paper	Car-ferry	'Comté de Nice'
07/02/1971	Between Marseille and Annaba, Algeria				Collision at sea	F.C., this paper	Car-ferry	'Comté de Nice'
05/07/1972	20 miles off Cape Corse, Corsica	Ligurian Sea	M	18	On bow	Duguy (1973)	Car-ferry	'Corse'
03/09/1972	Between Nice and Bastia	Ligurian Sea	M	12.6	On bow	Duguy (1973)	Car-ferry	'Corse'
April 1973	Gulf of Genova	Italy	M	17.25		Museum of Natural History, Verona		
06/04/1973	Gulf of Lions	France	M	16	Collision at sea	Casinos and Filella (1975)	Yacht	'Cabo San Sebastian'
30/08/1973	Between Nice and Calvi	Ligurian Sea		15	On bow	Duguy (1974)	Car-ferry	'Corse'
10/09/1974	15 miles off Antibes, Alpes-Maritimes	Ligurian Sea		15	Cut in two	Duguy (1975)		
24/01/1976	Zappulla, Messina	Italy		18.8	External and internal lesions	Di Natale and Giuffré (1976)		Propeller cuts, fractured lower jaw, gashes on the jaws
03/04/1976	Toulon, Var	France	M	14.3	On bow, internal lesions	Duguy (1977)	Merchant ship	Several ribs and cervical vertebra broken
01/01/1977	Gulf of Genova	Italy	M	12.9	On bow, internal lesions	Poggi (1982)	Ferry	'Leopardy', broken ribs and fractured cervical vertebra
15/08/1981	Between Marseille and Ajaccio	Ligurian Sea			Collision at sea	F.C., this paper	Car-ferry	'Napoléon'
27/05/1982	Puerto Valencia	Spain	M	12.13	On bow	Raga et al. (1991)		
14/09/1982	Marseille	France			On bow	Capoulade (2002)	Car-ferry	'Napoléon'
19/09/1982	Villeneuve-les-Maguelonne, Hérault	France		13.5	Cut in two	Duguy (1983)		
15/01/1985	La Palme, Aude	France	M	18	External lesions	Duguy (1986)		Propeller cuts on the back behind the dorsal fin
23/01/1986	Puerto Barcelona	Spain	F	12.5	On bow	Raga et al. (1991)		
23/06/1986	Castello Sonnino, Livorno	Italy	M	11.5	External lesions	Anonymous (1987)		Propeller cuts on the back
28/06/1986	9 miles off Gorgona Island, Livorno	Italy		14	External lesions	Anonymous (1987)		Propeller cuts on the back
10/08/1986	Puerto Barcelona	Spain		12	On bow	Raga et al. (1991)		
10/11/1986	Fos-sur-Mer, Bouches-du-Rhone	France		16	On bow	Duguy (1987)	Merchant ship	
21/05/1987	Puerto Valencia	Spain	M	13.9	On bow	Raga et al. (1991)		
22/05/1987	Olbia, Sassari	Italy	F	12.95	On bow	Anonymous (1988)		'Deledda'
11/08/1988	Between Nice and Ile Rousse	France				F.C., this paper	Car-ferry	'Corse'
29/09/1988	Puerto Valencia	Spain	F	15.2	On bow	Raga et al. (1991)		
20/05/1989	Olbia, Sassari	Italy	F	12	On bow	Anonymous (1991)	Ferry	
28/04/1990	Porto Torres, Sassari	Italy	M	16	External lesions	Anonymous (1992)		Whale found alive, propeller cuts on the back
30/04/1991	Genova	Italy	M	17.65	On bow	Anonymous (1994)	Ferry	
30/03/1993	Porto Torres, Sassari	Italy	F	15	Internal lesions	Anonymous (1996a)		Fractured lower jaw and broken tail
09/09/1993	Saint-Tropez, Var	France			Collision at sea	Laist et al. (2001)		
09/09/1993	Toulon, Var	France	F	16	On bow	Laist et al. (2001)	Ferry	'Ile de Beauté'
20/05/1994	Pula, Cagliari	Italy	M	13	External and internal lesions	Anonymous (1996b)		Propeller cuts on the right side, fractured right flipper
25/05/1995	Off Livorno	Italy	M	15.15	On bow, external and internal lesions	Anonymous (1997)		Fractured lower jaw and wounds
26/09/1995	Fos-sur-Mer, Bouches-du-Rhone	France	F	18	On bow	Laist et al. (2001)	Merchant ship	'Japan Senator'
26/07/1996	Off Bastia, Corsica	France	M	14	On bow	Laist et al. (2001)	Ferry	'Danielle Casanova'

