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ACOUSTIC SOURCE LEVELS OF FOUR SPECIES OF SMALL WHALES

by

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Absolute sound pressure level measurements were made at sea on herds of four species of marine delphinids: the common dolphin, *Delphinus delphis*; the pilot whale, *Globicephala macrorhynchus*; the bottlenose dolphin, *Tursiops truncatus*; and the northern right whale dolphin, *Lissodelphis borealis*. Average source levels were similar for *Delphinus*, *Globicephala*, and *Lissodelphis*: 145-160 dB re 1 μPa (per 120 Hz band). Peak levels varied from 170 to 180 dB for the four species, being the highest for *Globicephala*.

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SUMMARY

Absolute sound pressure level measurements were made at sea on herds of four species of marine delphinids: the common dolphin, *Delphinus delphis*; the pilot whale, *Globicephala macrorhynchus*; the bottlenose dolphin, *Tursiops truncatus*; and the northern right whale dolphin, *Lissodelphis borealis*. Average source levels were similar for *Delphinus*, *Globicephala*, and *Lissodelphis*: 145–160 dB re 1 μPa (per 120 Hz band). Peak levels varied from 170 to 180 dB for the four species, being the highest for *Globicephala*.

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CONTENTS

INTRODUCTION

At any specific point in the ocean, ambient noise is the composite noise from all sound sources, except desired signals. The relative contribution of biological sounds, commonly called "biologics" by sonar operators, to ambient noise may vary with location, time of day and season. Increases in ambient spectrum level of nearly 50 dB have been observed due to the presence of biologics (Reference 1). Biologics can occur in the frequency range from about 10 Hz to over 200 kHz.

Many species of marine mammals, fishes, and invertebrates emit sounds. The sounds of marine mammals are the most complex and variable. Invertebrate sounds, such as those of snapping shrimp, are somewhat stereotyped. All of the marine mammals studied thus far have produced some type of sounds. The sounds of the large whales are generally lower in frequency than those of the porpoises and seals.

The performance of military acoustic detection and classification systems can be significantly degraded by interference from biologics. In order to determine and predict the extent of interference to a particular system, it is necessary to know the sound pressure level of the biological sounds as a function of frequency. From a military systems standpoint, the sounds of marine mammals (particularly herds of animals) are more important than the sounds of fishes or invertebrates. Marine mammals range throughout the ocean, whereas most noisy species of fish and invertebrates generally are restricted to near-shore waters.

Many recordings have been made of marine mammals in tanks and at sea, but we know of no calibrated recordings of herds of animals from which source levels were computed; that is, sound pressure levels one meter from the source. We do know that individual porpoises, under certain experimental conditions, are capable of emitting clicks with overall peak-to-peak pressure levels in excess of 215 dB re 1 μPa (Reference 2). The previously published data on cetacean source levels are summarized in Table 1.

The objective of this study was to measure the received sound pressure levels of herds of porpoises and compute the source levels for the combined acoustic output of the herd as a function of frequency. The species studied were: The common dolphin, *Delphinus delphis*; the bottlenosed dolphin, *Tursiops truncatus*; the Pacific pilot whale, *Globicephala macrorhynchus*; and the northern right whale dolphin, *Lissodelphis borealis*.

METHODS

Most recordings of marine mammals have been made with either shorebased or shipboard systems. The disadvantages of these systems are that too much time is spent looking for the animals, and because of the limited visual capability, it is frequently difficult to identify the species, ascertain group composition, determine the number of

Table 1. Summary of source level data for cetaceans

Species	Source Level (dB, re 1 μPa at 1 m)	Comments	Reference Number
ODONTOCETE:			
Tursiops truncatus	217–228	Broadband peak-to-peak level of clicks.	2
	175	"	3
Lagenorhynchus australis	80	Broadband RMS level of clicks.	4
Orcinus orca	160	Broadband RMS level of screams (click trains)	5
Stenella lognirostris	108–115	Broadband RMS levels of pulse bursts	6
	109–125	"squeals"	
	85–95	clicks	
Inia geoffrensis	165	Broadband peak-to-peak levels of clicks.	3
Phocoena phocoena	100	Broadband RMS level of clicks.	7
	140 (132–149)	Mean and range of peak broadband level of clicks.	8
Physeter catadon	135	Peak broadband level of pulses. Thought to be *P. catadon.*	9
	173.5	Mean 1/3–octave level of clicks at 1 kHz.	10
	171.2 (165.5–175.3)	Mean and range of broadband level of clicks.	11
MYSTICETE:			
Megaptera novaeangliae	138.6	Mean 1/3–octave level at 5 kHz.	12
	148.6	Mean 1/3–octave level at 1 kHz.	
	155.4 (144.3–174.4)	Mean and range of broadband levels of various types of signals.	
Eubalaena glacialis	172–187	Levels in the 25–2500 Hz band for "belch-like" sounds.	13
Eschrichtius glaucus	138–152	Mean broadband levels for several different types of low-frequency signals. Highest level measured.	14

Table 1. Continued.

