Distinctive vocalizations from mature male sperm whales (*Physeter macrocephalus*)

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Received September 17, 1987

WEILGART, L. S., and WHITEHEAD, H. 1988. Distinctive vocalizations from mature male sperm whales (*Physeter macrocephalus*). Can. J. Zool. **66**: 1931–1937.

Groups of sperm whales (*Physeter macrocephalus*) were tracked acoustically off the Galapagos Islands between February and April 1985. In total, 716 h were spent in visual or acoustic contact with the whales, during which time vocalizations were recorded for 5 min/h. Distinctive loud, ringing clicks, called "slow clicks," were highly correlated with the presence of mature male sperm whales. Slow clicks were distinguished from usual clicks by their slower repetition rate or interclick interval, their longer duration, and, usually the presence of intensity peaks at about 1.8 and 2.8 kHz. Between clicks of individual males (identified by photographs of natural markings), there were differences both in interclick intervals and in the pattern of emphasized frequencies. These differences, however, were not distinct enough to allow us to reliably distinguish one male's clicks from those of another. We hypothesize that slow clicks may be a sign of a mature or maturing male and may inform other sperm whales on the breeding grounds of its competitive ability and maturity.

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Des groupes de Cachalots macrocéphales (*Physeter macrocephalus*) ont été suivis acoustiquement au large des îles Galapagos entre février et avril 1985. Un total de 716 h ont été consacrées à des contacts visuels et acoustiques avec les cachalots et les vocalises des animaux étaient enregistrés durant 5 min/h. Nous avons donné le nom de « claquements lents » à des claquements distinctifs, forts et sonores, fortement associés à la présence de mâles adultes. Les claquements lents se distinguaient des claquements ordinaires par leur taux de répétition plus lent, leurs intervalles inter-claquements plus longs, leur durée prolongée et aussi, généralement, par la présence de maximums d'intensité à environ 1,8 et 2,8 kHz. Chez les individus mâles reconnaissables à certaines marques particulières (sur des photographies), les intervalles inter-claquements et les patterns des fréquences accentuées différaient, mais pas de façon suffissante pour nous permettre de distinguer avec certitude les claquements d'un mâle de ceux d'un autre. Il est possible que les claquements lents soient des signaux utilisés par les mâles adultes ou en voie de maturation pour signaler leur capacité compétitive ou leur degré de maturité aux autres cachalots sur les territoires de reproduction.

[Traduit par la revue]

Introduction

The first thorough description of sperm whale (*Physeter macrocephalus*) clicks was given by Backus and Schevill (1966). They noted that the clicks were of broad band form from about 200 Hz to 32 kHz, that the average interval between clicks varied from about 0.025 to 1.250 s, and that the whole click lasted from 2 to 24 ms. Backus and Schevill (1966) proposed echolocation and communication as probable functions of these clicks. They also noted considerable variation from one whale's click series to another's, but great similarity among successive clicks of one whale. Watkins and Schevill (1977) went on to characterize click sequences that they called "codas," which were emitted in stereotyped, repetitive patterns. They suggested that these sounds served as a means of individual identification. These vocalizations, together with clicks of high repetition rates called "creaks" (Worthington and Schevill 1957), seem to have been the only sounds reliably attributed to the sperm whale so far.

Although most nonwhistling cetaceans are solitary (Herman and Tavolga 1980), sperm whales are a notable exception. The females and immatures form long-lasting, close associations in groupings of about 25 animals (Best 1979). The social system of sperm whales is unique in that the sexes are widely segregated geographically. Mature males are frequently found in polar waters, whereas groups of females occur mostly in the tropics (Best 1979). Mature males migrate to the lower latitudes during the breeding season (Best 1979). Sexual dimorphism is extreme, with mature males having 3.2 times the mass (data based on Lockyer 1976), and 1.4 times the length of mature females (Best 1979). Sexual selection through intermale competition seems to be the cause of this size difference (Best 1979).

To study the social organization and behavior of sperm whales, we have followed groups of whales for periods of days in waters off Sri Lanka, the West Indies, and, most recently, the Galapagos Islands. We have also made a preliminary study of single sperm whales on the Scotian Shelf off Nova Scotia. During the Galapagos study, but also on a few occasions in the other studies, we have heard a sperm whale vocalization different from those mentioned previously. We use the term "slow clicks" (SCs) to denote these loud, distinctive clicks which may sound "clanky," "whamming," "metallic," or like the cracking of a stick. They are principally distinguished from the clicks described by Backus and Schevill (1966), which we call "usual clicks" (UCs), by their slow repetition rates.