(*continued on next page*)

Table 1 (*continued*)

Date	Locality	Country	Sex	Length (m)	Injury type	Source	Vessel type	Notes
24/02/1997	Marseille, Bouches-du-Rhone	France	M	5.16	Internal lesions	Laist et al. (2001)		Whale found alive with umbilical cord, broken ribs and large hematoma on the right side
07/02/1998	Darsena, Livorno	Italy	M	13.8	External lesions	Anonymous (2000)		
04/06/1998	South Cap D'Armes, Porquerolles	France			Collision at sea	Capoulade (2002)	Roropax ferry	'Monte Cinto'
06/08/1998	43°05′N, 007°48′E	Ligurian Sea			Collision at sea	Capoulade (2002)	Fast ferry	'NGV Asco'
02/08/1999	Between Ajaccio and Nice	France		10	Collision at sea	Capoulade (2002)	Fast ferry	'NGV Aliso'
15/04/2000	Between Calvi and Nice	France			Collision at sea	Capoulade (2002)	Fast ferry	'NGV Aliso'
06/07/2000	North Giraglia, Corsica	France			Collision at sea	F.C., this paper	Car-ferry	'Corse'
09/07/2000	Haute-Corse, Corsica	France	M	18		F. Dhermain, personal communication		
20/10/2000	Marseille	France	M	17.8	On bow, external and internal lesions	F. Dhermain, personal communication	Merchant ship	Fast trader, two broken ribs, huge hematoma and a small wound on the right side
25/10/2000	La Seine Sur Mer	France		20	External lesions	F. Dhermain, personal communication		Propeller cuts
1958	Between Marseille and Alger				Collision at sea	F.C., this paper	Merchant ship	'Ville D'Alger'
1960	Between Marseille and Alger				Collision at sea	F.C., this paper	Merchant ship	'Ville D'Alger', data lacking, no precise date
1970					Collision at sea	F.C., this paper	Merchant ship	'Ville de Marseille' or 'Ville de Tunis', data lacking, no precise date
13/08/1973	Between Nice and Calvi	Ligurian Sea			On bow	Capoulade (2002)	Car-ferry	'Corse', uncertain species
1981–1982					Collision at sea	F.C., this paper	Car-ferry	'Liberté', data lacking, no precise date
18/08/1986	Tunis	Tunisia			On bow	F.C., this paper	Car-ferry	'Esterel', uncertain species, no necropsy
1994	Toulon, Var	France			Collision at sea	F. Dhermain, personal communication	Car-ferry	'Liberté', no precise date
18/11/1998		Ligurian Sea			Collision at sea	F. Dhermain, personal communication	Motorboat	Uncertain species, offshore competition 'Route du Rhum'
1998	Genova	Italy			On bow and external lesions	L. Borniotto, personal communication		No necropsy, found in Genova harbor, no precise date, large cut on lower jaw
1999		Ligurian Sea			Collision at sea	L. Borniotto and F. Dhermain, personal communication	Fast ferry	Uncertain species, no necropsy, found on Genova harbor, no precise date
06/12/2001	Genova	Italy	F	13.5	On bow	Anonymous (2003)	Merchant ship	'Colombian Star' arriving from Portugal

Notes include name of ship involved and injury type.

We performed chi-square tests to test annual, seasonal and monthly variation of ship strikes, as well as to test for a sex bias in collision events, and to assess whether ship categories were evenly involved in collisions. In some cases, where a small sample size violated the assumptions of the chi-square test, p-values were computed by Monte Carlo simulation (10 000 replicates).

We calculated the observed annual fatal collision rate by dividing the number of strikes by the years considered. Mortality rates due to collisions were calculated by dividing the annual collision strikes rate by the whale abundance, estimated in the western Mediterranean (Forcada et al., 1996) and in the Corso–Ligurian Basin (Forcada et al., 1995), respectively. Because reliable stranding reports were available only after 1972, we focused on the ship strikes that occurred since this date.

