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Summer social distribution of sperm whales (*Physeter macrocephalus*) in the Mediterranean Sea

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Sperm whale social distribution was investigated in the Mediterranean Sea, using data collected during summer surveys from 1997 to 2002. Variations in the size of sperm whale schools/underwater aggregations were assessed using both visual and acoustic data. Individual body lengths were estimated acoustically, using the click inter-pulse intervals. Regional comparisons were undertaken, taking the 41° parallel as a north/south boundary. In the southern region, schools of up to seven sperm whales were sighted and calves were relatively frequent. The animals ranged between 8.6 m and 13.1 m long. In the northern region, school sizes were significantly smaller, with a maximum of three whales sighted at the surface. However, the acoustic survey showed that sperm whales form loose aggregations of up to five animals in certain areas. Whales detected in the north were 12.6 m long on average, and the body size range was relatively small. This summer survey demonstrated a segregation of males, in the north, from larger schools including calves, which seemed to be confined to the southern region.

INTRODUCTION

Sperm whales display a marked sexual dimorphism, with males attaining an average length of 16 m compared with an average of 11 m in females (Rice, 1989). Sperm whales in the open ocean are organized in different types of groupings: the 'breeding schools' include females (sexually mature at 8.3–9.2 m long) and their offspring of both sexes; the 'bachelor schools' include pubertal (8.7–10.3 m long) to sexually mature males (11–12 m long and over); while large bulls, physically mature males (>16 m), are generally observed alone. Males leave the breeding school to join the bachelor schools as they approach sexual maturity. Bachelor schools consist of loose aggregations of similar-sized whales, rarely clustered close together (Lettevall et al., 2002). The regional distribution of sperm whales varies according to the sex and age composition of the groups and may be determined by the food sources and suitable conditions for breeding. In general, only mature males are found in the higher latitude cold waters, whilst the females and the young are limited to tropical and temperate seas (Rice, 1989).

Sperm whales perform deep dives in search of food, during which they emit an almost continuous sequence of loud impulsive clicks for echolocation (Møhl et al., 2000). Sperm whale clicks are made up of a number of regularly spaced pulses resulting from multiple reflection of the initial sound within the head of the animal. The spacing between the pulses within a click, termed inter-pulse interval (IPI), has been demonstrated to be related to the size of the animal (Gordon, 1991).

The Mediterranean Sea is located in temperate waters, between 30°N and 45°N and is almost totally land-locked, joined to the Atlantic, through a relatively narrow entrance at the Strait of Gibraltar. The sperm whale is one of the eight common species of cetaceans living in the Mediterranean Sea. The most frequent observations have been of isolated individuals and couples, although all age-classes have been sporadically reported, from new born to old bulls (Mangano, 1983). However, published results on the social distribution of sperm whale in the Mediterranean Sea are scarce and data are lacking to assess the conservation status of the species in this region. Sperm whales inhabiting the Mediterranean Sea may be threatened by continuous by-catch due to the drift-net fisheries. Until the ban in 1990, the Italian swordfish fishery was one of the largest drift-net fisheries in the world, using nets of 12–20 km in length, and sperm whale was one of the most frequently recorded within Mediterranean non-target catch species (Northridge, 1991). Mediterranean fisheries seem to be unusual in this respect as, in general, very few records of sperm whale entanglements are reported in most of the world's oceans. The number of by-caught sperm whales have decreased substantially since the 1990s, but, besides the ban, drift-net fisheries are still in use in the Mediterranean Sea and sperm whale entanglements still reported.

From 1997 to 2002, dedicated sperm whale surveys have been conducted over the Mediterranean Sea in the summer months. The results of these studies have contributed to the identification of regions of high sperm whale abundance such as the Gulf of Lions, the Balearic Sea and the eastern Ionian Sea (Gannier et al., 2002). The aim of this paper is to use both visual and acoustic data to investigate the social distribution of sperm whales in the Mediterranean Sea. More specifically, the objective is to assess the variations in school sizes and whale body length between the northern and the southern regions.

