SOUNDS FROM BRYDE, *BALAENOPTERA EDENI*, AND FINBACK, *B. PHYSALUS*, WHALES IN THE GULF OF CALIFORNIA

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ABSTRACT

Low-frequency moaning sounds were recorded from Bryde whales, *Balaenoptera edeni*, off Loreto, Mexico, in the Gulf of California. These utterances averaged 0.4 s in duration with most of the sound energy at about 124 Hz. Elsewhere in the Gulf, we recorded about 1,300 low-frequency moans from at least 35 feeding finback whales, *B. physalus*. The finbacks' most outstanding sound was a long moan with a 1.9-s component at 68 Hz and a 1.6-s component at 34 Hz. Overall sound source levels in the effective bandwidths ranged between 152 and 174 dB re 1 μPa (1 m) for Bryde whales, and 159 to 183 dB for finback whales. Short "20-Hz signals" that are typically associated with finback whales were not present in these recordings, apparently because of seasonal or behavioral differences.

The main objective of this study was to describe underwater sounds from two species of mysticete whales—the Bryde whale, *Balaenoptera edeni*, and the finback whale, *B. physalus*. We also wanted to compare the presently described finback sounds with those recorded elsewhere.

Contrasted with the typical whistles, squeals, and clicks of odontocetes, we continue to find that mysticetes utter mostly low-frequency sounds. However, exceptional and rare sounds of higher frequency have been reported (Cummings and Thompson 1971; Beamish and Mitchell 1971, 1973; Beamish 1978). The combination of low frequencies (Hz), long wavelengths, and high source levels of mysticete whale sounds enables their detection at distances up to 100 km or more, even with standard signal processing.

Low-frequency sounds (40-75 Hz, 1-s long, and others) have been recorded from finbacks in the North Atlantic (Schevill and Watkins 1962; Edds 1981). Short, powerful "20-Hz signals" have also been recorded from this species (Schevill et al. 1964). Watkins (1981) categorized underwater finback sounds as 20-Hz pulses, ragged broadband low-frequency pulses, low-frequency rumbles, higher frequency sounds, and broadband impulses.

We have long been interested in "20-Hz signals", having worked with many categories from widespread areas of the world (Cummings and Thompson 1966[4]; Northrop et al. 1968, 1971), and the prospects of recording them from the more accessible finbacks in the Gulf of California also was an important objective.

We are unaware of any other descriptions (except for 20-Hz pulses) of sounds from Pacific finbacks. Underwater sounds from the Bryde whale were unknown, this being the original description except for a brief abstract of the present work in 1969 (Thompson and Cummings).

MATERIAL AND METHODS

An expedition took place in June 1969, aboard the 27 m yawl, *Saluda*. The ship left La Paz (southeast Baja peninsula, Mexico) sailed northward to Mulegé, across the Gulf of California to Guaymas on the Mexican mainland, northward past Isla San Esteban, around Isla Angel de la Guarda, and southward to Santa Rosalia—a distance of about 1,500 km (Fig. 1). Except for Contact 3, all of the sounds recorded in the presence of unidentified large whales were generally the same as those that we determined to be from finbacks. However, we were not always certain which balaenopterid was being recorded, especially at long distances. Consequently, if an identification of a balaenopterid whale was questionable, the "contact" was noted simply as "*Balaenoptera* sp".

The water's surface varied from Sea State 0 to 2, and currents usually were minimal. The ship's operating equipment was shut down during all recordings. The instrumentation included a hydrophone-

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[4]Cummings, W. C., and P. O. Thompson. 1966. 20-Hz signals in the northeast Pacific. Unpubl. Rep., 17 p. Navy Electronics Laboratory, San Diego, 92152.

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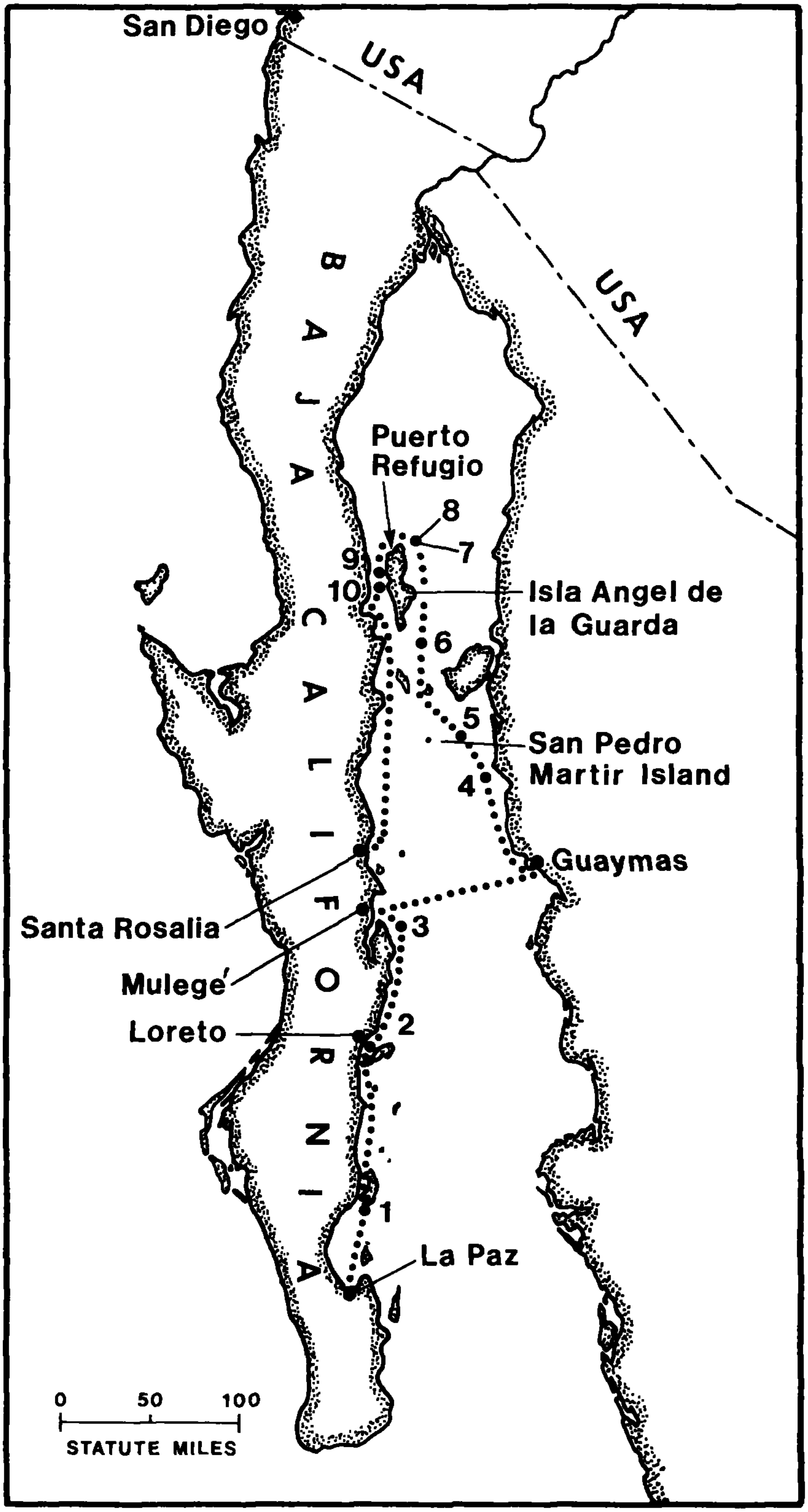