To investigate the type of boats involved in collisions with whales, we created five vessel categories: (1) *passengers ships, car-ferries, roropax*: large (>80 m) passenger ships traveling at speeds lower than 24 knots (44.4 km h^{-1}); (2) *high-speed car-ferries, fast ferries*: large (>80 m) boats traveling at speeds over 24 knots (44.4 km h^{-1}); (3) *merchant ships*: 70–320 m long vessels traveling at speeds up to 15 knots (27.8 km h^{-1}); (4) *yachts*: leisure boats from 15 to 80 m long, reaching 35 knots in speed (64.8 km h^{-1}); (5) *motorboats*: very fast boats (up to 80 knots, 148.2 km h^{-1}) with lengths less than 40 m.

2.2. Photo-identification data (living whales)

Data on live fin whales presenting evidence of collisions were gathered by contacting institutes involved in photo-identification projects and by examining photographs collected opportunistically. The majority of the data derive from the photo-identification catalogue compiled by the Tethys Research Institute from 1990 to 2001 during a long-term study in the offshore waters of the western Ligurian Sea, Sardinian Sea and Ionian Sea, including the Pelagos Sanctuary (Politi et al., 1994; Lauriano, 1997; Zanardelli et al., 1999; Panigada et al., 2005). The French identification catalogues compiled by the Groupe de Recherche sur les Cétacés (GREC, Antibes), and by the Ecole Pratique des Hautes Etudes (EPHE, Montpellier), have been similarly reviewed, as well as images collected by the Italian associations Delphis mdc and Isola Blu.

Animals with large wounds – whether healed or not – or propeller scars were considered as victims of a boat collision. Missing flukes or dorsal fins, "humpbacked" whales and large wrinkled white spots were defined as doubtful events. The loss of all or a part of a fin can indeed be the result of a ship strike, as directly observed by De Stephanis et al. (in press). However, Green et al. (1991) report that entanglements in fishing gear may lead bottlenose dolphins (*Tursiops truncatus*) to lose their dorsal fin. Malformations of the vertebral column – leading to humpbacked cetaceans – can be caused by ship strikes (possibly in juvenile age) as well as by other causes, including strenuous effort, bacterial infections or exposure to high levels of organochlorines (Berghan and Visser, 2000). Finally, large and wrinkled white spots present on whales' body could not be discarded as possible evidence of previous ship impacts, but neither could their source be definitively assigned.

For each injured whale, the date and position of sightings and eventual resightings, injury type and position on the whale's body, and source were recorded when available (Table 2).

Table 2
Geographic positions of the photo-identified whales presenting evidence of collisions, with injury type and position on the body

Whale code	Date	Lat	Long	Sex	Injury type	Resightings	Lat	Long	Injury position on the body	Source
Bp 93021A_g3	28/06/1993	42°59′N	006°58′E		Healed over lesion				Depressed scar on the caudal peduncle	GREC[a]
Bp 93061C_d1	23/07/1993	43°05′N	007°00′E		Healed over lesion				Depressed scar in the center of the back	GREC
Bp 388	07/06/1994	43°24′N	007°19′E		Healed over lesion				Depressed scar in the center of the back	TRI[b]
Bp 337	07/07/1995	43°36′N	008°03′E		Healed over lesion				Depressed scar in the center of the back	TRI
Bp 3039	17/08/1996	41°08′N	008°05′E		Healed over lesion				Depressed scar in the center of the back	TRI
Bp 487	21/07/1998	43°31′N	007°54′E		Healed over lesion	14/09/1999	43°29′N	008°20′E	Depressed scar in the center of the back, plus a cut on each side	TRI
Bp 130	22/07/1992	43°17′N	008°05′E	M	Propeller scars				Right side	TRI
Bp 499	21/09/1998	43°37′N	008°08′E		Propeller scars				Right side, departing from the center of the back	TRI
Bp 208	03/08/1993	42°51′N	008°39′E		Non-cicatrized wound	07/09/1994	42°47′N	008°05′E	Left side, departing from the center of the back	TRI, CIBRA[c]

[a] Groupe de Recherche sur les Cétacés.
[b] Tethys Research Institute.
[c] Centro Interdisciplinare di Bioacustica e Ricerche Ambientali.

3. Results

3.1. Stranding data (dead whales)

We found records of 287 fin whales stranded along the Mediterranean coasts, caught on the bow of a ship or found floating at sea. Of these, 46 animals (16.0%) were confirmed to have died because of a ship strike (Table 1).