Species	Source Level (dB, re 1 μPa at 1 m)	Comments	Reference Number
Balaenoptera musculus	159.2	Maximum broadband level of clicks.	15
	188	Mean level of moans in a 14–222 Hz band.	16
Balaenoptera physalus	173–181	Source level for 20 Hz pulses.	17
		Source level of 20 Hz pulses thought to be from *B. physalus*, based on source level calculations as cited in reference 16.	18
Balaenoptera acutorostrata	152.6	Maximum broadband level of clicks.	19

animals in the herd, and estimate the range of the animals from the hydrophone. Source level calculations require (1) good range information and (2) a calibrated broadband receiving/recording system.

Receiving/Recording System

An air deployable system was developed for making absolute sound level measurements of received underwater acoustic signals in the frequency band from 1 kHz to 40 kHz. The system consisted of SSQ-57A sonobuoys, modified by replacing their hydrophones and preamplifiers with small broadband hydrophones (Aquadyne special order) and broadband preamplifiers. Calibration circuit cards (designed and built at the Naval Undersea Center) were potted along with the preamplifiers and molded to the hydrophone cables (Figure 1). In order to extend the high frequency response of the sonobuoys, a capacitor was bypassed in the first stage of the audio amplifier section.

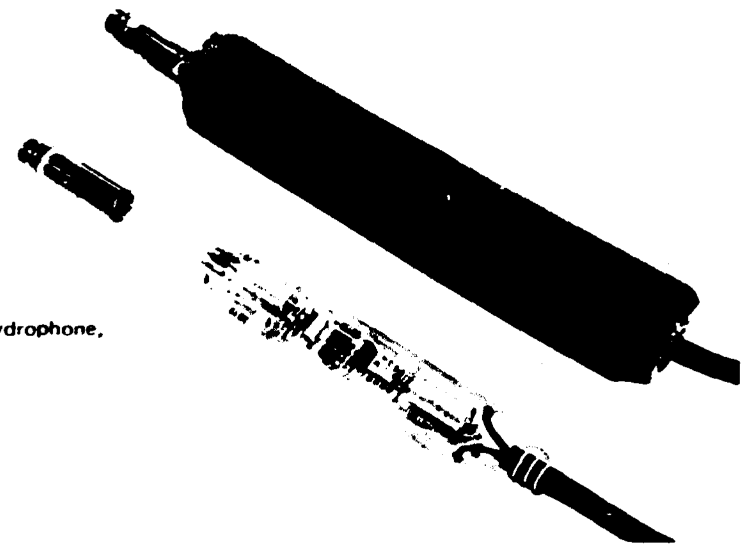

Figure 1. Circuit board showing hydrophone, preamplifier, and timer circuit.

The RF section was not modified. The "one-shot" saltwater battery system was replaced with an external battery that could be changed at the end of its 15 hour life. Batteries for powering the preamplifier and calibration circuits were placed inside the sonobuoys and replaced after about 25 hours of use.

The calibration signal, injected at the preamplifier input, was a two-kHz square wave generated by a Type 555 integrated circuit (Figure 2). The calibration signal occurred for five seconds every four minutes, with the timing being controlled by an additional integrated circuit. The voltage level of the calibration signal fundamental frequency was set to be equivalent to a received acoustic sound pressure level of 115 dB re 1 μPa at 1 m from the hydrophone. The spectrum of a square wave contains all the odd harmonics, decaying at 6 dB per octave from the fundamental frequency. The signal was injected at the input of the sonobuoy preamplifier and transmitted through the entire receiving system and onto tape. Thus, a measurement of the overall frequency response of the combined receiving-recording system was provided. A comparison of the taped square wave spectrum with the original spectrum showed what frequency response corrections had to be made to compensate for nonlinearities in the response of the total system. Since the hydrophones were not calibrated by this technique, they were measured separately at the Naval Undersea Center's transducer evaluation center (TRANSDEC). The usable upper frequency limit of the entire system was approximately 40 kHz, due to hydrophone directivity problems above that frequency.