The purpose of this paper is to (*i*) show that SCs are produced by mature males; (*ii*) describe SCs and how they differ from UCs both in their repetition rate or interclick interval (ICI) and in their frequency structure; and (*iii*) investigate differences between individual males in the ICI and frequency structure of their SCs.

Methods

Using a 10-m sloop with a crew of five, we spent a total of 716 h (30 days) in visual or acoustic contact with sperm whales in the waters west of the Galapagos Islands, from 21 February to 24 April 1985. It is not clear whether the sperm whales of the Galapagos, which lie on the Equator, are from northern hemisphere stocks, southern hemisphere stocks, or both (or whether this distinction is meaningful). However, observations of increasing numbers of mature males during

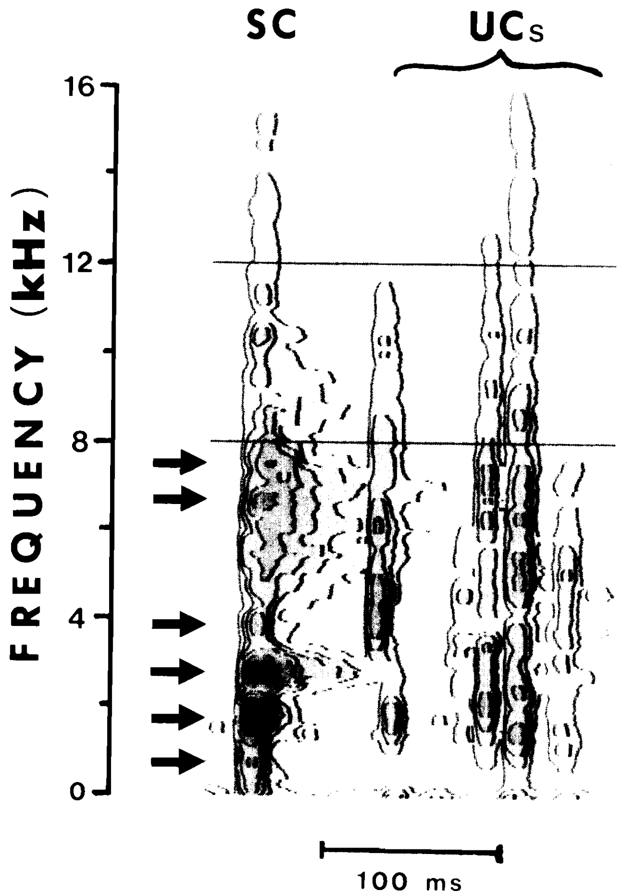

FIG. 1. Contour sonogram (frequency vs. time) of slow click and various usual clicks. Arrows denote peaks in intensity at 0.8, 1.8, 2.8, 3.8, 6.7, and 7.5 kHz. Notice the "ringing" character of the peak at 2.8 kHz.

the study and calves approximately 6 months old (the gestation period of the sperm whale is about 18 months) suggested that we were present at the start of the mating season (Whitehead and Arnbom 1987).

We tracked sperm whale groups acoustically, using a directional hydrophone to obtain bearings on the clicks made by the whales. Sperm whale vocalizations were recorded regularly for 5 min/h around the clock on Uher or Nagra tape recorders through a Benthos AQ17 omnidirectional hydrophone and Barcus-Berry standard preamplifier. The system was flat from 150 Hz to 10 kHz (± 3.5 dB) although a "roll-off" filter was used to de-emphasize low frequencies. The omnidirectional hydrophone was at a depth of 3 to 10 m (depending on the speed of the boat). A total of 56.4 h of sperm whale sounds were recorded off the Galapagos. In addition, one 5-min session of sperm whales recorded off the West Indies on 16 December 1984 was used for this analysis.

Using the same boat and the same methods, two single sperm whales were tracked acoustically on the Scotian Shelf, off Nova Scotia, between 17 and 25 June 1986. The sounds of these whales were recorded continuously for a total of 19.5 h.

During daylight, sperm whales were approached as discreetly as possible so that photographs of dorsal fins and flukes suitable for individual identification of whales could be taken (Arnbom 1987). The seven identified males were given identification numbers from 500 to 506 (Whitehead and Arnbom 1987).