The first fatal ship strike reported is dated 1897, and only two more records – in 1967 and 1971 – are available until 1972 (Fig. 2). Between 1972 and 2001, 43 whales were killed, yielding a mean fatal strike rate of 1.43 animals/year. We divided the study period in three decades and obtained annual mortality rate values of 1.0, 1.6 and 1.7, respectively. While there was no significant difference between the three periods (F-statistic = 0.7643, $p = 0.3894$), it may be noteworthy that in the latter two periods the observed annual fatal strike rate was almost 60% higher than the first period.

No statistical difference was found in the fatal ship strikes monthly frequency distribution ($\chi^2 = 47.91$, df = 35, $p = 0.0716$; simulated $p = 0.0607$) (Fig. 3), but there was a significant trend in the seasonal distribution ($\chi^2 = 13.46$, df = 3, $p = 0.0037$), with more collisions in the spring and summer months compared to the winter and autumn seasons. This matches the presumed Mediterranean fin whale feeding season (April–September) (Notarbartolo di Sciara et al., 2003) versus the assumed breeding months (October–March), with the majority of the accidents (76.7%, 33 versus 10) occurring within the feeding season ($\chi^2 = 12.30$, df = 1, $p = 0.0004$).

Sex was determined for 26 stranded animals, with significantly more males (73.1%, 19 whales) than females ($\chi^2 = 5.54$, df = 1, $p = 0.0186$). Total body length was reported for 35 fatally struck animals (Fig. 4). Only one calf was found in the sample. The average length of the whales was 14.7 m (SD = 2.9, range 5.16–20.00 m).

Among the 46 reports of confirmed fatal whale strikes, detailed injury descriptions were available for 16 specimens (34.8%). Of these, six (37.5%) showed only external lesions such as propeller cuts ($n = 5$) or other wounds ($n = 1$); two (12.5%) were split in two, four (25.0%) presented internal

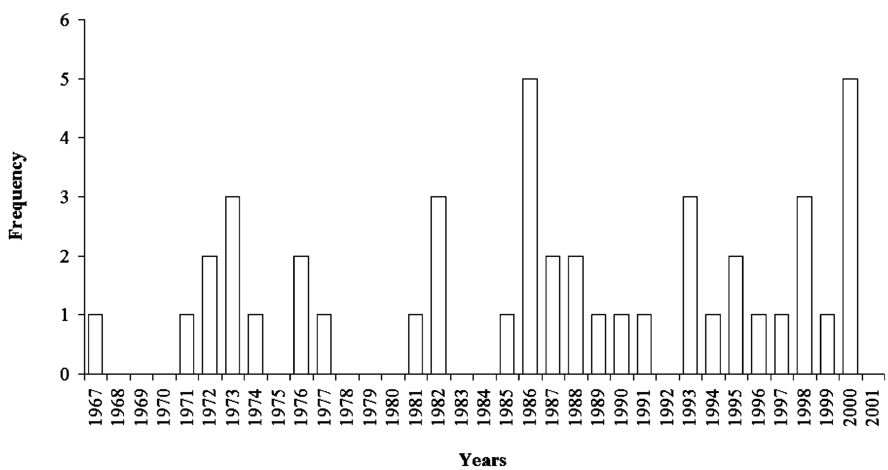

Fig. 2. Fatal ship strikes recorded in the Mediterranean Sea each year.

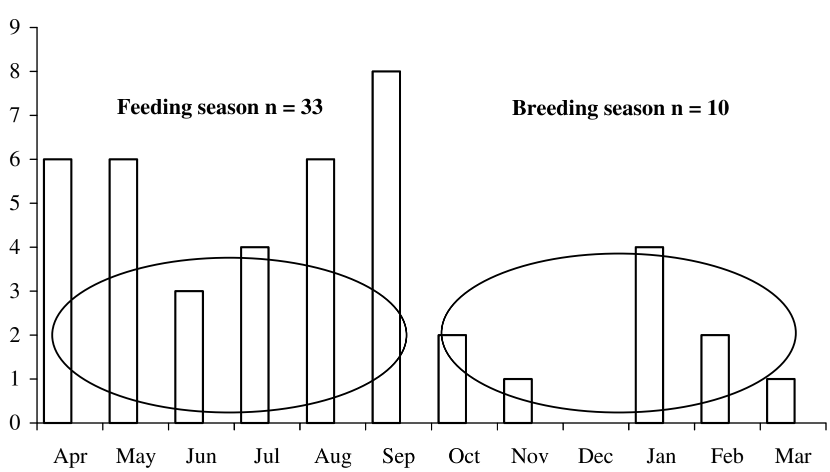

Fig. 3. Monthly frequency of fatal ship strikes. The feeding and breeding seasons for fin whales are shown in the circles.