FIGURE 1.—Track of *Saluda* in the Gulf of California (June 1969) with numbered cetacean contacts.

preamplifier (Wilcoxon,[5] Type M-H90-A) suspended at depths of 6 to 53 m below the surface. Up to 800 m of floating cable carried the signals to the ship, allowing the hydrophone to be stationary until the ship drifted out to this distance. The hydrophone was suspended from an inflatable 8 m spar buoy which provided effective acoustic isolation from low-frequency acceleration caused by surface waves. The hydrophone's response was attenuated at low frequencies (beginning with 3 dB down at 12 Hz) to further reduce low-frequency noise and to prevent most of the preamplifier blockage from any drag motion that remained. Without these or similar measures, we have found that hydrophone and sea noise below 100 Hz, even in relatively smooth seas, usually prevents satisfactory recordings of low-frequency mysticete sounds with suspended systems.

One track of a magnetic tape recorder (Magnecord 1020), powered by a DC-AC converter, carried a running commentary and airborne whale sounds from a radio microphone (Vega Telemike). The other track recorded signals from the hydrophone. Continuous visible records were made on station with a level recorder (Brüel & Kjaer, Type 2301), also powered by the converter which was acoustically isolated. A sound analyzer (General Radio, Type 1558) was used to monitor incoming signals and their absolute levels and to provide power to the hydrophone-preamplifier. Calibration was by means of a 1,000-Hz tone and pink or white noise which were inserted through the system and recorded at frequent intervals. Overall response of the recording system was ± 5 dB from 25 Hz to 18 kHz.

Without a hydrophone array we could not precisely localize sound sources. However, correlations between whale movements and changes in received sound level provided evidence that those sounds came from the whales observed.

At sea we find it difficult to distinguish the Bryde whale from other balaenopterids, especially the sei whale, *B. borealis*. An exception was the circumstance noted here, involving long contacts and good visibility above and below water, so that identifying features of behavior and form were revealed. Most useful of these field characteristics were 1) the presence of ridges on top of the head of Bryde whales, 2) the asymmetrical coloration of finbacks, usually a yellowish white on the lower right jaw and baleen that is contrasted with the darker appearance of the left area, and 3) the peculiar surfacing of sei whales whereby head and fin appear nearly simultaneously, without arching.

Received overall sound levels are reported in dB re 1 μPa, and source levels are referenced to 1 m. Analysis was accomplished using graphic level recorders, oscilloscopes, a sound spectrographic recorder, and a RTA (real time analyzer).

RESULTS

Sightings and Recordings

The locations of whale sightings associated with recordings of whale sounds are listed (Table 1). Unidentified balaenopterid whales were sighted off La Paz, where two low-level whale sounds were recorded during Contact 1.

We spotted two Bryde whales, about 11 m long, southeast of Loreto (Contact 2). The sea was calm and the surface water temperature was 24°C. The two animals separated as the ship approached. One swam away and remained mostly out of sight. The other began passing back and forth under the ship's keel. It dove about 10 m and surfaced every 1 to 6 min. W. C. Cummings dove on the whale and photographed it underwater for identification.

We recorded 288 low-frequency moans in 50 min from the Bryde whales during Contact 2. Some of these sounds were of very low signal-noise ratio (down into the ambient level of the sea noise) and presumably originated from the more distant of the

[5]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 1.—Contacts with sound producing whales in the Gulf of California.

Contact	Date	Time	Location	Subjects (No.)
1	6-11	1000	24°43.5′N, 110°36′W, 2 km S of Isla San Francisco	*Balaenoptera* sp. (1)
2	6-13	0700	25°57.5′N, 110°19′W, 8 km SSE of Loreto	*B. edeni* (2)
3		1930	26°50′N, 111°42′W, 14.8 km SE of Pta. Concepción	*B. edeni* (1)
4	6-17	1815	28°18′N,111°46′W, midway, Guaymas to Isla San Esteban	Large whale (1)
5	6-18	0530	28°25′N, 112°9.5′W, 18.5 km ENE of San Pedro Martir Island	*Balaenoptera* sp. (1)
6		1330	28°58′N, 112°53.5′W, 24.1 km ESE of Isla Angel de la Guarda	*B. physalus* (3)
7	6-19	0900	29°35′N, 113°31′W, 3.7 km ENE of Puerto Refugio	*B. physalus* (about 35)
8		1430	29°41.5′N, 113°27′W, 17.6 km NE of Puerto Refugio	*B. physalus* (2)
9	6-20	1430	29°14′N, 113°33′W, N. end of Ballenas Channel	*Balaenoptera* sp. (1)
10		1530	29°15.5′N, 113°30′W, N. end of Ballenas Channel	*Balaenoptera* sp. (1)

two whales. Coincidently, we were recording low-level, high-pitched whistles and squeals from a distant group of saddleback porpoises, *Delphinus delphis*. It was obvious that changes in the loudness of other low-frequency signals, as aurally monitored, and in the level on the graphic recorder were correlated with the nearby Bryde whale's proximity to the ship.

Later the same day, another whale was sighted off Pta. Concepción in the Mulegé area and tentatively identified as either a sei or Bryde whale of about 12 m (Contact 3). We recorded 407 sounds from this whale. The sounds were essentially the same as those recorded earlier from the Bryde whales of Contact 2. After analyzing the sounds, Contact 3 was identified as a Bryde whale. Sounds of these characteristics were not encountered again during the cruise, nor were any other Bryde whales seen.

About 100 km northwest of Guaymas, a large whale was sighted at a range of about 450 m (Contact 4). A brisk wind and choppy seas prevented identification, but one distinctly whalelike moaning sound appeared in the accompanying noisy recording.