Signals transmitted by the sonobuoys were received on a two-channel sonobuoy receiver (R-1170/ARR 52A), modified for battery operation by replacement of the standard AC-powered audio amplifier with a comparable transistorized model. The receiving system, weighing less than 30 kg, was completely battery operated and self-contained, and included aircraft communication inputs and outputs (Figure 3).

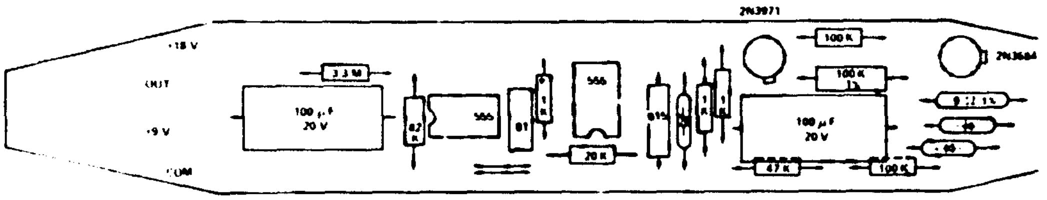

Figure 2. Component layouts of preamplifier and calibration-timer circuit.

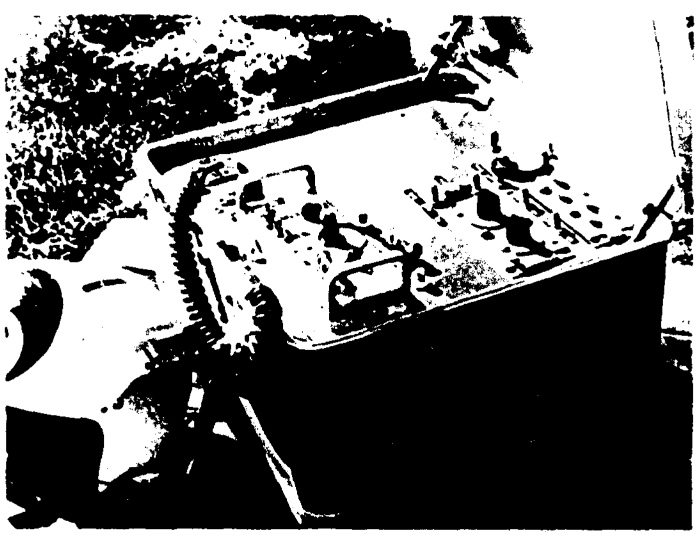

Figure 3. Portable battery-powered 2-channel sonobuoy receiver.

Recording Procedures

The receiving/recording system was operated from a U. S. Navy SH-3 helicopter. The helicopter platform provided:

a. good mobility in searching for animals.

b. positive species identification, herd composition, and estimates of herd size.

c. good estimates of aspect and range of the animals to the sonobuoy.

d. minimal interference with the behavior of the animals.

Figure 4 shows the areas from which the data were collected from December 1974 to April 1975. A search altitude of 200–300 m was maintained until a group of animals was located. Once the animals were sighted, an altitude of at least 200 m was maintained until they were identified, group size and composition noted, and the general direction of movement established. A sonobuoy was then deployed by flying 1000 to 2000 m ahead of the group, momentarily coming down to an altitude of 12 m, and lowering the sonobuoy into the water. A smoke flare was dropped adjacent to the buoy to maintain visual contact. During the entire recording session, a minimum altitude of 200 m was maintained at all times in an area as far away from the animals and sonobuoy as practical. The estimates of range were computed by the helicopter crew members by dividing the helicopter airspeed by the time required to fly from the herd of animals to the sonobuoy.