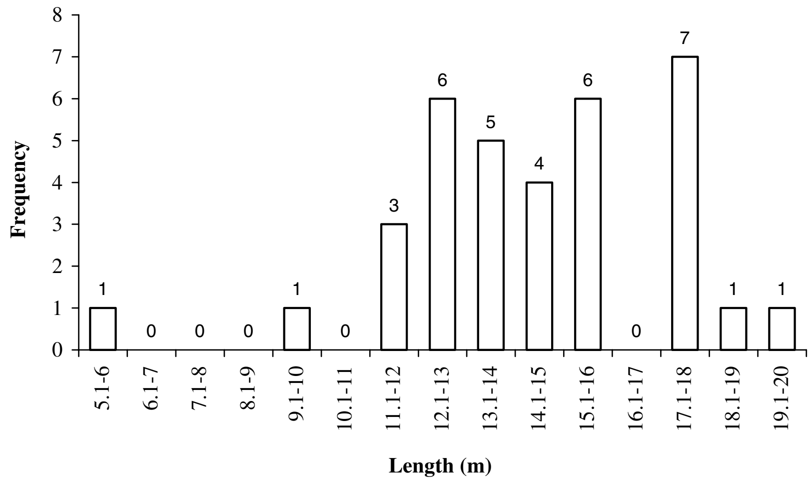

Fig. 4. Length frequency distribution of fin whales killed by ship strikes.

injuries such as hematomas or broken bones, and four (25.0%) showed both external and internal injuries. In 20 cases the whale was caught on the bow of a ship and was discovered only once in port during mooring maneuvers or unloading activities. No evidence of injuries on the ventral side of the examined whales was reported.

In 24 cases where we could ascertain the vessel class involved in a strike, ferries were most frequently implicated (15, 62.5%), followed by merchant ships (4, 16.7%), fast ferries (3, 12.5%) and yachts (2, 8.3%; $\chi^2 = 18.33$, df = 3, $p = 0.0004$). High-speed ferries were introduced into the area in 1996. In the six years following that period they accounted for almost 50% of the total collisions ($n = 7$; three caused by high-speed ferries, three by traditional ferries, and one by a merchant ship). However, no significant difference was found in the annual number of fatal ship strikes before and after this period (Wilcoxon rank sum test, $p = 0.8015$).

The large majority of strikes (37 of 45, 82.2%) were recorded in the Pelagos Sanctuary for Marine Mammals, the Gulf of Lions or in adjacent waters ($\chi^2 = 48.53$, df = 2, $p < 0.001$), while the remaining eight collisions were reported in Spanish waters (5, 11.1%) and in the South of Italy (3, 6.7%).

Considering an estimated Mediterranean fin whale population of 3583 individuals (SE = 967) (Forcada et al., 1996), and the calculated mean annual fatal ship strike rate of 1.43 individuals, the known mortality rate due to ship collisions was a minimum of 0.0004. Within the Pelagos Sanctuary, the Gulf of Lions and adjacent waters only, there are an estimated 901 whales (SE = 196.1) (Forcada et al., 1995). The fatal collision mortality rate here is 0.0013, three times higher than for the whole Western basin.

3.2. Photo-identification data (living whales)

Nine out of 383 photo-identified whales (2.4%) had wounds positively attributed to a ship strike (Table 2). No information on the year or the location was available in any case, as no animal was seen before and after the collision.

Body scars and marks have been divided into three categories: (a) healed over lesions (depressed scars from old wounds) were present on six whales (66.7%); (b) propeller scars (multiple, parallel and evenly spaced slashes) were found on two whales (22.2%); (c) non-cicatrized wounds – one whale (11.1%) showed dorsal muscles and cicatricial or fatty tissue covering the injury.

Six whales had a cut dorsal fin or fluke, four animals had a "humpbacked" body, and 11 whales presented large wrinkled spots (28.6%).

No variations in the scar appearance were evident in the two resighted animals.

