natural food of this species of whale. Our captive's habit of sweeping a few centimeters off the smooth tank bottom does not deny the probability that sweeping a soft or irregular bottom at sea could get mud on the sweeper's back (cf. Fay in Pike, 1962, p. 823), especially if the prey is actually benthic.

Cetological literature is full of poorly supported conjecture, and we hesitate to add more. Although we have learned a number of things from the captive Gigi, there is still much unknown. For one thing, her jetting water in pulses from a particular restricted part of her mouth seems to imply, perhaps, a special activity of the tongue. Furthermore, we do not understand the mechanics of the hydraulics that bring the food-bearing water into the mouth. This is no mystery in whales that swim along with the mouth wide open, but it is not so obvious in a whale which swims along rather slowly with only a narrow slit open, as did our *Eschrichtius*. Here it seems necessary to increase the volume of the mouth to cause useful inflow of water. We are handicapped by our imperfect understanding of the functions of the muscular tongue. W. E. Evans (pers. comm.) has told us that Gigi's tongue once pressed his hand painfully hard against her palate. Such pressure might serve to push the gular region downward, enlarging the mouth cavity, and this idea fits with the observations of Donahoo and Ray of the migrating tongue-bulge visible from beneath.

Thus we suppose, from the assorted evidence, the following concatenation of events in feeding: First the whale rolls over far enough so that the cheek is about parallel with the bottom, and the lip is opened as the tongue, pressing against the palate, pushes the gular region away so that it expands, producing an inflow which brings in the epibenthic food. Then the tongue relaxes and the gular musculature tightens, reducing the size of the mouth cavity and expelling water; the food is trapped in the baleen fringes. We do not know exactly what happens next; perhaps a slight renewed suction of water removes the food from the baleen fringes, and swallowing presumably follows.

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MFR PAPER 1054

Sounds Produced by the Gray Whale, *Eschrichtius robustus*

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ABSTRACT

Underwater sounds produced by a young captive gray whale are described. A "metallic-sounding pulsed signal," consisting of 8 to 14 pulses in bursts lasting up to 2 sec was the most common vocalization. Other sounds included a low-frequency "growl" or "moan," similar to a sound recorded from gray whales at sea; a short, broadband, "gruntlike" sound; a low-pitched "blowhole rumble"; and a long "metallic-sounding pulse train" that merged into a low-frequency "groan." The sounds could not be correlated with specific behaviors. Also described are "clicks" recorded in the presence of the whale when she was returned to sea and similar "clicks" recorded from gray whales in Wickaninnish Bay, Vancouver Island, Canada.

This report describes a variety of sounds recorded from Gigi, a young gray whale, *Eschrichtius robustus*, while she was in captivity at Sea World, a marine park in San Diego, Calif., and sounds recorded in the vicinity of the whale when she was returned to the ocean nearly a year later. Also described are the sounds recorded in the presence of gray whales in Wickaninnish Bay, Vancouver Island, Canada.

Table 1.—Summary of previously published data on gray whale sounds.

Reference	Signal type	Duration (sec)	Frequency (Hz)	Pulses per burst	Pulse Repetition rate (per sec)	Pulse duration (msec)	Peak energy (Hz)
Eberhardt & Evans, 1962	"Croaker-like grunts"		40-700				80-300
	"Low-frequency rumbles"		40-700				80-300
Painter, 1963	"Pulses"			4-6		100	
	"Low-pitched grunting"			4-9 pulses per grunt	Approx. 33	11	
[1]Wenz, 1964	"Clicks"		<200->3,000		10		
Rasmussen & Head, 1965	No sounds						
[2]Gales, 1966	"Clicks"		<200->3,000		10		
Hubbs, 1966	No sounds						
Asa-Dorian & Perkins, 1967	"Echolocation-like pulses"		70-3,000	5-22	3-7	1-1.5	400-800
	"Variable whistles"						
Cummings et al., 1968	"Moans"	1.5	20-200				
	"Underwater blow"	Approx. 1	15-175				<100
	"Bubble-type sounds"	0.7	15-305				
	"Knocks"		to 350				
Poulter, 1968	"Croak-like grunts"						
	"Rumbles"						
	"Cries"						
	"Grunting"						
	"Rasping"	1 to several					
	"Pulses"				5-18		
	"Chirps"	2-5			8		
	"Bong"						
	"Clicks"		to 12,000	3-5			

[1,2] Both references show data on sounds recorded by Asa-Dorian in 1955.