For the examination of ICIs of SCs, 84 acoustic recording sessions of 5 min each were used, containing a total of 1663 ICIs. Because of the large quantity of UC sequences heard simultaneously, clicks from a single individual were impossible to pick out on all but a few

TABLE 1. The number of recording sessions and sonograms used for the analysis of SCs (slow clicks) of each known male (one SC per sonogram)

Male ID No.	Date	No. of sessions	No. of sonograms per session
555	84-12-16	1	3
506	85-03-08	2	2, 2
502	85-03-31	6	2, 1, 1, 3, 3, 1
505	85-04-12	1	2
501	85-04-12	4	2, 2, 1, 1
503	85-04-14	3	2, 2, 3
	85-04-15	2	1, 1
500	85-04-17	3	3, 4, 2
	85-04-19	2	4, 2
504	85-04-19	1	2
Total		25	52

occasions. Therefore, ICIs of UCs were measured from only nine recording sessions, containing a total of 1397 ICIs. Probably each of the nine sessions represents clicks from a different individual, although we cannot be sure of the identity of the vocalizing whale because of the large number of female and immature whales present during the recordings.

In comparing the ICIs of different males, SCs were attributed to a particular male if he was identified (from a photograph of his flukes) within 35 min of the recording session and if no other male was seen within 1 h of the recording. Two exceptions were made for whales recorded 65 min after and 48 min before, respectively, the identifying fluke-up, since no other male was sighted on those days. One recording session of a male in the West Indies (identification No. 555) was also used because, while not identified, he was nevertheless assumed to be different from the Galapagos males. Including these three exceptions, there were 25 sessions that could be ascribed to a particular male. Most of the recording sessions took place within 15 min after the identifying fluke-up. Still, the association of a particular SC series to an identified male is imperfect and does not definitely prove the identity of the vocalizing whale.

ICIs were determined using a computer as an event recorder. The timer of the computer was actuated (by pressing the space bar) each time a click was heard.

For the examination of the frequency structure of SCs, 52 sonograms were used, each depicting one SC (Table 1). Usually, more than one SC was depicted by sonograph per session, but an attempt was made to choose SCs as widely separated in time as possible, i.e., one from the beginning of the session and another from the end. Six known males and two males of questionable identity were represented. The same 25 sessions mentioned previously (in the ICI analysis), which related a particular male to a SC series, were used to compare the frequency structure of the SCs of different males.

Thirty-eight UCs from six recording sessions (all on different days) and 11 sonograms were examined with respect to frequency structure. They were divided into 12 series. Because of the regular repetition rate of clicks within a series, we believe that each series represents the clicks of a single individual. Different series from the same sonogram had independent and different ICIs and were almost certainly from different individuals. Thus, clicks from the same sonogram were not necessarily from the same individual, yet clicks from more than one sonogram were attributed to the same individual if they belonged to the same uninterrupted series. Given the number of individuals in the population (ca. 272; H. Whitehead, unpublished manuscript) and assuming that the majority of animals vocalize, it is likely that all or most of the 12 series were from different animals.

Sonograms were produced on a Kay digital Sona-Graph, model 7800. The frequency range sampled was 0–16 kHz, with a 1.28-s sampling time, and 300-Hz analysis filter. The shading contour

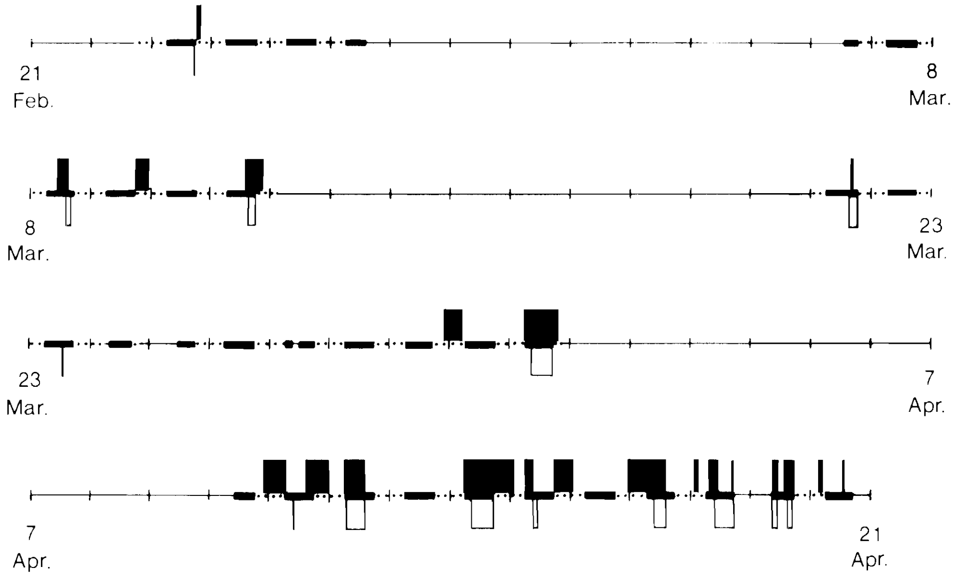

FIG. 2. The association between hearing SCs and sighting mature males. Times during which we were in visual and (or) acoustic contact with sperm whales are denoted by either a darkening of the horizontal time scale line (day) or dotted lines (night). Solid blocks above the time line indicate times when SCs were heard. Open blocks below the time line indicate when mature males were seen. If the gap between consecutive sightings of males or detections of SCs was 4 h or less, the two events were combined into a single block.