MATERIALS AND METHODS

Survey methodology

A 12 metre motor-sailer, 'Anacaona', with an 80 hp diesel engine was used for all surveys. A dual channel hydrophone (IFAW-type rebuilt by Magrec Ltd) was used. Each unit included one Benthos AQ-4 transducer element and a miniaturized pre-amplifier, with integrated 200 Hz high pass filter. During the 1998 survey, a mono hydrophone (Magrec, HP 30MT) of similar specifications was used. An external 1kHz high-pass filter unit was used to improve the quality of listening and recording. The filtered signal output was connected to a TCD-7 DAT recorder.

The data were collected during summers 1997 to 2002, in different regions of the Mediterranean Sea, including the Tyrrhenian Sea, the Ionian Sea and the north-western basin as a whole (Gannier et al., 2002). The surveys were dedicated to the study of cetacean distribution, which determined that the survey vessel follow pre-defined linear transects at a constant speed of 6 knots. The method described by Gannier et al. (2002), combining visual searching with systematic acoustic sampling was used. The acoustic survey sampling method consisted of one-minute operator listening sessions every two nautical miles along the survey tracks. The perceived levels of both bioacoustic signal (i.e. whale clicks) and overall noise were recorded subjectively using a five level scale based on a sample tape provided by IFAW. The visual survey consisted of continuous, naked eye observation by rotating shifts of three observers sharing the 180° sector ahead of the boat. An index of sighting conditions (V), from 0 (null) to 6 (best), was used as a criterion to discard transect portions with poor observation conditions. Once sperm whales were detected acoustically, continuous recording was performed. When animals were sighted the following parameters were recorded: bearing and distance of the whale from the boat (from binocular measurements), number of whales seen, presence/absence of calves. The period of 'off-transect' data collection was limited to one hour, after which the transect was resumed.

Data analysis

Only the section of transect with good sighting conditions ($V > 3$) and the sampling positions featuring low underwater noise ($U \leqslant 3$) were considered for the analysis. Based on satellite imagery of sea surface temperature and primary production (Morel & André, 1991), the Mediterranean Sea was divided into a southern and a northern region, taking the 41° parallel as a boundary. At this latitude, cold and warm water masses are segregated by one of the most important divergence of the western basin, the Algerian–Provençal divergence. In terms of biomass, regions located north of the 41° parallel appear to be relatively rich, with a primary production of 0.5 to 1 mg Chla m^{-3} in the Gulf of Lions and around 0.4 mg Chla m^{-3} in the Ligurian Sea. The southern region is characterized by a marked oligotrophic throughout the year, although some sites of increased productivity occur locally and seasonally.

In this study, the term 'school' was used to define an association of whale at the surface, observed within 1 km radius from the boat (surface sightings). The term 'underwater aggregation' was used to refer to the whales detected within the range of the hydrophone (around 6 km). For each acoustic sequence (consecutive acoustic stations where sperm whales were heard) the number of whales heard within the range of the hydrophone was estimated from post-survey analysis of the recordings, using Rainbow click software (IFAW). Although this software allowed counting of the number of whales, by providing the bearing of the vocalizing animals, the method was relatively limited when there were more than five whales in the area. The sizes of sperm whale schools/underwater aggregations were then compared between the regions north and south of the 41° parallel.

The IPIs were measured from regular click sequences emitted by animals involved in deep dives. Only sequences where clicks of a single animal were clearly distinguishable were used to ensure that the clicks measured were from the same individual. The click sequences were sampled at 62.5 kHz and filtered digitally with a 2 kHz high-pass