Vocalizations have been recorded from migrating gray whales off the southern California coast (Wenz, 1964, and Gales, 1966, both reporting on recordings made by P. V. Asa-Dorian in 1955; Asa-Dorian and Perkins, 1967; Cummings, Thompson, and Cook, 1968) and from gray whales in the lagoons of Baja California, Mexico, where the whales breed (Eberhardt and Evans, 1962; Painter, 1963; Poulter, 1968). Unsuccessful attempts to obtain sounds from gray whales off southern California and in the lagoons have been made by Rasmussen and Head (1965) and by Hubbs (1966). The published data on gray whale sounds are summarized here in Table 1.

Gigi had already been in captivity at Sea World and hand-fed by her trainer for about 2 months before the tank recordings were made. Although she seemed quite content in her unnatural surroundings, her behavior was certainly not representative of a free-ranging gray whale of the same age. Hence, the sounds may or may not be similar to sounds emitted by a young gray whale in its natural environment. A second problem with any tank recording is the effect of tank resonance and reverberation on the physical characteristics of the sounds. Certain frequencies were probably accentuated in amplitude and extended in time. Nevertheless, the data at least represent the general frequency range and variety of a young captive gray whale's sound emissions.

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SOUNDS OF GIGI AT SEA WORLD

Sounds were recorded simultaneously in water and in air on a 2-track tape recorder (Uher 4200)[1] at 19 cm/sec. The hydrophone (Wilcoxon M-H90-A), connnected to one channel of the recorder, was suspended 1 m above the bottom of the circular concrete tank (11 m wide × 4 m deep). The frequency response of the underwater recording system was 40 Hz to 16 kHz, ±3 dB. The microphone, connected to the other channel, was lowered over the lip of the tank

[1] Use of trade names in this publication does not imply endorsement of commercial products by the National Marine Fisheries Service.

