SPERM WHALE SIZE DETERMINATION: OUTLINES OF AN ACOUSTIC APPROACH

B. MØHL, E. LARSEN and M. AMUNDIN

Abstract

By measuring the duration of interpulse intervals of the sound clicks of sperm whales and relating them, following the theory of Norris and Harvey (1972), to the length of the spermaceti organ, and then relating this length to total body length, it may be possible to estimate the size of a sperm whale once the pulse interval of its clicks is known. This method and visual measurement have given the same results in the case of a 9-m whale and a 21-m whale – lengths at the lower and the very highest ends of the range of sperm whale lengths, indicating that the acoustic method may be used throughout the entire range of sizes. These 2 estimates also follow an independently derived, empirical mathematical relation between total length and interpulse interval, though no inference should necessarily be drawn from this match. The development of a relation between interpulse interval and age must await clarification of the upper end of the curve relating length to age. It appears that this method is technically feasible and that a station recording sperm whale clicks would have a range of 2 km (12 km^2) or more; use of the method would allow the size and perhaps the age of sperm whales to be determined without killing them or even without visual contact. Further research is needed on the acoustic behaviour of sperm whales and on their mechanism of sound generation.

Résumé

En mesurant la durée entre les impulsions des cliquètements des cachalots et en établissant une relation, selon la théorie de Norris et Harvey (1972), avec la longueur de l'organe des animaux, puis en établissant un rapport entre cette longueur et la longueur totale du corps, il pourrait être possible d'estimer la taille d'un cachalot quand on connaît l'intervalle entre les émissions de ces cliquètements. Cette méthode et les mesures visuelles ont donné les mêmes résultats dans le cas d'un animal de 9 m et d'un animal de 21 m, longueurs qui se situent au minimum et au maximum de la gamme de tailles des cachalots, ce qui indique que la méthode acoustique pourrait être utilisée sur toute la gamme de tailles. Ces deux estimations suivent aussi une relation mathématique empirique obtenue de façon séparée, entre la longueur totale et l'intervalle séparant les impulsions, encore qu'on ne doive pas nécessairement tirer des conclusions de cette concordance. L'élaboration d'une relation entre l'intervalle des impulsions et l'âge doit attendre une clarification de la partie supérieure de la courbe liant la longueur et l'âge. Il apparaît que cette méthode est techniquement réalisable et qu'une station enregistrant les cliquètements des cachalots aurait une portée de 2 km (12 km^2) ou plus; l'utilisation de la méthode permettrait de déterminer la taille et peut-être l'âge des cachalots sans les tuer et même sans contact visuel. Des recherches plus poussées sont nécessaires pour ce qui est du comportement acoustique des cachalots et du mécanisme de production du son.

Extracto

Midiendo la duración de los intervalos entre impulsos en los sonidos emitidos por los cachalotes y poniéndolos en relación, según la teoría de Norris y Harvey (1972), con la longitud del órgano que segrega el esperma y poniendo luego en relación esa longitud con la longitud total del cuerpo, puede ser posible estimar la talla de un cachalote cuando se conoce el intervalo entre impulsos de los sonidos que emite. Con este método y con mediciones visuales se han obtenido resultados idénticos en el caso de un cachalote de 9 m y otro de 21 m, longitudes que se encuentran en el extremo inferior y superior de la gama de longitudes de los cachalotes, lo que indica que el método acústico puede utilizarse para animales de todas las tallas. En estas dos estimaciones se aplica también una relación matemática empírica, derivada independientemente, entre la longitud total y el intervalo entre impulsos, aunque de esa correspondencia no ha de inferirse necesariamente ninguna conclusión. Para obtener una relación entre el intervalo entre impulsos y la edad es necesario aclarar el extremo superior de la curva que pone en relación la talla con la edad. Parece que este método es técnicamente viable y que una estación receptora de los sonidos emitidos por los cachalotes tendría un radio de acción de 2 km (12 km^2) o más; con este método se podría determinar la talla y quizás la edad de los cachalotes sin necesidad de matarlos e incluso sin contacto visual. Son necesarias más investigaciones sobre el comportamiento acústico de los cachalotes y sobre el mecanismo de emisión de sonidos.