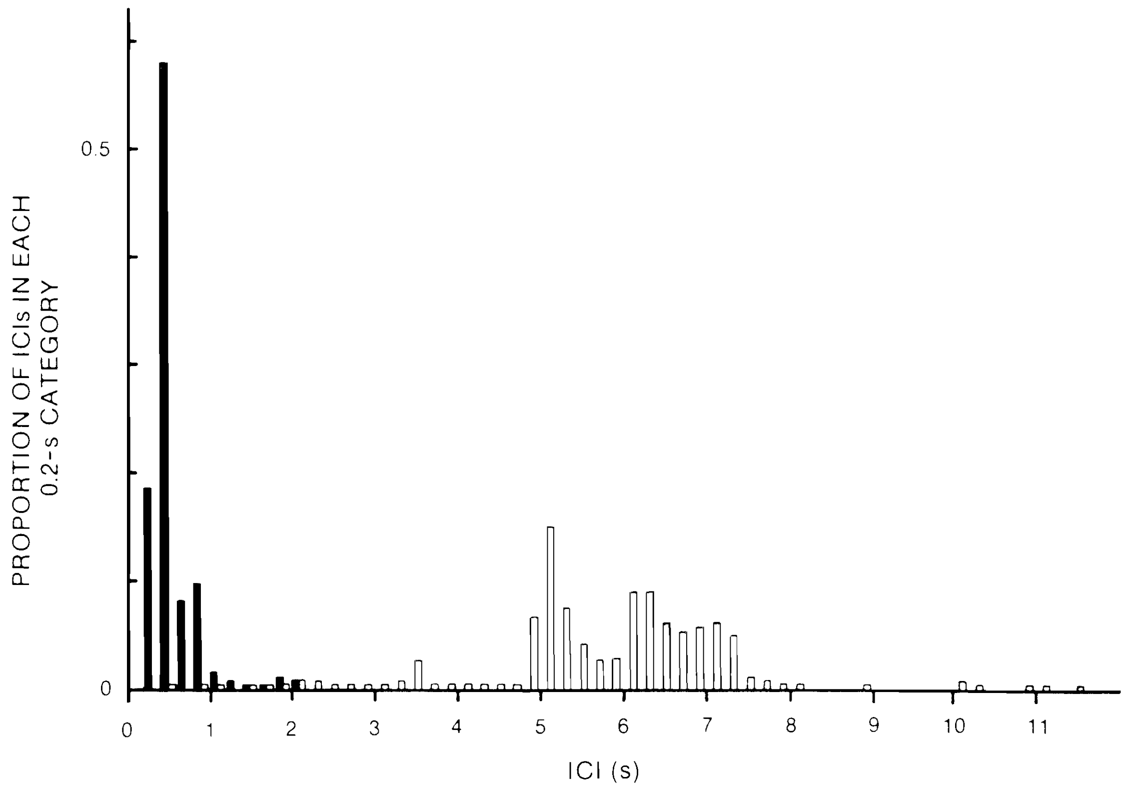

FIG. 3. The distribution of ICIs (interclick intervals) of UCs (solid bars) and SCs (open bars). The vertical axis represents the proportion of the total ICIs (for UCs or SCs) that falls into a particular 0.2-s interval (n = 1397 intervals from nine sessions for UCs; n = 1663 intervals from 84 sessions for SCs).

option was used, which produced contour lines connecting points of equal sound intensity. Eight shades of grey distinguished each intensity level, with a 6-dB increment from one shade to the next. These contours allowed intensity peaks within clicks to be recognized (Fig. 1). One to three calibration lines produced by the sonograph were printed on each sonogram.

A transparent overlay of calibration lines spaced at 500-Hz intervals was used to determine at which frequencies the intensity peaks of each click were located. For each click, the frequencies of two to seven peaks were recorded (depending on how many were evident), in order of decreasing intensity. The duration of the longest portion of each click was also measured.

