ACOUSTICALLY DERIVED SIZE DISTRIBUTION OF SPERM WHALES IN THE MEDITERRANEAN SEA

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INTRODUCTION Sperm whales (*Physeter macrocephalus*) vocalisations consist primarily of series of clicks, emitted almost continuously while animals are diving. These clicks are unique to the species and are made up of a number of regularly spaced pulses resulting from multiple reflection of the initial sound pulse within the head of the animal. The spacing between the pulses in a click, termed Inter-pulse Interval (IPI), has been demonstrated to be related to the size of the animal. Through a knowledge of this relationship, it should be possible to assess the geographic size distribution of sperm whale acoustically, without having to spot and approach the animals. In the Mediterranean sea, the distribution of sperm whales is poorly known, while in other oceans it has been shown to vary according to sex and age composition of the groups. One of our longer term project aims is to assess whether the analysis of the clicks could provide an insight into the size distribution of sperm whales within the Mediterranean Sea.

MATERIAL AND METHODS Our recordings were collected during four summer surveys of different regions of the Mediterranean: the northwestern basin, the southwestern basin, the Tyrrhenian Sea and the Ionian Sea. A mono hydrophone was used, towed behind a 12 metre motor-sailer boat. The recording equipment consisted of a Sony WMD6 analog recorder and a TCD-7 DAT recorder. The best quality sequences were sampled onto a computer hard-disk using a Cambridge Electronic Design (CED) 1401 laboratory interface (Goold and Jones, 1995), using a sampling frequency of 62.5 kHz. The sequences were bandpass filtered to retain frequencies between 2kHz and 6kHz, and analysed with the CED Spike 2 software. Wherever a clear pulsed structure was observed within a click, the first 3 pulses of the click were marked, and the first and second inter-pulse intervals (IPI) were calculated. When a single whale was distinguished, the mean IPI of the sequence was used to estimate its body length after Gordon's equations (1991):

$$\text{Body length} = 9.75 - 0.521\ SL + 0.068\ SL^2 + 0.057\ SL^3 \quad (1)$$

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

where SL is the Spermaceti sac Length (in m): SL= IPI × speed of sound in spermaceti /2. The sound velocity used was 1430m.s^{-1} (Goold *et al.*, 1996).

RESULTS A total of 38 recording sequences were retained for IPI analysis. Among them, 25 click sequences where from single animals, emitting 'usual clicks' during deep feeding dives. In the 13 other sequences, several animals were vocalising at the same time so that one animal could not be distinguished from another. These sequences included either 'usual clicks' from several diving animals, or social vocalisations such as codas and chirrups. The IPI results calculated for each region are summarise in Table 1. Overall, the IPI ranged from 2.4 to 6.0 ms. When comparing IPI measurements between different regions of the Mediterranean, the northwestern basin showed significantly greater IPI values than the other surveyed areas (Kruskall-Wallis Tests). In the northwestern basin, the IPI's were 5.3ms long on average, with minimum value of 4ms. In the other regions, the IPI's were significantly

smaller, with mean values of 3.9ms, 2.8ms and 4.4ms in the South-western basin, the Tyrrhenian Sea and the Ionian Sea respectively. The southwestern basin and the Ionian Sea showed a relatively wide data spread, with large 95%CI and IPI values laying from 2.6ms to 5.7ms.In contrast, the IPI's measured in the Northwestern basin were distributed more closely around the mean, with 95% of the IPI ranging between 5.1ms and 5.6 ms. Thus the IPI's in the Northwestern basin were significantly larger and more consistent, while they were more evenly spread in the Ionian and Southwestern basin.

For the 25 recording sequences in which only a single whale was evident, the body length extrapolated from the mean IPI, ranged from 9.3 to 13.2m for equation (1), and from 8.3m to 13.5m for equation (2) (Table 2). Thus, it appears that both equations give reasonable length estimates for the measured whales. Figure 4 shows that small individuals (estimated size less than 9.5m) were present in the southwestern basin, the Tyrrhenian and the Ionian Sea, while in the northwestern basin only larger animals, of estimated size above 10.5m, were detected.

DISCUSSION The distribution of IPI values indicates that the IPI's were consistently greater in the Northwestern basin than in the other areas. Extrapolating for body length with equations (1) & (2) shows that whales detected in this region were around 12 m long on average. Thus the results suggest that the whales heard in the Northwestern basin were principally large animals, thus probably sexually mature. These results were consistent with those of Pavan *et al*. (1997), which gave mainly length estimates of 11-12m for whales detected in this area. Sexual maturation in males begins at about seven to eleven years of age and a length of 8.7 to 10.3m (Rice 1989), and is not complete until the age of 18 to 21, and a body length of 11-12m, at which time the animal is regarded as sexually mature (Rice, 1989). As males approach physiological sexual maturity, they decrease in sociality and rarely cluster together in close group as females do (Reeves and Whitehead, 1997). The wider IPI distribution found in the southwestern basin and the Ionian sea might indicate a more heterogeneous population of animals in these regions, including calves, juveniles and adults. Individual size estimation indicated animals of around 8 and 9 m long were present in these areas. These results were consistent with our visual observations (Gannier *et al*. In prep.). In fact, nursery groups were observed in the three regions where small whales were acoustically detected. In the northwestern basin, no such social structure has ever been observed, and the sightings consisted mostly of solitary animals. Pavan *et al*. (1997) also showed that large males (13 -14 m long) were present in the southern regions of the Mediterranean (South Tyrrhenian Sea and Ionian Sea). Our results tend to be consistent with a previous 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.

CONCLUSION Manual measurement appears to be an accurate method of obtaining inter-pulse interval (IPI) data from sperm whale recordings. The study shows that the analysis of click waveforms may be an appropriate technique to asses the geographic distribution of animals by body size. Coherent results were found and tend to indicate a regional segregation of males (long IPI) from the groups of females with young (wide range of IPI data). Further work comparing IPIs with reliable length measurement is however desirable in order to calibrate and cross-check the expressions relating IPI and total length.

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Table 1. Results of Inter-Pulse Interval (ms) measured in the 4 regions of the Mediterranean.

Region	N	Mean IPI (ms)	StDev	SE	Min	Max
Northwestern basin	14	5.34	0.56	0.15	4.09	5.97
Southwestern basin	11	3.91	1.13	0.34	2.59	5.57
Tyrrhenian Sea	3	2.82	0.41	0.24	2.36	3.17
Ionian Sea	10	4.39	1.03	0.33	2.94	5.69

Table 2. Results of the individual length estimates for the 4 regions investigated

	Region	N	Mean length (m)	StDev	SE	Min	Max
Equation (1)	Northwestern basin	15	11.8	1.1	0.8	9.9	13.2
	Southwestern basin	5	11.7	1.8	0.6	9.5	13.2
	Tyrrhenian Sea	1	9.3	-	-	9.3	9.3
	Ionian Sea	2	10.3	1.1	0.7	9.5	11.0
Equation (2)	Northwestern basin	15	12.3	1.3	0.3	8.6	13.4
	Southwestern basin	5	12.1	1.7	0.7	9.2	13.5
	Tyrrhenian Sea	1	8.3	-	-	8.3	8.3
	Ionian Sea	2	10.5	1.8	1.3	9.2	11.7