East of San Pedro Martir Island, we recorded 42 sounds from another whale (Contact 5) identified as a finback, about 15 m in length. Three large finback whales were sighted off the southern tip of Isla Angel de la Guarda (Contact 6). All of the 376 moans recorded from these whales occurred when the animals were below the surface.

On 19 June, we sighted about 35 finback whales outside the entrance of Puerto Refugio (Contacts 7, 8). They surfaced in series of 2 to 7 times, usually in pairs or in trios. Their blows were accompanied by smooth resonant sounds similar to that expected from air rushing through a confined space. Climaxing the final appearance in a series of surfacings, the whales strongly arched their backs and appeared to dive at a steep angle. Some of the finbacks' dorsal fins were distorted. Large concentrations of whales, porpoises, and sea lions occurred over an area of at least 6 km around the ship where they

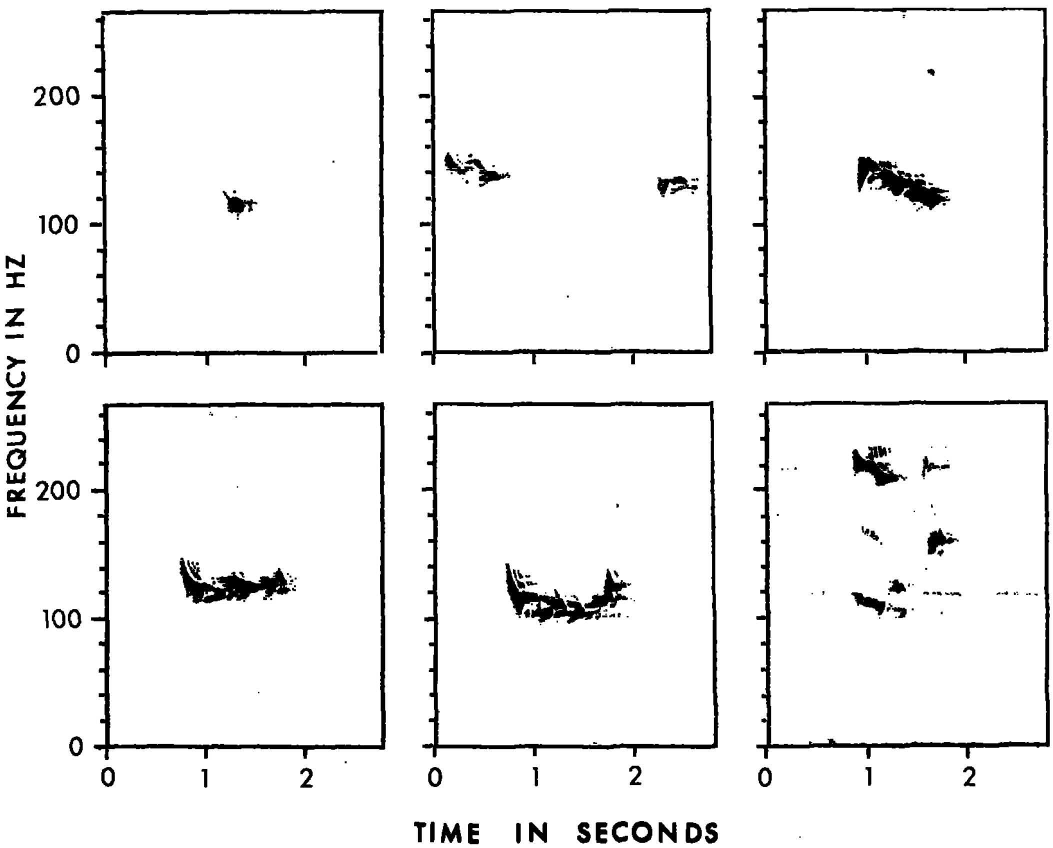

FIGURE 2.—Spectrograms of typical Bryde whale moans. The effective analyzing filter bandwidth was 3 Hz.

were feeding on red crabs, *Pleuroncodes planipes*, that swarmed at the surface during the early morning and evening. We distantly accompanied two of the whales which were swimming at 18 km/h and surfacing every 1 to 1.5 min. They rose high enough above the surface for us to clearly identify them as finbacks. Extensive sound recordings were made among the large concentration of whales near shore (Contact 7) and also much farther offshore (Contact 8), away from the main group.

Recordings of whale sounds from Contacts 9 and 10 were made in Ballenas Channel near finned whales on the west side of Isla Angel de la Guarda.

Analysis of Whales Sounds

Most sounds attributed to Bryde and finback whales, other than those from blows, were in a class we called "moan"—emissions longer than 0.2 s and <250 Hz in frequency. Many other sounds of biological origin, including clicks, knocks, etc., were recorded in the presence of the whales, but only when other possible sources were present, such as porpoises and sea lions.