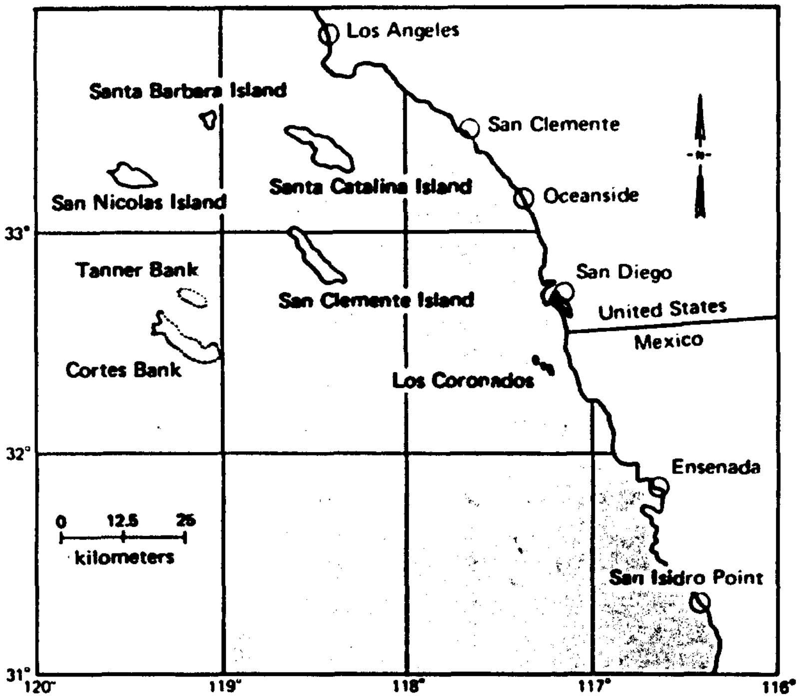

Figure 4. Offshore Southern California waters in which data were collected.

The audio output from the sonobuoy receiver was "split" and recorded on three direct-record channels (−10 dB, 0 dB, and +10 dB input gains) and three FM channels (−10 dB, 0 dB, and +10 dB input gains) on a one-inch tape recorder (Honeywell 5600C) at 60 ips. A seventh track of the recorder was dedicated to servo-speed control. Voice comments, taped on a separate dedicated voice side-track, included range, behavior, and aspect information. The frequency response of the tape recorder was flat from dc to 40 kHz on the FM tracks and down 3 dB at 300 Hz and 300 kHz on the direct channels.

At the end of the recording session, the sonobuoy was picked up with a grappling hook from a 12 m hover. All data were collected on clear days, sea state 0 to 1, and in the absence of shipping traffic. Ambient noise was at least 15 dB below the minimum received levels measured from the animals, at all frequencies.

Data Analysis

The tape recorded data were replayed at an 8:1 reduced speed (7.5 ips) on the same recorder used for making the field recordings into a real-time spectrum analyzer (Nicolet Scientific UA-500A) set at the 5 kHz analysis range. This provided an overall analysis bandwidth of 40 kHz (8x5 kHz) with an "effective" analyzing filter bandwidth of 120 Hz. Hard copies of spectral displays were made on an X-Y plotter (Hewlett-Packard 7035B). Two analysis modes were used:

Sum average: In this mode each redundant spectrum generated by the analyzer is added to the previous spectra stored in memory. At the termination of N ensembles, the average is normalized.

Peak hold: The content (amplitude) of each frequency cell in memory is compared with the cell amplitudes of the new input spectrum. If the memory content at a particular cell location is equal to or greater than the new input, the memory is unchanged. If the new input is larger, the memory content is updated with the larger input value. The resulting final spectrum for a given value of N ensembles represents the highest amplitude values per frequency cell.

The recording from the different herds of animals were analyzed by generating 19 contiguous spectra (each compiled from a 256-ensemble average) from a section of tape and plotting them as consecutive overlaps on the X-Y plotter. Each individual spectrum represented 3.2 seconds of real-time data, making the total duration of each sample nearly one minute long (19x3.2 sec). This technique of overlaying the 19 contiguous spectral plots on a single piece of graph paper was a convenient way to display the degree of variation in source level as a function of frequency over a one-minute period. Both the sum-average plots and the peak-hold plots were taken from the same locations on the tape.

Source levels were computed by taking the absolute received sound pressure levels measured at the hydrophone (received level), and applying the necessary range corrections for spherical spreading loss (20 log r) and corrections for frequency dependent attenuation.

to arrive at an estimate of the absolute levels at 1 m from the hydrophone (defined as source level). The results are presented in terms of the actual effective bandwidth in which the analysis was performed (120 Hz). The levels were not reduced to spectrum levels (sound pressure levels per 1 Hz band) due to the presence of numerous peaks in the frequency spectra. A spectrum level conversion would be invalid for such data.

Absolute received levels used in the computations of source levels were measured at ranges of 200 to 1000 m from the animals. In all instances the sounds came from a herd of animals rather than a single individual. The range estimate used for any given calculation was the distance from the sonobuoy to the center of the herd. No data are shown for herds so dispersed that a "reasonable effective center" could not be estimated.

RESULTS

The predominant peak near 14 kHz in the spectrum shown in Figure 5, from a group of 10 Pacific pilot whales, *Globicephala macrorhynchus*, appeared to result from the repetitive, whistle-like signals produced by the animals. The higher end of the spectrum resulted from the broadband clicks.