4. Discussion

The data presented in this paper show that in the Mediterranean Sea since 1972 a minimum of 43 fin whales were killed by a ship strike and nine whales survived after a collision event occurred. However, some biases are implicit when dealing with this type of information. Occurrence and frequency of collisions can be either underestimated (unnoticed or unreported events, incomplete or lacking necropsies, masking of fatal ship strikes by advanced carcass decomposition, inadequate data collection techniques) or overestimated (e.g. carcasses struck post-mortem) (Pesante et al., 2000; Laist et al., 2001; Clapham, 2002). Considering all the biases possibly affecting the Mediterranean Sea dataset, we believe that our numbers are more likely to be an underestimate rather than an overestimate. For instance, an accurate examination of the archives of two French ferry companies revealed many fatal collisions that were not otherwise listed. Italian ferry companies' files could not be checked, but a similar situation is likely. The likelihood of underestimation is also supported by interviewing ship captains, who claimed that they witnessed fatal collisions with large cetaceans several times, some suggesting their own rate as "at least once every three years". These assertions suggest that the real number of fatal collisions is likely to be higher than that reported in this paper. Kraus et al. (2005) analyze North Atlantic right whales strandings and relate them to estimated mortality rates and suggested high values of underestimation for human-caused mortalities.

Lethal collisions were more frequent between April and September than between October and March. This pattern reflects the seasonal increase of recreational and passenger vessel traffic in the area during the spring and summer. It also reflects the distribution of Mediterranean fin whales, which concentrate in spring and summer in the Corso–Liguro–Provençal Basin for feeding (Gannier, 2002; Notarbartolo di Sciara et al., 2003; Panigada et al., 2005). Little is known about the fall and winter distribution of Mediterranean fin whales, but at least some whales are still present in these waters year-round (Clark et al., 2002; Laran et al., in press). During spring and summer whales engage in intensive feeding activities, and may be focused on their prey and less aware of approaching boats (Laist et al., 2001). Hence the seasonal peak could be related to levels of vessel traffic, whale abundance and behavior, or a combination of these factors.

Aguilar et al. (1988) reported sexual maturity at a length of 17.4 m for female and 18.5 m for male fin whales; these values are reported to be constant between different Northern Hemisphere populations. According to these results the great majority (33 out of 35) of whales in our stranded sample had not reached sexual maturity. However, the estimates of length at maturity were derived from previous carcass data, which may be biased upwards (e.g. Stevick, 1999, showed that in North Atlantic humpback whales lengths of stranded confirmed mature individuals were below what whaling data would classify as mature). Similarly, some of the whales stranded along the Mediterranean coasts and considered immature may be incorrectly classified. However, Laist et al. (2001) showed that a high proportion (75%) of mortally struck right and humpback whales were calves and juveniles, and 55% of southern right whale mortal ship strikes in South Africa from 1963 to 1998 involved calves or juveniles (Best et al., 2001). As suggested by Laist et al. (2001), the relatively low number of fatally struck adults might be explained if juveniles spend more time at the surface and therefore are more often exposed to collision. This may be compounded if the animals are relatively naïve, and learn how to avoid ships with time and experience.

Almost half of the fin whales that were reported as fatally struck were lodged on the bow of the ship (Laist et al., 2001; Clapham, 2002). In the majority of these collisions the whale was discovered only once the vessel was in port, suggesting that in cases where the carcass did not become lodged, or fell off prior to arrival at the ship's destination, the strike could have gone unnoticed. Many of these whales showed no noticeable external lesions, confirming that such fatalities might be missed if complete necropsies are not performed regularly (Moore et al., 2004). Such complete necropsies are also critical to ascertain whether the collision occurred after the whale was already dead.

Photographed whales present three different kinds of scars. These differences could be attributed either to the boat size or speed, or to the part of the boat that hit the animal. It is likely that the vessels involved were of small enough size and weight to allow the whale to survive the force of the collision. The low number of live whales presenting evidence of collisions may indicate that few animals survive a ship strike or that collisions with small boats are less frequent.

The temporal stability of markings showed by the resighted individuals may reflect the durability of scars on the animal's body. The majority of the photo-identified whales also showed sign of a collision in the central area of the body. Most injuries were located in front of or surrounding the dorsal fin, with only a small percentage in the peduncle or in the fluke area. This might suggest that whales tend to take the strike on their back, away from exposed internal organs which would be unprotected by a lateral or ventral strike. In one witnessed collision with a humpback whale (*Megaptera novaeangliae*), the animal was seen to roll in this way at the last minute (M.W., unpublished data).