Bryde Whales

As seen in Figures 2 and 3, upper, Bryde whale

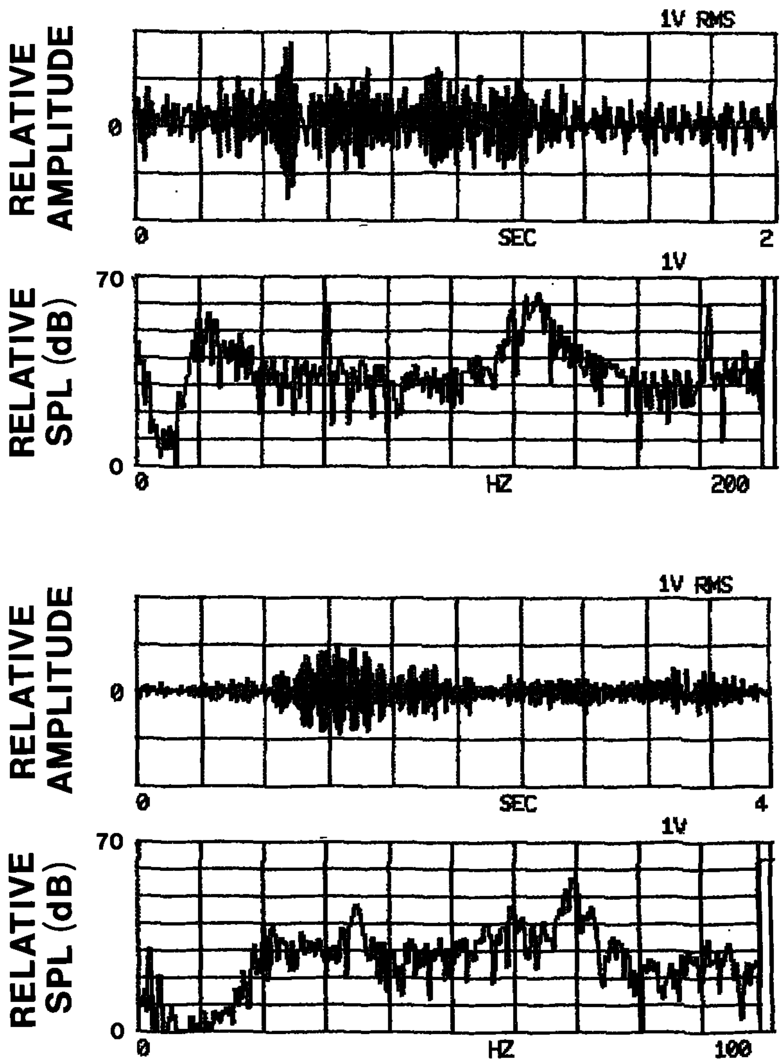

FIGURE 3.—Waveform and spectrum (/Hz) for Bryde whale (upper) and finback whale (lower). Effective analyzing filter bandwidth was 0.75 Hz (Bryde whale sound), 0.375 Hz (finback whale).

moans varied widely in duration and frequency (Hz). Of the 93 miscellaneous moans analyzed (Table 2), the principal sound energy occurred at a mean frequency of 124 Hz; that of individual moans varied from 70 to 245 Hz. Seventy-three percent of these sounds exhibited frequency shifts (mean of 15.2 Hz) that were downward or upward, or a combination thereof. The mean duration of the moans was 0.42 s (range, 0.2 to 1.5). These sounds occurred at intervals of 0.2 to 9 min.

The Bryde whale that apparently was attracted to the ship (Contact 2) did not emit moans when very closeby. The received overall sound level for a typical moan, when this whale was estimated to be 300 m away, was 102 dB. Assuming a spherical spreading loss of 20 $\log_{10}$ 1.094(R), R being distance in

TABLE 2.—Analysis of whale sounds.

		68/34-Hz moans				Miscellaneous moans					
Contact	Identification	No.[1]	Range (m)	Received level (dB)[2]	Source level (dB)[3]	No.[1]	Mean frequency (Hz)	Duration (s)	Range (m)	Received level (dB)[2]	Source level (dB)[3]
1	*Balaenoptera* sp.	2(2)	—	83	—	0	—	—	—	—	—
2	*B. edeni*	0	—	—	—	288(93)	123.9	0.42	300	102	152
3	*B. edeni*	0	—	—	—	407(35)	132.0	0.40	600	116	168
									250	126	174
4	Large whale	0	—	—	—	1(1)	75.0	0.60	—	90	—
5	*Balaenoptera* sp.	30(10)	250	121	169	12(8)	49.6	0.55	200	121	166
	No visual contact	44(16)	—	90	—	21(21)	50.7	0.63	—	92	—
6	*Balaenoptera* sp.	203(6)	2,000	115	183	173(14)	53.7	1.23	2,000	115	183
7	*B. physalus*	164(20)	—	108	—	468(131)	59.8	0.59	100	125	165
8	*B. physalus*	201(30)	—	99	—	550(42)	65.5	0.73	—	117	—
9	*Balaenoptera* sp.	3(3)	2,000	95	—	102(17)	63.3	0.70	2,000	118	181
10	*Balaenoptera* sp.	90(5)	800	108	166	12(8)	77.5	0.68	800	101	159

[1]Number of sounds encountered with number analyzed in parenthesis. [2]dB re 1 μPa. [3]dB re 1 μPa at 1 m.

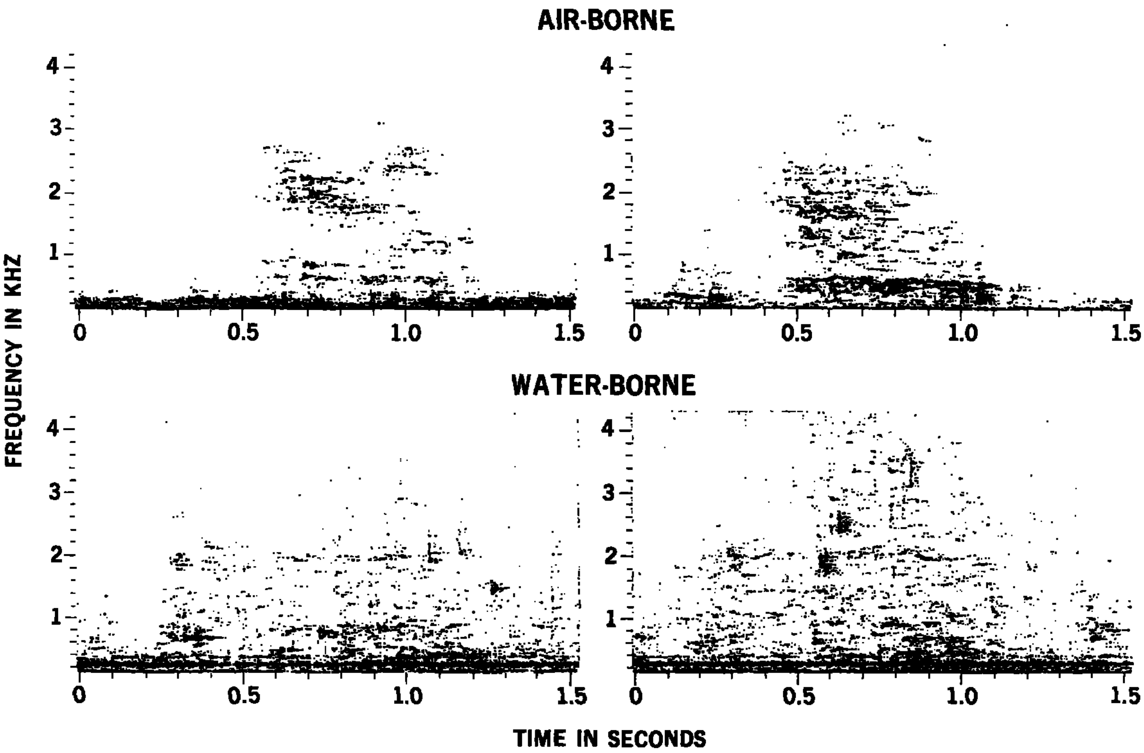

FIGURE 4.—Spectrograms of two blows from a Bryde whale recorded in air (upper) and in water (lower). The effective analyzing filter bandwidth was 20 Hz.

meters, this received level would indicate an overall source level of 152 dB in the effective bandwidth. The whales were close enough and the frequencies low enough that attenuation was probably minimal. However, these particular moans could possibly have been emitted by the other whale that was about 500 m away at the time. In this case, the estimated overall source level would have been 157 dB in the effective bandwidth.