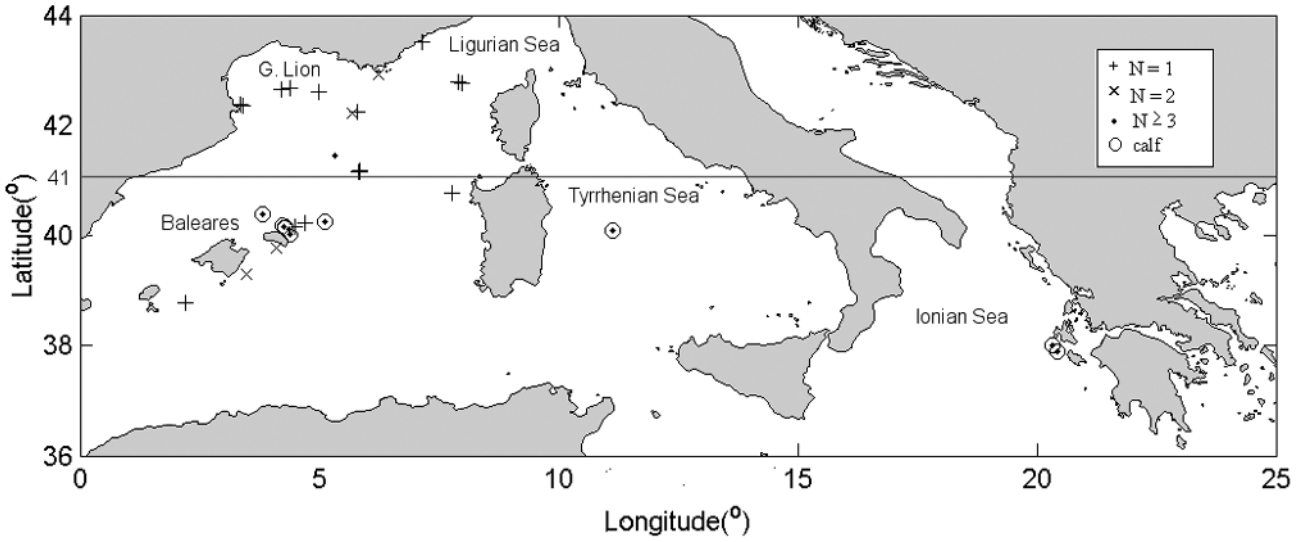

Figure 1. Map showing the position of sighting according to group size N. The sightings including calves are circled. Dotted line indicates the 41° parallel.

filter to clarify the pulse structure of the clicks. The waveform of the clicks were displayed using CED Spike 2 software V.4.70. Wherever a clear pulsed structure was observed within a click, the first three pulses of the click were marked manually and the first and second IPIs were calculated. From each click sequence, 30 IPI measurements were taken at random. The mean IPI of each individual click sequence was used to estimate the whale body length (in m), according to Gordon's (1991) equation:

$$\text{Body length} = 4.833 + 1.453\ \text{IPI} - 0.001^2 \quad (1)$$

Non-parametric statistical methods (Kruskal–Wallis tests) were used to assess regional variations in IPI and individual body length estimates. The regional comparison relied on the assumption that all sequences were from different whales (in cases where no photo-identification was possible and only acoustic data were available).

RESULTS

The survey effort coverage comprised a total of 19,998 nautical miles (n.m.) of transect achieved with good observation conditions ($V > 3$). The acoustic survey included 3664 acoustic stations with low underwater noise ($U \leqslant 3$), performed over a distance of 23,430 n.m.. The northern region received a coverage of 8625 n.m., while 11,373 n.m. was achieved in the southern region.

School and underwater aggregation sizes

A total of 51 sightings was made, including 19 in the north and 32 in the south (Figure 1). Single animals and pairs occurred in both regions (Figure 2). In the northern Mediterranean Sea, 73.7% of sightings were single animals. In the south, most of the sightings (81.1%) included calves and in half of the sightings, three or more individuals were observed together at the surface. The schools sighted included on average 1.23 whales in the north, with a maximum of three animals, and 3.40 whales in the south, with a maximum of seven animals (Table 1). This regional difference in school size was shown to be statistically significant ($\chi^2 = 11.96$, df = 1, $P = 0.001$).

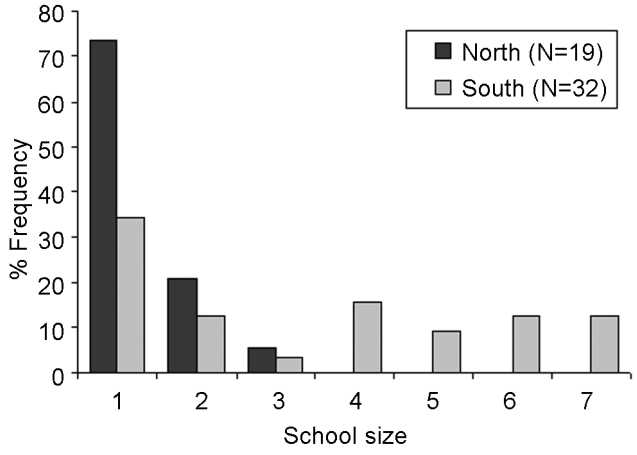

Figure 2. Frequency distribution of the group size of the sightings made during the distribution summer survey from 1997 to 2002, north and the south of the 41° latitude (N, number of sightings).