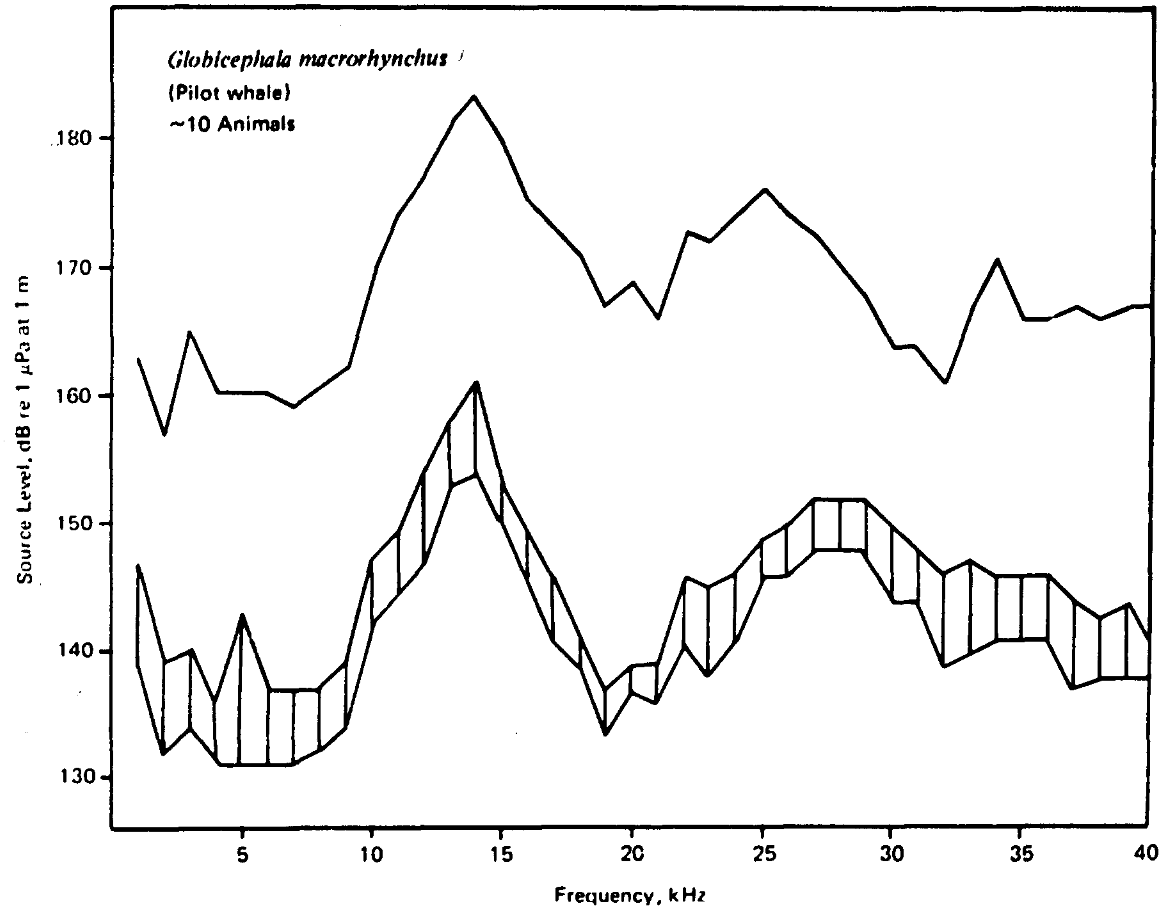

Figure 5. Sum-average and peak-hold source levels of Pacific pilot whale (*Globicephala macrorhynchus*).

Figure 6 shows the source level for a herd of about 200 *Lissodelphis borealis*. The only sounds recorded from these animals were clicks emitted at very high repetition rates, with energy extending well beyond the upper frequency limit (40 kHz) of the sonobuoy system that was used for making the measurements.

The source levels of clicks and whistles of 10 Pacific bottlenose dolphins, *Tursiops truncatus*, are shown in Figure 7. During this particular recording session, there was no obvious instance when both clicks and whistles were being emitted by the herd at the same time. The data shown were analyzed with the peak-hold averaging technique (see data analysis section of methods for explanation). The sum average could not be used, since the signals from this species were emitted very intermittently; there were long periods of time when the animals were completely silent.

Figure 8 shows the source level of clicks emitted by a group of approximately 300 common dolphins, *Delphinus delphis*. Peak energy in the clicks probably occurred at frequencies well above the limit of the sonobuoy system. Figure 9 shows a combined spectrum for whistles and clicks. At a given point in time, individual whistles, or whistles from a single animal, were spread over a relatively narrow frequency band of a few kHz. However, since many of the 300 animals were emitting whistles simultaneously and at different frequencies, the total "herd effect" resulted in the relatively broad, flat spectrum of Figure 9. In addition, the flatness was further enhanced by the one-minute-long averaging process.