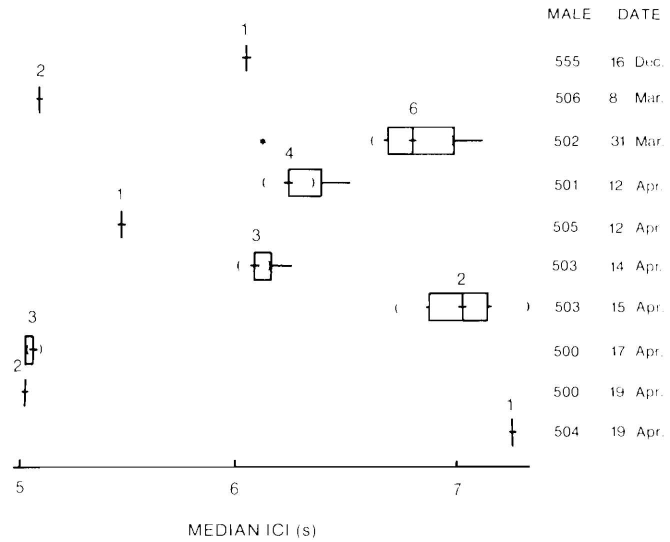

FIG. 4. Box plots of median ICIs for each known male (identification Nos. 500−555) and date. Males 503 and 500 were each recorded on 2 different days. Overall medians (+) were calculated from the median ICI of each 5-min recording session of a given male on a particular date. The ends of the boxes represent the interquartile range; parentheses represent the simultaneous confidence interval around the median. If the parentheses do not overlap with those of another box plot, the population medians are different at approximately $P < 0.05$. Horizontal line denotes adjacent (usually outermost) values. One outlier is represented by an asterisk. The number of sessions is given above the box plots. The same 25 sessions used for this figure are also used for the SCs of the males in Fig. 6.

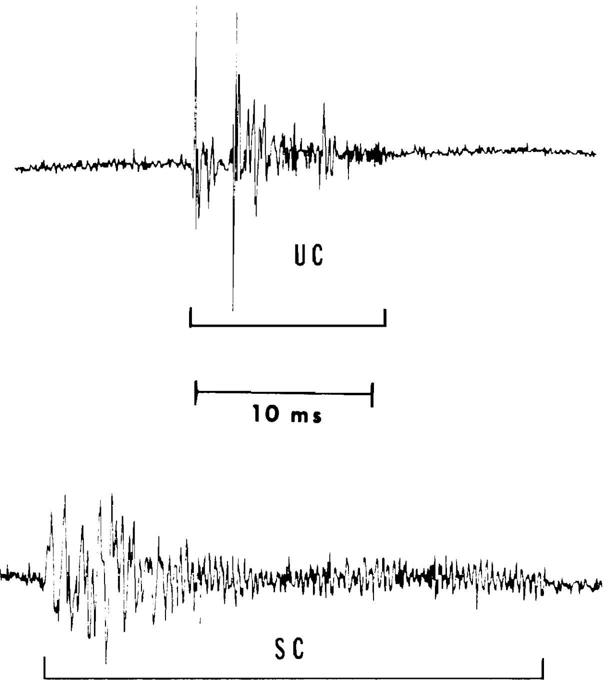

FIG. 5. Oscillograms of wave forms (amplitude vs. time) of a usual click (UC) and a slow click (SC). The UC represented was particularly loud, whereas the SC depicted was fainter than most used in the acoustic analysis, to demonstrate that the ringing quality of the SC was not due to resonance in the receiving system. A Gould 20-MHz digital storage oscilloscope, type 1421, with an $X-Y$ plotter, was used to produce the traces.

Results

There is a close relationship between occasions when males were seen and when SCs were heard: if SCs were heard during daylight, a male was usually seen (Fig. 2).

The histogram of all ICIs (Fig. 3) shows that the distributions for UCs and SCs are almost discrete. ICIs over 9 s probably indicate that a SC was missed in a click series. Very small ICIs (<2 s) for SCs were usually the result of two different, offset SC series, probably from different males heard at one time. The overall median ICI was 0.51 s for UCs, and 6.03 s for SCs. The median ICI for UCs is close to 0.64 s, the middle of the range of ICIs given by Backus and Schevill (1966).

When the distributions of the session medians for each identified male and day were depicted by box plots (Fig. 4), differences in ICIs between males were apparent. These differences, however, were not sufficiently distinct to allow positive identification of the eight males from their ICIs alone. In only two instances was the same identified male recorded on 2 different days: male 500 showed no difference in ICIs between 17 and 19 April, while male 503 altered his ICI radically from 14 to 15 April.