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A technique that is commonly employed when estimating the effect of exploitation on a given species of marine mammal is the determination of the age distribution within the species. In most cases, this requires that a representative sample of animals be killed to provide teeth, baleen, ovaries and measurement of total length, or whatever parameter or organ that can be processed to indicate the age of the late owner. Clearly, killing a substantial number of specimens for ageing purposes is contra-indicated in most cases, including that of the sperm whale. This paper describes a passive acoustic method that holds promise for the remote size estimation of sperm whales.

The sperm whale owes its peculiar shape to the disproportionate development of the forehead, which has been described as "the biggest nose on record" (Raven and Gregory, 1933). The anatomical structures inside the forehead include the spermaceti organ and a variety of airsacs, respiratory tubes, valves and specially arranged fatty tissues. Widely divergent functions have been attributed to this enigmatic complex. In fact, the very name of the species reflects the idea that the forehead is a formidable sperm cell reservoir. Recently, Norris and Harvey (1972) have proposed an acoustic function for the complex: they suggest that it serves to generate the well-known powerful sound clicks that are presumably used for long range sonar. This theory has many attractions: it attributes homologue functions to homologue anatomical assemblies within the suborder of odontocetes, it provides an explanation for many of the otherwise perplexing anatomical features and it links the fine structure of the sound pulse to the dimensions of the generating mechanisms.

Sperm whale sound clicks consist of trains of brief transients with an exponentially decaying amplitude (Fig. 2). According to Norris and Harvey (1972), this pattern is generated by a single transient, produced in the space between two sound-reflecting mirrors (i.e., air sacs, bounding the anterior and posterior ends of the spermaceti organ as illustrated in Fig. 1). Most of the sound energy leaves the system directly, but a fraction of the energy is intercepted by one of the mirrors, returned to the other mirror, and sent back again before it leaves the system. Part of this delayed sound pulse is again intercepted. The repeated interception of a single original sound creates a series of decaying pulses.

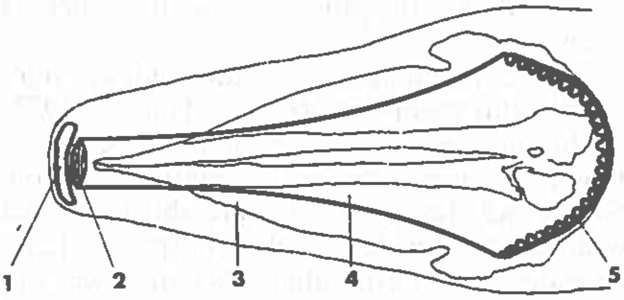

FIG. 1. – Sketch of the relative position of the anatomical structures with a proposed acoustic function in the sperm whale forehead. 1. Distal airsac. 2. Museau. 3. Skull. 4. Spermaceti case. 5. Frontal airsac. The museau is located posterior to the distal airsac and is considered to be the most likely organ for the generation of clicks (Norris and Harvey, 1972).

The spacing between the pulses in a click will then be solely a function of the distance between the mirrors (i.e., the length of the spermaceti organ) and the speed of sound in spermaceti oil. Assuming the latter to be a constant property and the length of the spermaceti organ to be related to total body length, it follows that the size of a sperm whale may be

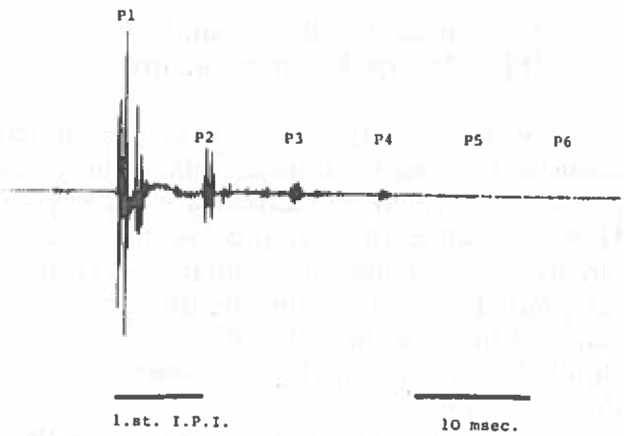

FIG. 2. – Oscillogram of sperm whale click. The pulses of the click are labelled P1 through P6. All interpulse intervals are of equal duration and thought to reflect the size of the whale.

estimated once the pulse interval of its clicks is known.