Weak exhalation sounds were recorded simultaneously from underwater and in the air from the nearby surfaced Bryde whale. The exhalation sounds received underwater were nearly obscured by splashing sounds as the animal broke the surface (Fig. 4).

For the 35 moans analyzed from the Bryde whale of Contact 3, the mean frequency of the strongest component was 132 Hz and the mean duration was 0.40 s, both values close to those from Contact 2 (Table 2). However, the overall source level estimates of 168 and 174 dB (in the effective bandwidths) were greater.

The nearby Bryde whale (Contact 2) was totally submerged as it produced all of its moaning sounds, but no other apparent behavior was associated with the moans.

Finback Whales

In addition to miscellaneous moans (Fig. 5) that were similar to, but lower in frequency than those recorded from Bryde whales, the sounds of identified finback whales (Contacts 7, 8) included unique moans characterized by a long 68-Hz component that was usually followed by another component at 34 Hz (Figs. 6, 3 (lower)). Of the miscellaneous moans analyzed from recordings of the finback whales of Contacts 7 and 8, the mean frequency of the strongest component was 59.8 and 65.5 Hz, and the mean duration was 0.59 and 0.73 s, respectively (Table 2). Typically, these moans showed some frequency shift with <10% of the signals changing more than 20 Hz, generally downward. Overall source level

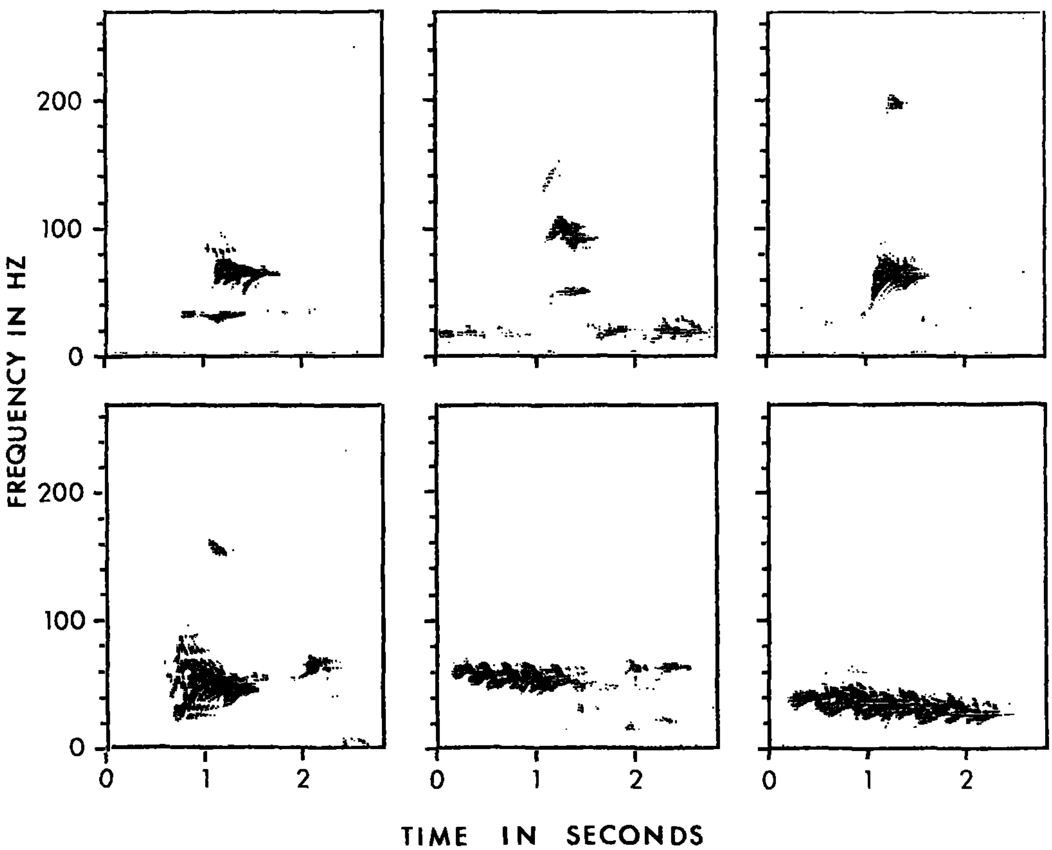

FIGURE 5.—Spectrograms of miscellaneous whale moans from finback whales off Isla Angel de la Guarda. The effective analyzing filter bandwidth was 3 Hz.