Qualitatively, SCs seemed longer in duration than UCs and often had a "ringing" quality at a particular area of emphasis which usually appeared only at one or two fairly low (<4.0 kHz) frequencies. This ringing is shown clearly in both sonograms (Fig. 1) and wave forms (Fig. 5). The intensity of these emphasized peaks was also usually greater than that of the peaks in UCs.

To examine each click's pattern of intensity peaks over the range of frequencies studied, the peaks of all 52 SCs and all 38 UCs were displayed (Fig. 6). Clicks were grouped according to the identity of the vocalizing whale. Since only two or three SCs of males 555, 504, and 505 were represented by sonogram, all from the same sessions, sample sizes are small and results should be interpreted with caution. Two consistent bands of peaks at about 1.8 and 2.8 kHz are discernible in the display of the SCs. The 2.8-kHz band was shifted somewhat in the SCs of the West Indies male (555, the male at the extreme left in Fig. 6). There were no similarly obvious bands of peaks running through the UCs. While some males appeared to use individually "preferred" areas of the frequency scale, no obvious patterns of peaks were peculiar to particular individuals. Male 501 did not seem to use the higher frequencies of males 503 and 500, for instance, but this tendency alone does not allow for positive individual identification. The UCs showed more variation between individuals, but again, the variation shown in Fig. 6 is not sufficient to definitely identify individuals. Generally, the UCs contained peaks at higher frequencies than the SCs. UCs were also notably shorter than SCs, with a median of 24 ms compared with 72 ms for SCs. The range for SCs was 28 to 124 ms.

Peaks of each click were compared with those of every other click to determine if there was more variation between individuals than within them in the pattern of emphasized frequencies. If the two clicks being compared shared peaks within 300 Hz of each other, a match was tallied. The greater the number of matches present between two clicks, the more similar they were thought to be. The number of matches was then examined in relation to the association the two compared clicks had to each other, e.g., each produced by a different male, both produced by the same male but from different sessions, or a SC being compared with a UC (Fig. 7).