Table 1. *Number of sperm whales seen per sightings in the northern and southern regions of the Mediterranean Sea, during the 1997–2002 summer surveys.*

Region	N	Mean	SE	SD	Min	Max
North	19	1.31	0.133	0.582	1	3
South	32	3.41	0.401	2.269	1	7

N, number of sightings; SE, standard Error; SD, standard deviation; Min, minimum; Max, maximum.

Table 2. *Underwater aggregation size in the northern and southern regions of the Mediterranean Sea, during the 1997–2002 summer surveys.*

Region	N	Mean	SE	SD	Min	Max
North	39	1.87	0.188	1.174	1	5
South	33	2.88	0.339	1.949	1	7

N, number of aggregations; SE, standard error; SD, standard deviation; Min, minimum; Max, maximum.

Sperm whale acoustic detections were clustered into 72 independent acoustic sequences, with a minimum number of 168 whales counted. The mean number of whales heard during the acoustic sequences was 2.3 and ranged from one to seven animals. The underwater aggregation size was significantly lower in the north than in the south

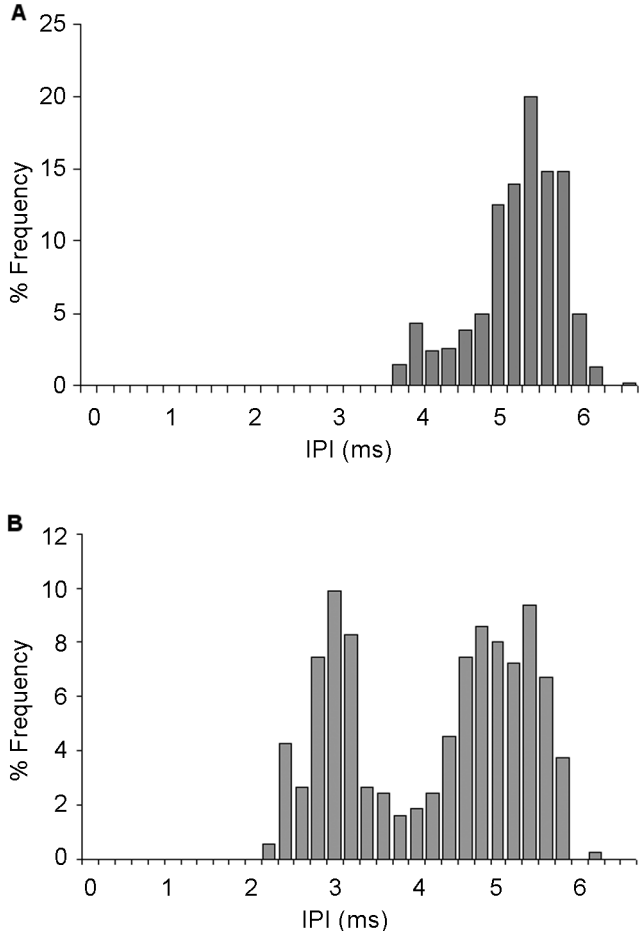

Figure 3. Frequency distribution of IPIs measured in (A) the northern and (B) the southern regions.

Table 3. *Body length (in m) estimated from Gordon's (1991) equation, using inter-pulse interval measurements.*

Region	N	Mean	SE	SD	Min	Max
North	17	12.58	0.179	0.739	10.76	13.47
South	13	11.08	0.448	1.617	8.59	13.07

N, number; SE, standard error; SD, standard deviation; Min, minimum; Max, maximum.

(Kruskal–Wallis test: H=5.72, P=0.017), with mean size of 1.9 and 2.9 whales heard, respectively (Table 2). Within the northern basin, all but one acoustic sequence recorded in the Ligurian Sea came from a single animal, while the majority of the acoustic sequences from the Gulf of Lions were of two to three whales. Thus underwater aggregation size appeared to differ not only at large scale (north vs south), but also at a smaller regional scale.