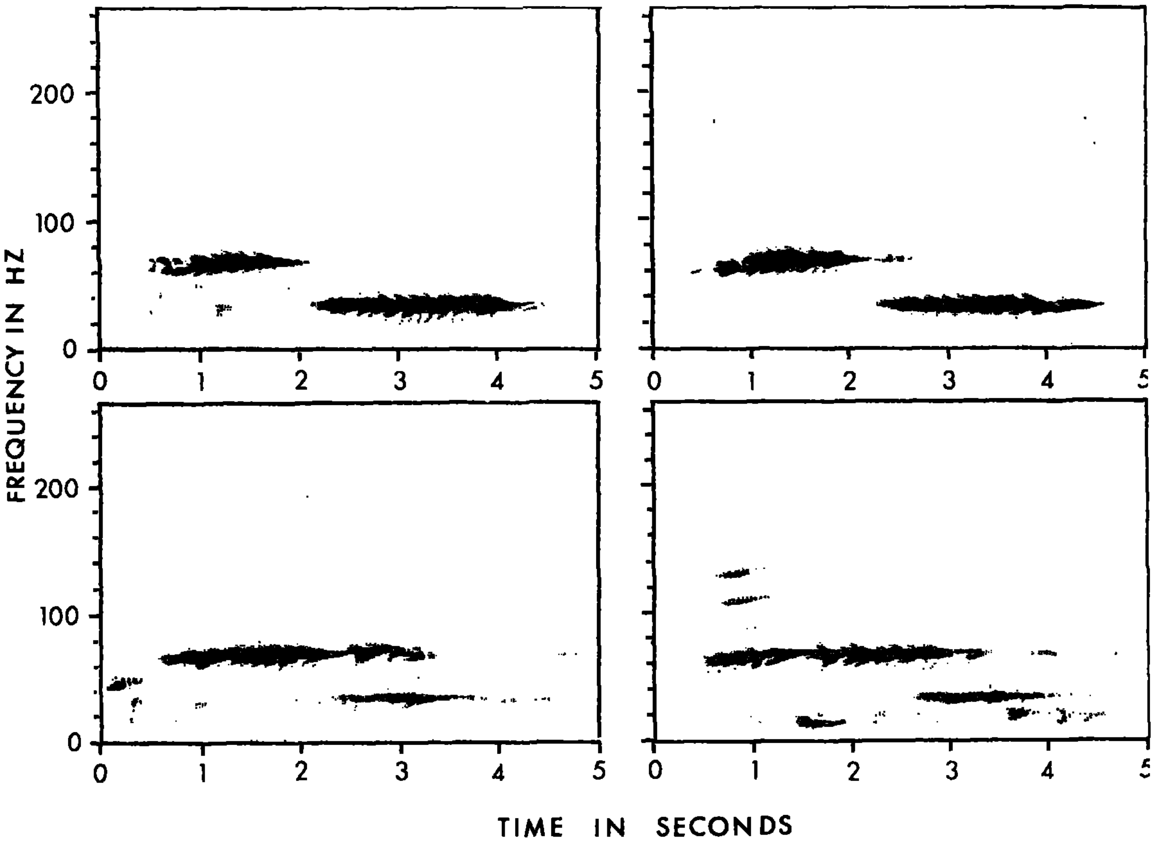

FIGURE 6.—Spectrograms of typical 68/34-Hz moans from finback whales recorded off Isla Angel de la Guarda. The first component of the moans began at 65 Hz and increased to 68 Hz in the first sec. It was accompanied by weaker modulation products at about 23-Hz intervals, mostly above the main frequency. The 34-Hz component followed and sometimes overlapped the first component (lower spectrogram). The effective analyzing filter bandwidth was 3 Hz.

of the sounds was 165 dB in the effective bandwidths.

Of the 50 long moans from finbacks that were analyzed, the mean frequency of the main, or first, component was 68.2 Hz; the mean frequency at onset being 66.1 Hz. The mean duration was 1.5 s. Thirty moans exhibited additional lower frequency components with a mean frequency of 33.5 Hz and a mean duration of 1.3 s. The overall mean duration of these two-part moans was 3.1 s. The 365 moans of this type encountered in Contacts 7 and 8 occurred on the average of 1.6 and 2.2 times/min, respectively.

In the case of unidentified balaenopterid whales, the mean frequency of the strongest component of the 68 miscellaneous moans analyzed was 58.5 Hz (range from 15 to 95 Hz), and the mean duration was 0.8 s. Of these sounds <10% had any frequency shift >10 Hz. Thirty-seven of the analyzed moans were the same as the long two-part moans recorded in the presence of finbacks. Their mean frequencies were 68.1 and 34 Hz, the mean component duration was 1.9 and 2.6 s, respectively, and the mean total duration was 3.4 s. The mean starting frequency of the 68-Hz component was 63.9 Hz. These two-part moans occurred at a rate of 1.5 to 3.2/min. Overall source levels ranged from 159 to 183 dB in the effective frequency bandwidth.

The blows of finback whales were as high as about 7 m above the water's surface, and often they were clearly audible in air at distances out to 200 m. The last blow in a series was followed by an inhalation that sometimes involved a low-frequency whistlelike sound just before a long dive (Fig. 7). The physical characteristics of blow sounds varied slightly from one whale to another, providing a certain degree of uniqueness for an individual whale (Fig. 7). Wheezing, shriek, and hornlike sounds produced by humpback whales in association with their blows have been described by Watkins (1967) and Thompson et al. (1977).

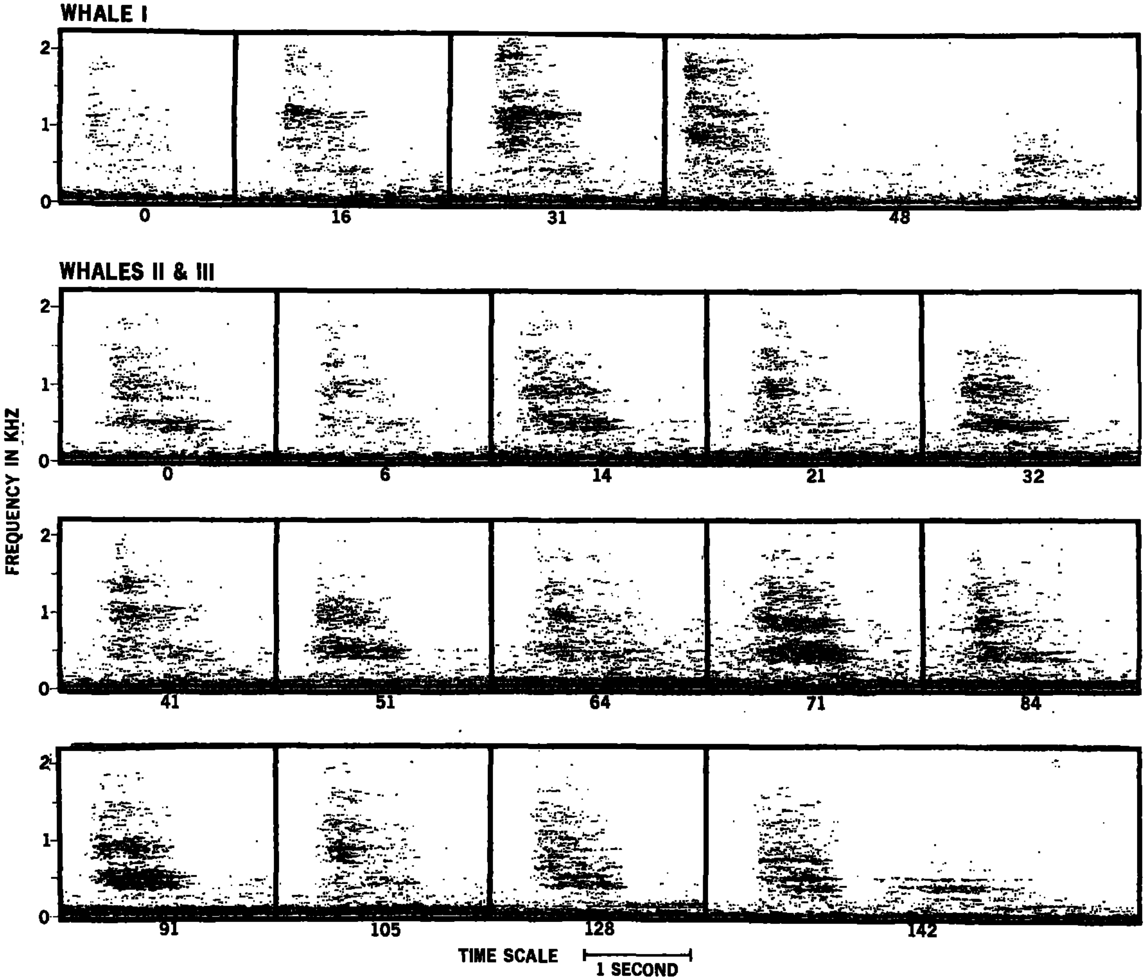

FIGURE 7.—Spectrograms of whale blow series recorded in air. Running time in seconds relative to the first blow is indicated on the abscissa. Whales II and III (second series) can be distinguished throughout the first 105 min by the unique physical characteristics of their alternating blows. Just before a long dive, the whales produced a low-frequency whistlelike sound at inhalation (last spectrogram, first row; last spectrogram, last row) which was not apparent during earlier blows of a series. In the second series, two low-level blow sounds at 110 and 132 min are not shown. The effective analyzing filter bandwidth was 20 Hz.