A detailed account of the evidence relevant to this theory (Norris and Harvey, 1972; Møhl and Amundin, 1978) is not given here. However, using the pulse interval method, Norris and Harvey (1972) were able to predict with accuracy the length of a 9 m sperm whale; an independent estimate of its length was obtained using an optical comparison method. Recently Møhl and Amundin (1978) obtained identical photographic and acoustic size estimates of a 21 m specimen. The lengths of these two individuals happen to fall at the lower and the very highest, giving reason to believe that that body lengths throughout the entire range may be established using this method.

The acoustic method is assumed to measure the length of the spermaceti organ, which is roughly equal to the length of the head. Nishiwaki, Ohsumi and Maeda (1963) have established the relationship between the length of the head and the total body length of sperm whales. Using their data, and the double mirror hypothesis of sperm whale sound production, the following empirical relationship has been derived (using a least squares fit to a 2nd order polynomial):

$$TL = 0.76 + 4.64 \times IPI + -0.259 \times IPI^2 \quad (1)$$

where

TL = total length, m, and
IPI = Interpulse interval, msec.

As Fig. 3 shows, the above mentioned acoustically based estimates follow the independently derived prediction of equation (1). However, since the variance of the data is largely unknown and since equation (1) is used for predicting values considerably above the range of the morphometric data, no inference should be drawn from the coincidence *per se* of the 2 sets of data.

Nishiwaki, Ohsumi and Maeda (1963) also given the relation between total length and number of dentinal growth layers (repre-

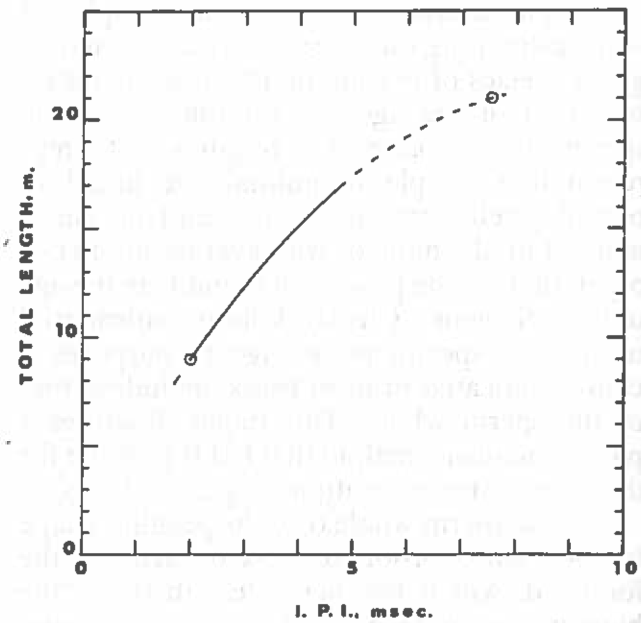

FIG. 3. – Relation between total length and interpulse interval, according to TL = 0.76 + 4.64 × IPI + – 0.259 × IPI²: Solid line shows the range for which the ratio between total length and length of head is known. The two points are acoustic/optical length estimates of two whales.

senting age). The curve they obtain suggests negative growth when a length of 16 m has been reached. This is inconsistent with length records published by other workers (Scammon, 1874; Matthews, 1938; Tomilin, 1957; Berzin, 1972, p. 30-1). Development of a relationship between IPI and age must await clarification of the nature of the upper end of the growth curve.

The acoustic power of sperm whale clicks is fairly high. Levenson (1974) reported it to be of the order of 170 dB re. 1 μ Pascal in the 2 to 8 kHz range. He obtained recordings at a calculated distance of 3.153 km. Assuming an average ambient noise corresponding to sea state 3 (Albers, 1965) and a minimum acceptable signal to noise ratio of 10 dB, a range of 2 km (equal to a coverage of 12 km²) can be expected from a single recording station. This could be increased by an order of magnitude under favourable conditions as also by properly designed recording and analysing equipment.

This paper is intended to describe the principles of the proposed sperm whale sizing technique and its expected range. Its potential for monitoring the size distribution in various sperm whale stocks, both exploited and unexploited, without requiring either visual or physical contact, may justify further research into its validity, accuracy and feasibility. Research is needed into both the acoustic behaviour of sperm whales (including sex, size and herd effects), and the mechanism of sound generation. Further, a number of subtle technical/economical factors have to be considered. Significantly, the technical aspects of the method appears to be well within the state of the art of underwater acoustics (Levenson, 1974; Watkins and Schevill, 1975; Watkins, 1976).

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