Body length estimation from IPI measurements

The IPI measurements were analysed from 31 click sequences from well-individualized animals, emitting regular clicks during deep feeding dives. In the other sections, where several animals were vocalizing simultaneously, it was impossible to distinguish one animal from another with confidence. On average, 20.2% of the clicks sampled showed a clear pulse structure and IPIs could be marked.

In the north, the mean IPI was 5.40 ms (SD=0.52), whereas in the south the mean IPI decreased to 4.40 ms (SD=1.05). The IPIs measured in the north were distributed normally around the mean (Figure 3A). By contrast, the southern region showed a wider data spread, with a marked bimodal distribution, including a peak around 3 ms and one around 5 ms (Figure 3B). The non-parametric statistical tests demonstrated that the IPIs measured from whales from the northern basin were significantly larger than the ones from the southern region (Kruskal–Wallis test: H=243.44, $P<0.001$).

Individual body length estimated from IPI ranged from 8.3 to 13.5 m. No large bulls have been observed during the surveys. In the north, the whales had a mean body length of 12.6 m (SD=0.74), with a relatively small range (Table 3). In this region, all whales were more than 10 m in length and 88% of the animals measured were longer than 12 m. In the southern region the mean whale size was 11.1 m (SD=0.45) and the estimated length ranged from 8.6 m to 13.1 m. This regional difference in sperm whale body length was statistically significant (t-test: t=3.12, P=0.0070, df=15). As calculations were made on regular clicks emitted from isolated diving whales, new-born calves were not represented.

DISCUSSION

It was observed that both surface sightings and underwater aggregations increased significantly in size from the northern to the southern regions of the Mediterranean Sea. In the north, solitary or paired individuals were usually observed at the surface. However, the acoustic survey demonstrated that more animals could be detected simultaneously underwater, within the range of the hydrophone. Thus the northern region seemed to host sperm whales which tended to gather in certain zones without forming cohesive groups at the surface. It was interesting to note that in areas sustaining a high relative abundance of sperm whales such as the Gulf of Lions (Gannier et al., 2002), whales tended to gather in loose aggregations of two to three animals, while in areas of lower abundance (Ligurian Sea) animals were usually observed alone, both visually and acoustically. Aggregation of sperm whales in the Gulf of Lions might result from the increased productivity of the area, characterized by numerous submarine canyons and frequent upwelling events.

By contrast, whales in the southern region tended to form clusters of up to seven animals at the surface. The presence of large schools was previously reported in the Tyrrhenian Sea (Mangano, 1983; Notarbartolo di Sciara et al., 1993), and in the Ionian Sea (Frantzis, 2001). The sightings including calves were relatively frequent in three different basins: the Tyrrhenian Sea, the Ionian Sea and the south-western basin (Baleares), strongly suggesting that reproductive and breeding activity occurs within the southern Mediterranean Sea. Assuming a 15 to 16 month gestation period, as proposed by Best et al. (1984), the presence of very small calves in early July suggests a calving season around May–June, and a mating season in February–March. Although further studies are needed to determine precisely sperm whale calving and mating periods in the Mediterranean Sea, these results are consistent with the northern hemisphere figures (Best et al., 1984). Sightings including one or more calves were located south of the 41° parallel, where the water temperature remained above 14°C down to 15 m depth all year round (from the Mediterranean Oceanic Data Base, University of Liège, Belgium). In areas such as off Minorca (Baleares) and off the Peloponnese islands (Greece), the association of warm water temperatures and topographic factors such as relatively broad continental shelves and steep edges, could provide suitable breeding and feeding conditions for females and their offspring. The regularity of sightings including calves around the Balearic islands (and particularly north of Minorca) over several years during this survey (in 1999, 2001, 2002) support the hypothesis that sperm whales exhibit breeding site fidelity. Long-term photo-identification studies are required to identify the groups observed in these locations and to determine whether they consistently inhabit the Ionian, Tyrrhenian and Balearic Seas.