DISCUSSION

The moans recorded on this cruise from visually unidentified or unseen whales were very similar to those found to be from finbacks, except for Contact 3 involving Bryde whale sounds. Thus we believe the former also were from finback whales.

Some of the moans recorded in this study only slightly resembled short "20-Hz signals" described by several investigators (Walker 1963; Patterson and Hamilton 1964; Schevill et al. 1964; Weston and Black 1965; Cummings and Thompson 1966 [fn. 4]; Northrop et al. 1968; Watkins 1981). However, none of the presently described signals could be categorized as short "20-Hz signals" noted in other studies, because of differences in frequency (Hz) of major sound energy, signal repetition, and intervals between repetitions. Typical short "20-Hz signals" are narrowband pulses with principal sound energy near 20 Hz. They are repeated at remarkably constant intervals. Only about 3% of the sounds reported here had components as low as 20 Hz.

The miscellaneous moans that were recorded from finbacks mainly resemble the category that Watkins (1981) called "higher frequency sounds". However, most of his recordings of these sounds were downward-sweeping pulses, e.g., 75-40 Hz, with emphasis around 40 Hz. We did not record sounds similar to Watkins' low-frequency rumble or ragged pulse categories, nor did we record his nonvocal, sharp impulsive category.

Our experience with finback and Bryde whales in the Gulf of California showed that underwater-generated sounds were not produced when visible animals were at or very close to the surface. Exceptions were those sounds which, although principally airborne (e.g., blow and snort sounds), established a physical coupling with the water medium allowing detection by hydrophone. The typical short "20-Hz signals" noted from finback whales in other locations (Northrop et al. 1968) appear in trains that are interrupted after 3 to 22 min of pulsing (equivalent to expected dive times, Fig. 8). We believe that these interruptions that last from 1 to 6 min represented surface time. Blue whale sounds in southeast Pacific waters had silent interruptions that were associated with surfacing and ventilation (Cummings and Thompson 1971). Winn et al. (1970) correlated certain "cries" and "ratchet" sounds with surfacing behavior of humpback whales. Data from the present cruise, our recordings of typical short "20-Hz signals", our recordings from blue whales, and from work on humpback whales, apparently reveal surface and dive times as learned through monitoring underwater whale sounds.

Possible explanations for our lack of 20-Hz short pulses in the presently described recordings and for the absence of other classes of sounds that Watkins (1981) has commonly recorded from finbacks are seasonality and insufficient sampling. We now know that seasonality is involved.

Watkins (1981) recorded the pulses in the North Atlantic only from late October to early May. Cummings and Thompson (fn. 4) recorded them in the North Pacific from September to April, and Thomp-

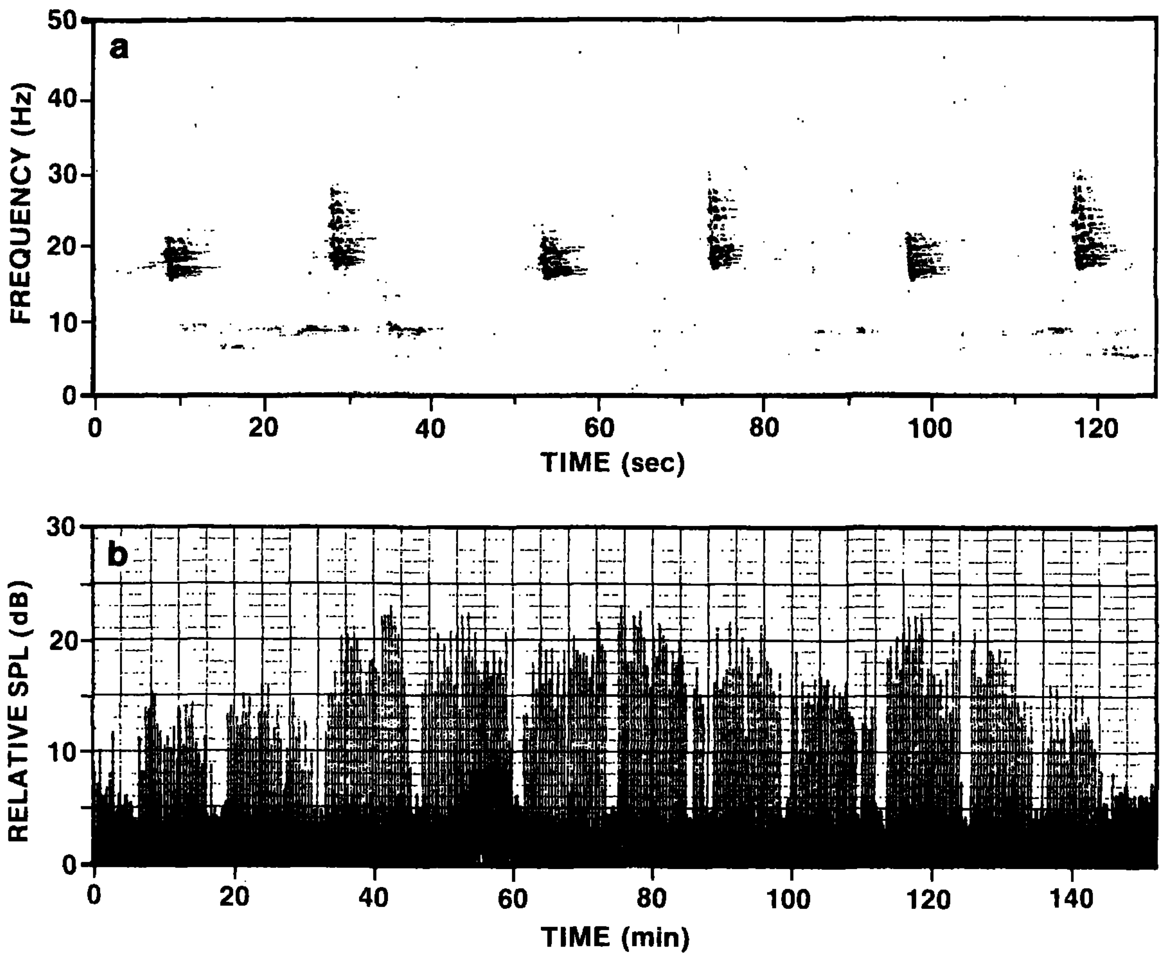

FIGURE 8.—(a) Spectrogram of short "20-Hz signals" from finback whales; the effective analyzing filter bandwidth was 0.4 Hz. (b) Strip chart showing 11 trains of short "20-Hz signals" with interruptions between; the filter passband was 12.5-25 Hz.