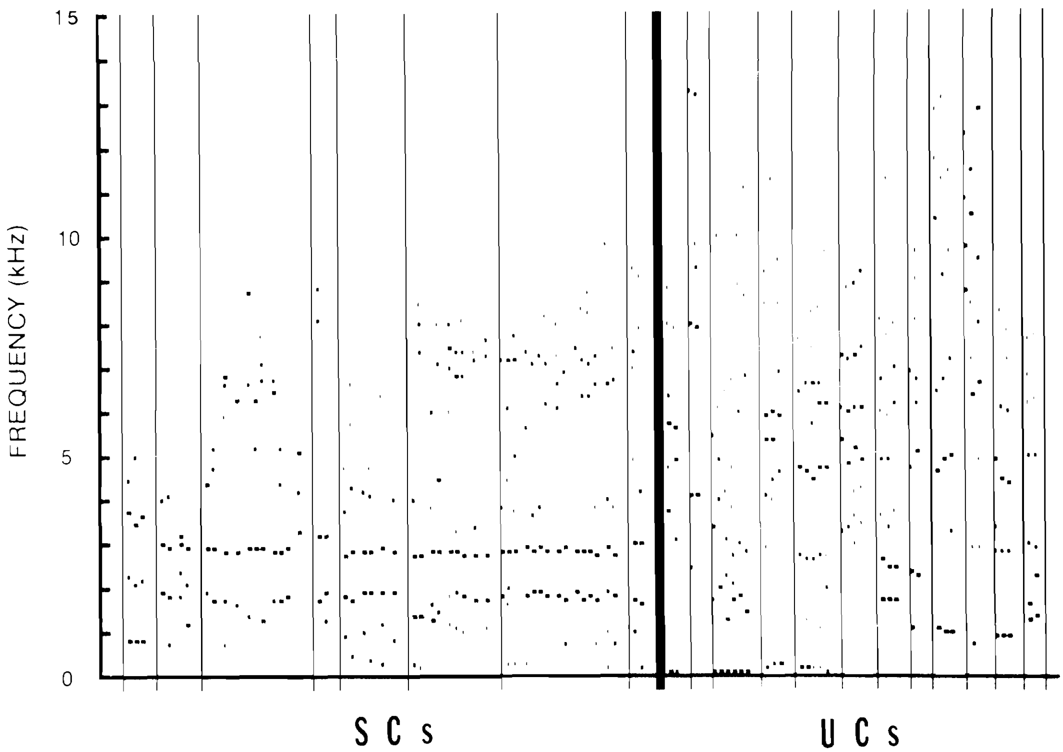

FIG. 6. The pattern of emphasized frequencies in clicks from individual sperm whales. Each point denotes a peak in intensity, with larger points representing peaks of greater intensity relative to other peaks in that click. Each series of vertically arranged points represents one click, and clicks from the same whale are plotted adjacent to one another with vertical lines separating individuals. In the case of UCs, we cannot be sure that all sections separated by vertical lines represent different individuals: this plot may represent less than 12 individual whales, although this is unlikely. Clicks within one section are taken from the same series of clicks and thus, from the same individual. The 25 recording sessions used for the SCs are the same as those used in Fig. 4. (n = 25 sessions for SCs; n = 6 sessions for UCs.)

The greatest similarity (highest mean number of matches) in the pattern of emphasized frequencies was present between clicks from the same male recorded on two different dates. This was followed in mean number of matches by clicks from the same male in the same session, and then by clicks from the same male but from different sessions. The grand mean from these three within-individual associations was 3.13 matches. This value can be compared with a mean of 2.34 matches between clicks from different males, and 1.87 matches between UCs and SCs. This test, though very insensitive, revealed a greater similarity in the frequencies emphasized in clicks from the same individual than in clicks from different individuals. However, the greatest differences in frequency structure occurred between UCs and SCs. The results of this analysis were similar when different criteria for a match were used (e.g., peaks within 200 Hz of each other).

Recordings of sperm whales from the Scotian Shelf provide some information about the acoustic behaviour of individual whales. Continuous recordings of two separate subadult males (12–14 m long) were made for 12.5 and 7 h, respectively. Both males produced UCs, with mean ICI of 0.96 s (n = 18) for male 1 and 0.69 s (n = 20) for male 2. However, SCs with a mean ICI of 4.57 s (n = 40) were also heard from male 2. SCs were heard only 5% of the time spent clicking and were produced, on at least two occasions and probably always, when the whale was at the surface or just before surfacing. In general, however, the males were usually silent at the surface.

Discussion

SCs could be distinguished from UCs by their longer ICIs, longer durations, and lower frequency emphasis. Males did show individual differences in their ICIs and the frequencies they emphasized in their clicks. However, these differences are not pronounced enough for us to reliably distinguish individual whales from one another at present. They do lend additional support to the evidence that SCs are produced by mature males, since different males tend to have different SCs. It may be possible to use information from the ICI and intensity peaks in conjunction to help identify a particular male from his SCs. The UCs also seemed to show individual differences in their frequency structure, but without the ability to determine the identity of the vocalizing whale, conclusions in this area remain tentative.

The association between the SC and the presence of a mature male was first made on 11 November 1983 when a mature male was sighted off Sri Lanka. The male was alone; no whale was seen within ca. 1.5 h, and only a slow, loud clicking was heard, which stopped when the male surfaced and resumed when it dove. This evidence, together with the strong correlation observed in the Galapagos between seeing the males and hearing the SCs, left little doubt that in these areas this vocalization was produced entirely by mature males. The standard UCs, usually associated with sperm whales, were heard from the much more common groups of females and immatures (mature males comprised only 2–3% of the population in the Galapagos and accompanied groups of females and immatures only 16% of the time; Whitehead and Arnbom 1987). This does not mean, however, that mature males may not also produce UCs.