Comparisons with studies conducted in other parts of the world are difficult to establish as different methodologies were used. Off the Galápagos Islands, mark–recapture techniques of photo-identification have allowed to define different types of sperm whale entity among females and their offspring (Whitehead & Kahn, 1992): 'units' (association of individuals over several years, including approximately 13 animals), 'groups' (association of units for several days, including about 23 animals on average), and 'aggregations' (temporary association of groups, including 43 whales). Although the period of sperm whale associations was not determined in this study, school sizes appeared to be relatively small, suggesting that the social organization has been adapted to the smaller scale of the Mediterranean Sea and maybe

to lower food resources. It has been suggested that sperm whales changed the group size as a response to variations in the distribution and abundance of their food. Recent work from Jaquet & Gendron (2002), based on squid catches in the Gulf of California, tends to confirm that the size of sperm whale aggregations is related to the size of prey patches. However sightings of 10 to 30 individuals were reported in the Mediterranean Sea in the past (Bolognari, 1951; Mangano, 1983), suggesting that the basin had the potential to sustain larger sperm whale schools. A decrease in sperm whale school size could result from the impact of human activity, either directly through by-catch in drift-nets or indirectly by depleting food resources and generating disturbance.

The distribution of IPI values indicated that the IPIs were consistently greater in the northern basin than in the southern areas. Body length extrapolations indicated that the whales heard in the north were principally large animals, around 12 m long, thus probably sexually mature males. These results were consistent with those of Pavan et al. (1997), which gave mainly length estimates of 11 to 12 m for whales detected in the northern basin, although they mentioned that large males (13 to 14 m long) were also detected in the southern regions of the Mediterranean (south Tyrrhenian Sea and Ionian Sea). The individual size estimations from IPIs indicated a more heterogeneous population in the southern regions in terms of animal size, including young and adult whales. Furthermore, our results did not include IPI measurement from calves, which would further discriminate southern and northern regions. Our results have the same trend as a study carried out in the northern Atlantic (Adler-Fenchel, 1980), which showed that sequences recorded at lower latitudes, where females and immature males were expected, had shorter IPIs than those from higher latitudes where only large males are found.

Isolated animals, considered as males (>12 m) were also detected in the southern region, particularly around the Baleares. It would be interesting to investigate whether the presence of isolated males in this region is a seasonal event or if they are present all year round. Frantzis (2001) suggests that both males and mixed groups co-habit in the waters off Crete all year round. In the southern Tyrrhenian Sea, both schools and single animals have been reported (Mangano, 1983; Notarbartolo di Sciara et al., 1993) and the three year seasonal study of Marini et al. (1996) in the central Tyrrhenian Sea showed the occasional presence of lone and paired individuals from April to October.

Over the whole survey area, the maximum whale size encountered was 13.5 m, suggesting that physically mature bulls were scarce, if not absent, in the Mediterranean Sea during the survey period. However, large specimens were known to inhabit the Mediterranean Sea until the early 1990s. The occurrence of whales between 15 and 19 m have been reported until 1995 along the Italian coast and, from 1986 to 1998, out of the 27 sperm whales reported entangled or stranded (with evidence of drift-net fishing interactions such as piece of net around the fluke), 77.8% were greater than 12 m in length (Centro Studi Cetacei, 1986–1998). The absence of large bulls, during the study period, might result from the heavy by-catch from drift-net fisheries that seemed to reach a peak in 1987–1988, before the ban in 1990 (Northridge, 1991). Besides the lack of by-catch data and fishing effort needed to assess the real impact of drift-netting on sperm whales in the Mediterranean Sea, the observations reported in this study suggest an impact on the population composition, with a possible depletion of large, physically mature males.

This study presents the first integrated results allowing comparison between northern and southern regions of the Mediterranean Sea. Although located in temperate latitudes, both males and females accompanied with their calves, inhabit the Mediterranean Sea. The overall picture provided by this study suggests a social distribution analogous to the situation found in other oceans, where sub-adult and adult males tend to feed in higher latitudes during summer, and nursery schools are more constrained to temperate/sub-tropical latitudes between 40°N and 40°S (Rice, 1989). However, the summer presence of some whales larger than 12 m in southern regions was evidenced. Our study reflects a summer situation, and the autumn, winter and spring distribution pattern still need to be investigated.

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