son and Friedl (1982), working off Hawaii, recorded them only from the end of August to late April. Northrop et al. (1968), in the North Pacific, noted them from October to March. Finally, in recordings from finbacks in March 1985 (Gulf of California) typical 20-Hz short pulses were the predominant sound (Thompson et al.[6]). Like the well-known songs of humpback whales, these sounds are probably a manifestation of social or other behavior which occurs seasonally. According to Watkins (1981) they "perhaps were a courtship or reproductive display". Watkins and others apparently have not noted our frequently recorded 68-34 Hz long moans.

There have been many technical advances in bioacoustic signal acquisition and processing. Long-term recordings can be used for obtaining information about certain behaviors, presence or absence of animals, or perhaps distribution of a given species, without the presence of an observer (Cummings et al. 1983). Great gains are being made in the field of signal processing wherein computer- and optically aided automatic acoustic pattern recognition is possible for a number of sounds with recognizable physical criteria. However, regardless of technical advances, the use of such tools is severely limited without first knowing the behavioral significance of the animal sound production. In reality, the two are mutually dependent. An analogous situation would be the use of the most refined instrumentation available for listening in on a conversation carried out in a foreign language that is unfamiliar to the observer. Although extremely difficult to fulfill, the need for related behavioral information on finback whales is paramount.

For these and other reasons, descriptions of sounds from identified sources should be given in detail along with adequate description of the recording instruments. Recording procedures and analyses can greatly affect the apparent variability of sounds. Moreover, one must be careful to consider the large variety of sounds that is apparent in any species of marine mammal (including the finback whale, as shown in this report) and the relatively limited number of recorded sounds of any species.

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[6]Thompson, P. O., L. T. Findley, and O. Vidal. Finback whale underwater sounds recorded near Guaymas, Mexico. Manuscr. in prep. Paul O. Thompson, 4256 Sierra Vista, San Diego, CA 92103.

LITERATURE CITED

BEAMISH, P.
1978. Evidence that a captive humpback whale (*Megaptera novaeangliae*) does not use sonar. Deep-Sea Res. 25:469-472.

BEAMISH, P., AND E. MITCHELL.
1971. Ultrasonic sounds recorded in the presence of a blue whale, *Balaenoptera musculus*. Deep-Sea Res. 18:803-809.
1973. Short pulse length audio frequency sounds recorded in the presence of a minke whale (*Balaenoptera acutorostrata*). Deep-Sea Res. 20:375-386.

CUMMINGS, W. C., D. V. HOLLIDAY, W. T. ELLISON, AND B. J. GRAHAM.
1983. Technical feasibility of passive acoustic location of bowhead whales in population studies off Pt. Barrow, Alaska. Tracor, Inc., San Diego, Doc. No. T-83-06-002, 169 p.

CUMMINGS, W. C., AND P. O. THOMPSON.
1971. Underwater sounds from the blue whale, *Balaenoptera musculus*. J. Acoust. Soc. Am. 50:1193-1198.

EDDS, P. L.
1981. Variations in vocalizations of fin whales, *Balaenoptera physalus*, in the St. Lawrence River. M.S. Thesis, Univ. Maryland, College Park, 126 p.

NORTHROP, J., W. C. CUMMINGS, AND M. F. MORRISON.
1971. Underwater 20-Hz signals recorded near Midway Island. J. Acoust. Soc. Am. 49:1909-1910.

NORTHROP, J., W. C. CUMMINGS, AND P. O. THOMPSON.
1968. 20-Hz signals observed in the central Pacific. J. Acoust. Soc. Am. 43:383-384.

PATTERSON, B., AND G. R. HAMILTON.
1964. Repetitive 20 cycle per second biological hydroacoustic signals at Bermuda. *In* W. N. Tavolga (editor), Marine bio-acoustics, p. 125-145. Pergamon Press, N.Y.

SCHEVILL, W. E., AND W. A. WATKINS.
1962. Whale and porpoise voices. Woods Hole Oceanogr. Inst. (with a phonograph record), 24 p.

SCHEVILL, W. E., W. A. WATKINS, AND R. H. BACKUS.
1964. The 20-cycle signals and *Balaenoptera* (fin whales). *In* W. N. Tavolga (editor), Marine bio-acoustics, p. 147-152. Pergamon Press, N.Y.

THOMPSON, P. O., AND W. C. CUMMINGS.
1969. Sound production of the finback whale, *Balaenoptera physalus*, and Eden's whale, *B. edeni*, in the Gulf of California (A). *In* Proceedings of the Sixth Annual Conference on Biological Sonar and Diving Mammals, p. 109. Stanford Res. Inst., Menlo Park, CA.

THOMPSON, P. O., W. C. CUMMINGS, AND S. J. KENNISON.
1977. Sound production of humpback whales, *Megaptera novaeangliae*, in Alaskan waters. [Abstr.] J. Acoust. Soc. Am. 62(Suppl. 1):S89.

THOMPSON, P. O., AND W. A. FRIEDL.
1982. A long term study of low-frequency sounds from several species of whales off Oahu, Hawaii. Cetology 45, 19 p.
WALKER, R. A.
1963. Some intense, low-frequency, underwater sounds of wide geographical distribution, apparently of biological origin. J. Acoust. Soc. Am. 35:1816-1824.
WATKINS, W. A.
1967. Air-borne sounds of the humpback whale, *Megaptera novaeangliae*. J. Mammal. 48:573-578.
1981. Activities and underwater sounds of fin whales. Rep. Whales Res. Inst. 33:83-117.
WESTON, D. E., AND R. I. BLACK.
1965. Some unusual low-frequency biological noises underwater. Deep Sea Res. 12:295-298.
WINN, H. E., P. J. PERKINS, AND T. C. POULTER.
1970. Sounds of the humpback whale. *In* Proceedings of the Seventh Conference on Biological Sonar and Diving Mammals, p. 39-52. Stanford Res. Inst., Menlo Park, CA.