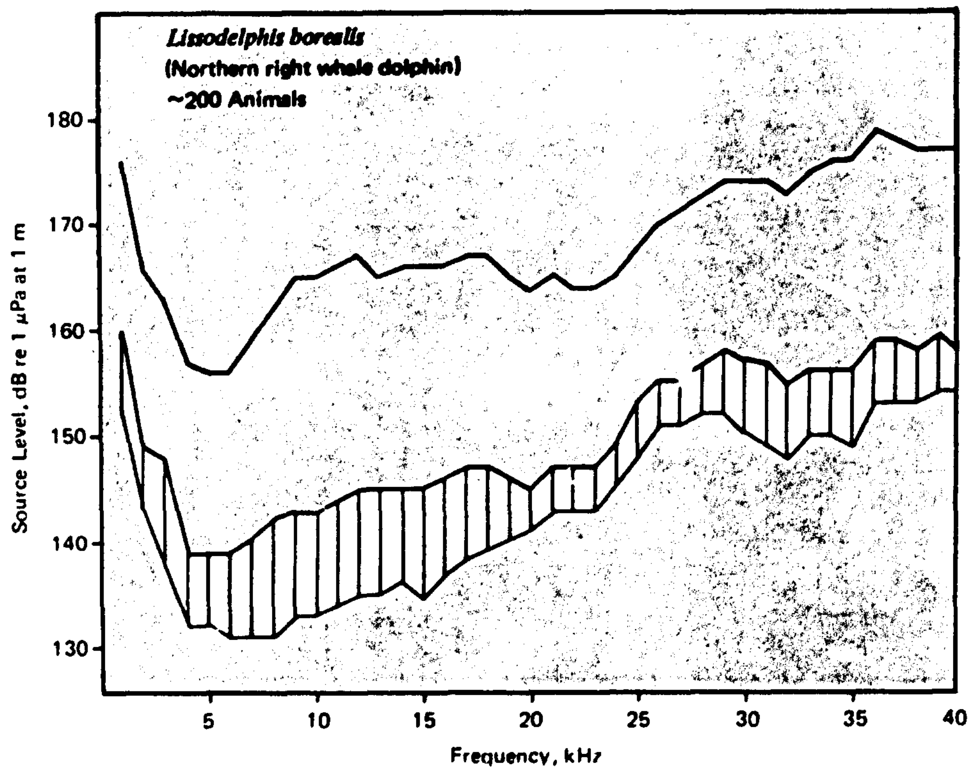

Figure 6. Sum-average and peak-hold source levels of northern right whale dolphin (*Lissodelphis borealis*).

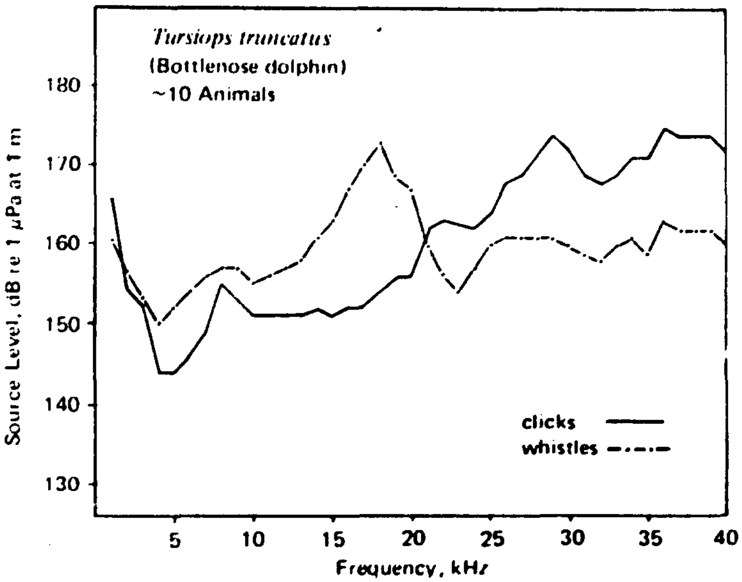

Figure 7. Peak-hold source levels of Pacific bottlenose dolphins (*Tursiops truncatus*).