But how and why do mature males produce a click different

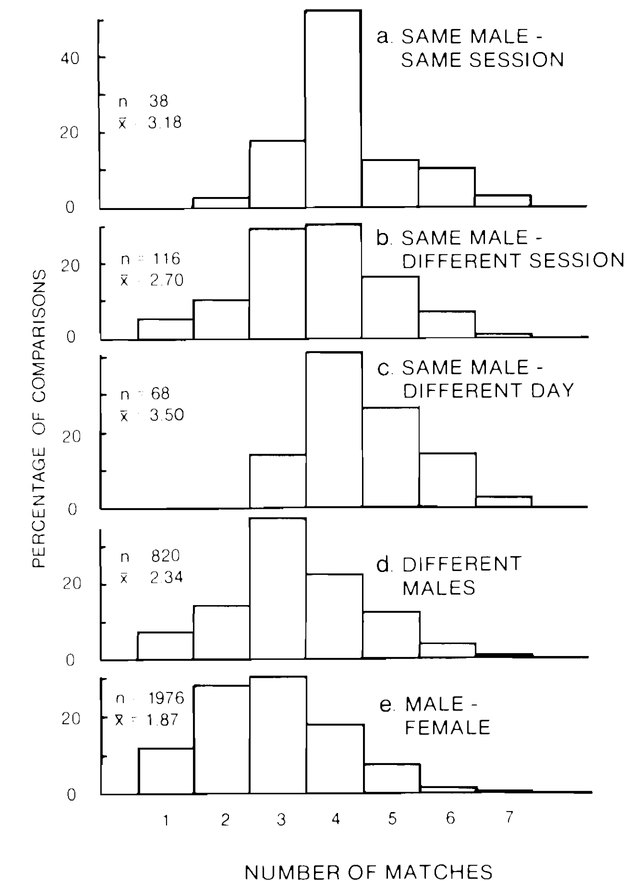

FIG. 7. The percentage of the total number of comparisons made (n) between two clicks of a particular association that resulted in a given number of matches. The number of times peaks of intensity from two different clicks were within 300 Hz of one another was tallied as the number of matches. Clicks were associated in one of the following ways: (a) both were from the same session, and thus the same male and date; (b) clicks were from two different sessions, but from the same male and date; (c) clicks were from two different days, but from the same male; (d) clicks were from two different males; or (e) clicks were from individuals of different sex. $\bar{x}$, mean number of matches for each association. The overall mean for the number of matches between clicks of the same male (a, b, c,) was 3.13.

from that of females and immatures? The forehead of the sperm whale (especially the spermaceti organ) is strongly implicated in sound emission (Norris and Harvey 1972). It is also proportionally larger in males than in females, comprising 20% of the total length in an 11-m female, 23% of the total length in an 11-m male, but 26% in a physically mature male of 16 m (Nishiwaki et al. 1963). The relative size of the organ may alter the acoustical properties of the head, and thus change the sound of the click. Norris and Harvey (1972) and Møhl et al. (1981) were able to estimate the size of at least one sperm whale each from attributes of the wave form of its click.

Mature males, probably to sustain their larger size, generally inhabit a different ecosystem than females and immatures. They reside mainly in colder waters (Best 1979), and usually feed on larger prey than do the females (Clarke 1980). As a consequence, mature males may have evolved a different kind of click (if indeed clicks function in echolocation). Their larger heads may enable them to produce clicks of greater intensity which, in turn, may allow them to increase their detection range for prey. This feature would be especially important when the whales are feeding on larger, and therefore generally more dispersed, prey. The longer ICIs of the males also support the idea that males were scanning greater distances ahead. However, whether males could detect anything at ranges of 5–6 km (which corresponds to the maximum range of an average to long ICI of a SC) is unknown.

The results from the maturing male on the Scotian Shelf, however, showed that the SC can be used when the whale is neither feeding (since he was at the surface) nor breeding (since he was far from the breeding grounds). Moreover, it was found that the male could alternate between SCs and UCs, and that the two vocalizations remained discrete, with no gradual change in ICI. This result strongly suggests that the function of the SC is different from that of the UC, and that the SC is not solely the inevitable acoustical result of larger head size in males.

Vocal characteristics, like the male's SC, are often a good indicator of sex. In addition, such vocal characteristics may become more striking or appear for the first time at puberty (Alcock 1975). Thus, the SC may be a sign of a mature or maturing male. If this signal informs other sperm whales of a male's state of maturity, competitive ability, or physical fitness, it may function in repelling other males, as in toads (Davies and Halliday 1978) or red deer (Clutton-Brock and Albon 1979), and in attracting females. Practicing these signals before entering the breeding grounds may then result in greater reproductive success.

Acknowledgements

We thank Tom Arnbom, Mel Brooks, and Vassili Papastavrou for their help at sea, Tom Arnbom for doing the photographic identification of the males, and Julia Mullins for analysis of the sounds from the males on the Scotian Shelf. The Galapagos study was funded by M. Clark, F. C. Whitehead, the Green Island Foundation, the Connecticut Cetacean Society, the O. Engkvist Foundation, and Dieter Plage. World Wildlife Fund—Netherlands, David Day, and Dieter Plage loaned vital equipment. We are grateful to Dr. Günter Reck, Dr. Mario Hurtado, and staff of the Charles Darwin Research Station, Miguel Cifuentes of the Galapagos National Park Service, and Captains Galo Davila and Mario Pinto of Instituto Oceanografico de la Armada for their considerable assistance. The research in the West Indies was funded by the Ocean Research and Education Society. The Scotian Shelf study and some of the analysis were funded by the Natural Sciences and Engineering Research Council of Canada. Dr. I. A. McLaren kindly reviewed the manuscript. We thank Dr. Fred H. Harrington and Dr. Stephen Shaw for the use of equipment.

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