Our findings of the majority of whales being struck by ferries are consistent with the suggestion of Laist et al. (2001) that vessel speed and size influence both the frequency and severity of ship strikes. Yachts and motorboats can travel at speeds greater than 20 knots (37 km h^{-1}), but are generally small and quite maneuverable, and may avoid whales more easily; in the case of a collision, these vessels are more likely to injure the animals without causing their death.

Fast ferries caused 12.5% of fatal ship strikes in the entire dataset, but since they were introduced in 1996 they have been involved in 42.9% of the accidents. The likely reason for this considerable percentage lies in their high speed and in the increase in their number and departures in the Mediterranean Sea year after year. In the Sanctuary area five ferry companies currently operate 14 high-speed ships from the beginning of spring till the end of autumn, with daily crossings that generally double during summer, coinciding with the seasonal peak in fin whale abundance (Notarbartolo di Sciara et al., 2003). While we did not find a significant difference in the annual numbers of fatal strikes before and after fast ferries were introduced, this may be an artifact of the shorter time period in the latter category; if the strike rates remain as they have been in the post-1996 period, a significant difference will likely be found in time. Weinrich (2004) also suggested that the number of reported ferry collisions with whales of all species is heavily biased towards fast ferries despite their relatively recent introduction in many areas.

Our data suggest that the Pelagos Sanctuary, the Gulf of Lions and the adjacent waters are high-risk areas for whale collisions. The high number of lethal ship strikes recorded in the Pelagos area reflects the uneven distribution of Mediterranean fin whales (Gannier et al., 2003; Notarbartolo di Sciara et al., 2003). However, areas of medium concentration of fin whales – like the Tyrrhenian, the Adriatic and the Ionian Basins – do not present intermediate levels of ship strike occurrence, indicating that the high maritime traffic levels in the Pelagos Sanctuary present an unusual risk. Finally, in the region between Algeria, Morocco and Spain all the killed whales were found near the ports of Barcelona and Valencia, both harbors with a relatively high number of ships and ferries.

It is hard to assess the actual effects that fatal collisions with Mediterranean fin whales may be having on the population. The reported mortality rates for ship strikes, for the whole basin and for the Sanctuary area, are higher than any cetacean species or areas except for North Atlantic right whales (Kraus et al., 2005) despite its likely substantial under-representation of true ship strike mortality in the Mediterranean Sea. Kraus et al. (2005) suggested that for North Atlantic right whales the detection rate of carcasses (including fatally ship struck animals) was approximately 17%. If we assume a similar detection rate, the annual fatal ship strike rate of the last 30 years (1.43 animals/year) extrapolates 8.4 animals/year.

At present there are no natural mortality rate estimates specific to this population. However, natural mortality rates for *Balaenopterids*, including fin whales, are generally estimated between 0.04 and 0.06 per year (Clark, 1982; De La Mare, 1985; Buckland, 1990). This would suggest that between 140 and 210 natural deaths occur annually in a population estimated at approximately 3500 (Forcada et al., 1996). Another way to obtain a more accurate estimate of the actual number of fatally struck animals is to compare the number of animals killed by a ship strike (46) to those stranded for presumed natural reasons (241). Since ship strike deaths should be additive to natural mortality rates, this would result in 19.1% of additional mortality due to fatal ship strikes. Using this ratio, 27–40 whales (19.1% of 140–210 deaths per year) are predicted to have been killed annually by ship strikes during the study period. If different population abundance estimates are considered (e.g. Gannier, 1997) the estimated number of ship struck animals will change, but it relevance to the population would remain consistent. However, a carcass from a ship struck animal may have a greater probability to be detected than a natural mortality because (a) it is more likely to have been hit close to shore, where vessel traffic is higher, (b) it may be brought closer to shore after death by the vessel itself, and (c) it may be in good health, with a thicker blubber layer, thus leading to a floating carcass which is eventually detected.

The effect of ship strike fatalities can also be considered in relation to fin whales in the Pelagos Sanctuary and adjacent waters, where 82.2% of collisions were reported. Abundance in this area was estimated at 901 (Forcada et al., 1995), so natural mortality in this area would be 36 (0.04) to 54 (0.06) animals per year. If we attribute the correct proportion of ship strikes to this smaller area, it suggests that there may be a mortality of 6.9 whales/year (82.2% of the 8.4 whales/year estimated by using Kraus et al., 2005 detection ratio), 22 whales/year (82.2% of the 26.74 whales/year in the 0.04 mortality rate above), or 33 (82.2% of the 40.11 whales/year from the 0.06 mortality rate above). In all cases, these numbers added to the natural mortality rate may be cause for concern.