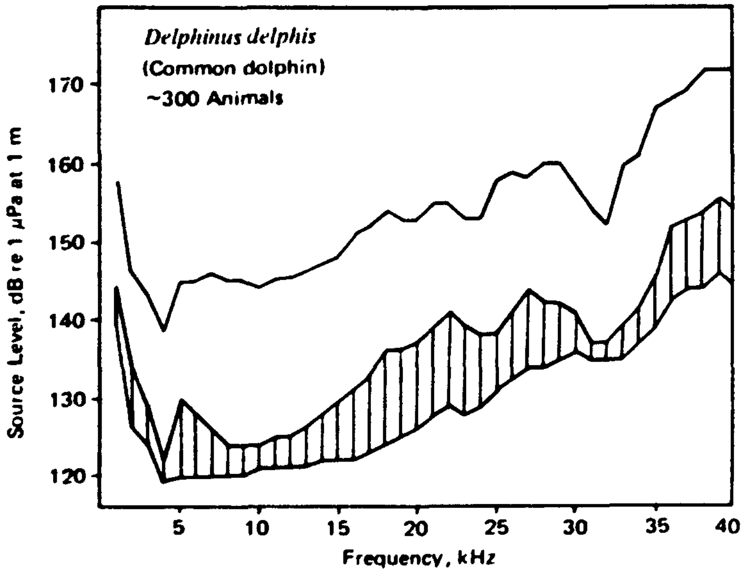

Figure 8. Sum-average and peak-hold source levels of "clicks" of common dolphins.

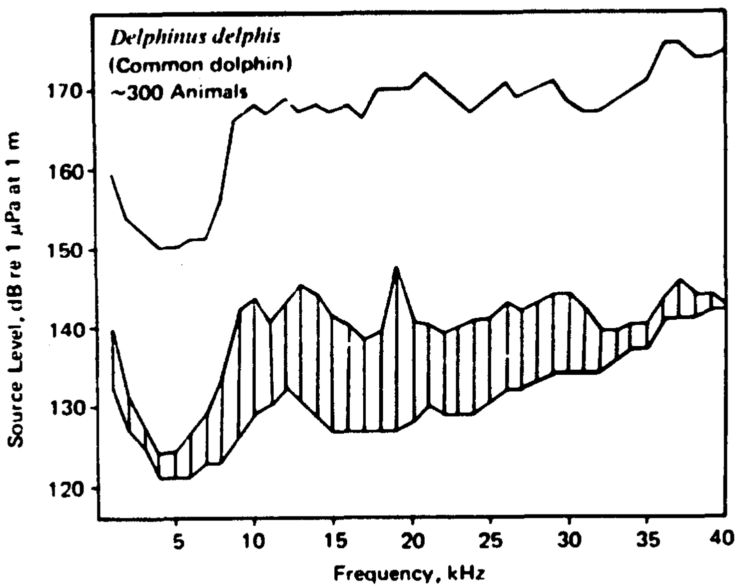

Figure 9. Sum-average and peak-hold source levels of whistle and clicks of common dolphins.

The source level of a different and smaller group of common dolphins, about 80 animals, is shown in Figure 10. The only evident sounds recorded from this group were clicks which had two sharp energy peaks near 25 and 35 kHz. The data from the three Delphinus recordings are compared in Figure 11.

All of the source level data presented above were collected from animals that were heading toward the sonobuoys. Although detailed quantitative information was not obtained on source level as a function of frequency and herd aspect angle, there was one occasion when a group of about 200 common dolphin passed close to the sonobuoy and continued on course away from it. The overall source level was approximately 10-15 dB less when the animals were heading away from the buoy.

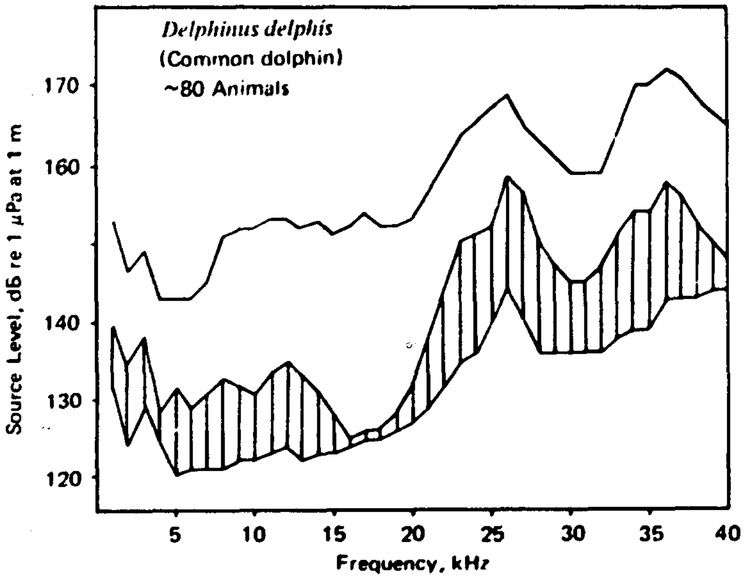

Figure 10. Sum-average and peak-hold source levels of clicks of common dolphins.

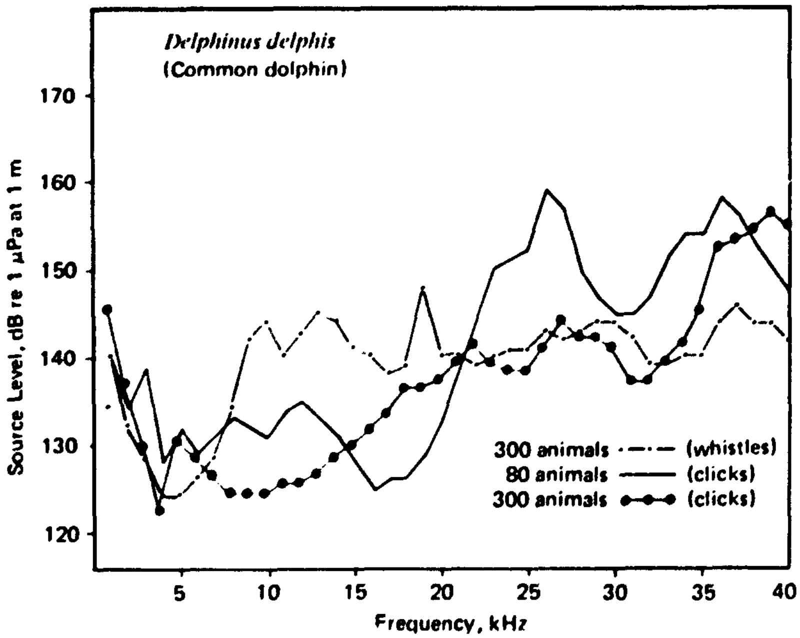

Figure 11. Comparison of maximum sum-average source levels of common dolphins.

Based upon the data collected during this study, it would be difficult to give a very specific absolute source level value for any of the four species considered. As might be expected, the results indicate that there is a great deal of variability in the sound output (and source level) from a herd of porpoises, including the (1) kinds of signals emitted and frequency bands emphasized, (2) number of signals emitted during a given period of time, (3) directional characteristics of the sound field, and others.

A number of factors contribute to the overall variability, including the number, sex, and age of the individuals in a group, their behavioral activity, and the aspect angle of the group relative to the location of the hydrophone.

An in-depth study of each species under a wide variety of behavioral conditions would be required to reach a point where one might predict what sounds would occur from a given group of animals.

In general, the normalized (sum average) spectrums for *Globicephala*, *Lissodelphis*, and *Delphinus* were all about the same amplitude (145–160 dB re 1 μPa at 1 m) in their respective areas of principal energy. The maximum levels were approximately 180 dB for *Globicephala* and 170 dB for *Lissodelphis*, *Tursiops*, and *Delphinus*.

There was no obvious correlation between group size and signal level. Larger groups of animals do not necessarily contribute more noise. It is quite common for a herd to be completely silent.

We know of no published source level data for *Delphinus*, *Globicephala*, or *Lissodelphis* with which to compare our data. The source level data (and most of the other data) presented in Table 1 of Evans (Reference 20) do not exist in the references cited in that table. A discussion with Evans (Reference 21) indicated that an editorial error must have been made in the citations; the data were intended to be referenced as "personal communication". Au et al cited the same source level data from Evans' table in their report (Reference 2).

Broadband source level estimates have been published for *Tursiops truncatus* (Reference 2). The authors reported overall average peak-to-peak source levels for clicks of 220.4 dB re 1 μPa from one animal and 222.3 dB from another, with the principal energy falling in the 120 130 kHz region. These results were obtained while the animals were involved in a target-detection experiment conducted in open waters at target ranges of 54 m to 78 m. The high ambient noise level of the test environment at Kaneohe Bay, Hawaii, may have accounted for the high-level clicks and the high-frequency emphasis. We have measured broadband peak-to-peak levels as high as 211 dB re 1 μPa during similar sonar discrimination experiments with a *Tursiops truncatus* in San Diego Bay. The source levels we report in this paper for *Tursiops* clicks are considerably lower, probably for several reasons. They are not presented as broadband peak-to-peak levels, but rather as source levels in an effective analyzing bandwidth of 120 Hz. Also, they are based on root-mean-square measurements rather than peak-to-peak measurements. The recordings were made from animals under natural field conditions during times when the ambient noise was low, in contrast to the recordings made from animals performing difficult target-detection tasks under noisy conditions.

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