Whether or not ship strikes themselves threaten the population, when combined with other threats they may have a synergistic effect which may be even more detrimental. Fossi et al. (2003) reported significantly higher DDT metabolite values in Mediterranean fin whales than in odontocetes. These compounds, known to have strong estrogenic and anti-androgenic effects, could negatively affect the reproductive rate of fin whales. Entanglements of fin whales in fishing gear have been reported along the Mediterranean coasts (Cagnolaro and Notarbartolo di Sciara, 1992; Notarbartolo di Sciara et al., 2003). Whale-watching efforts in the Sanctuary have increased greatly in the past decade (Notarbartolo di Sciara et al., 2003), with the whales actively avoiding vessels by increased swimming speeds and decreased surface times (Jahoda et al., 2003). Other vessel traffic may also lead to additional acoustic stresses.

Concern about population status may also be suggested by the encounter rate decrease between 1995 and 1999 reported by Panigada et al. (2005) for Ligurian Sea fin whales. This further suggests that this small, isolated and vulnerable population appears to be particularly threatened by a combination of anthropogenic pressures.

The reason why fin whales do not avoid being struck by ships is not completely evident. In contrast to other baleen whales, fin whales are fast swimmers, with short peaks up to $55.5\ \mathrm{km\,h^{-1}}$ (Slijper, 1979); their speed suggests that they would be able to avoid boats by moving away from the ship's trajectory once detected in time. However, particular behaviors, like feeding or resting, may reduce fin whales attentiveness to environmental sounds. In particular, Mediterranean fin whales perform unusually deep foraging dives (Panigada et al., 1999, 2003). Some baleen whales (blue, fin and North Atlantic right whales) glide during the final stages of ascent from a dive, thus reducing their ability to abruptly change their trajectory upon arrival of a ship (Williams et al., 2000; Nowacek et al., 2001). In addition, they may not be able to detect sounds originating from surface vessels until they have reached the end of their ascent, in the path of the vessel.

In order to reduce the risk of collisions, many different solutions have been proposed, ranging from instruments to detect whales mounted onboard ships (e.g., sonar, or night vision devices (Bondaryk, 2002; Capoulade, 2002)), to acoustic alerting devices to warn whales of approaching boats (Nowacek et al., 2004), bottom-anchored passive sonar systems designed to detect whales locations (André et al., 2002), and specially trained observers onboard ferries

(Capoulade, 2002). None of these solutions alone seem to be effective or suitable for a concrete reduction of ship strikes, since each one either has undesired side-effects (it interferes with whales' communication or is too expensive) or is efficacious only in particular situations (at day time or at night time, when whales vocalize, at short distances or within certain angles from the ship's bow).

In the absence of a better understanding of why fin whales are struck by ships, we suggest that more effective and realistic mitigation measures include:

(1) reducing ship speed when crossing through high density areas, both to give the whales time to avoid the oncoming vessel and to give the operator increased time to react to the whale's presence. This solution may be difficult, since it counters the current trend of increasing speed (Clapham, 2002);
(2) yearly monitoring of whale presence and distribution to suggest dynamically moving ferry routes from areas of particular concentration of fin whales to areas of lower density.

This approach has been applied by the Canadian authorities in the Bay of Fundy to protect right whales (Clapham, 2002). In the Ligurian Sea this solution will probably be very difficult since, as already stressed, the great majority of ferries connecting the Islands with the Italian and the French mainland cross the region where fin whales are most concentrated. Nevertheless, the recently declared Pelagos Sanctuary for Marine Mammals – with its inclusion, in November 2001, by the Parties to the Barcelona Convention in the List of Specially Protected Areas of Mediterranean Importance (SPAMIs) – would represent an ideal place to apply similar regulations. Such measures could be limited to particularly risky vessel types or possible sub-areas characterized by high concentration of fin whales (Gannier, 2002). In addition, it may eventually be possible to forecast areas of high fin whale densities from remote sensing data using habitat selection models (Littaye et al., 2004; Panigada et al., 2005).

Future research to describe the whales' behavior in relation to approaching vessels, including controlled exposure experiments combined with passive tracking and multi-sensors recording devices (Nowacek et al., 2001, 2004) may help to increase our understanding of interactions between whales and boats, and lead to other effective measures of avoiding whale strikes.

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