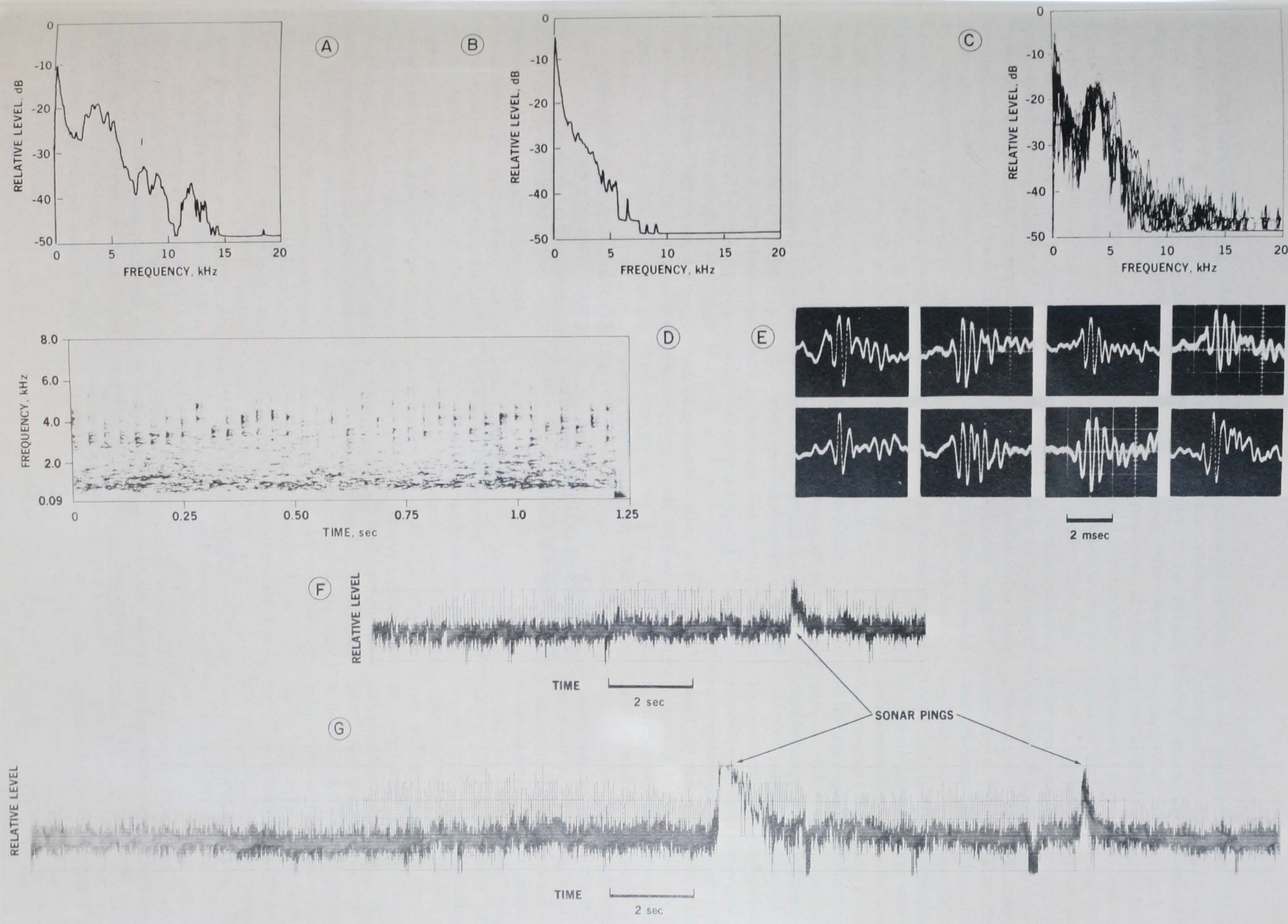

Figure 2.—A. Spectral display of clicks recorded during release of Gigi. Spectrum analyzer set in Peak Hold mode for a 9-sec sample of clicks (about 200 clicks). B. Spectrum of ambient noise during preceding 9 sec. For A and B, data in each of 250 filter locations updated, but only in a positive direction, every 0.0125 sec. Analyzing bandwidth 120 Hz. C. Overlapping spectra of the eight individual clicks shown in E below. Spectrum analyzer set in Transient Capture mode. D. Spectrogram of a typical click train. E. Oscilloscope photographs of typical clicks. F and G. Brüel and Kjaer level recordings of two different repetition rate click trains.

to record the commentary of the trainer in the tank with the whale. The 3-hr recording session began about 1 hour before a feeding period and lasted until the water level, which initially was about 1 m above the whale's back, was too low to make useful underwater recordings.

Spectrographic analyses were made in the laboratory with a "Vibralyzer" (Kay Electric Company) to determine frequency vs. time, and a real-time spectrum analyzer (Spectral Dynamics SD330) connected to an X-Y recorder (Hewlett Packard 7035B) to portray the relative amplitude vs. frequency. The waveforms were monitored with either the spectrum analyzer in the Scope Time mode or an external oscilloscope. All of the sounds described below were recorded from the hydrophone output.

The whale was very inactive and emitted no sounds until the water was lowered enough for the trainer to stand in the tank and touch her back. None of the sounds could be consistently associated with a particular behavior. However, one type, a "metallic-sounding pulsed signal," was emitted nearly every time the trainer tapped the whale lightly on the back.

A low-frequency "growl" or "moan," similar to one type of sound recorded from gray whales off San Diego, Calif., by Cummings et al. (1968), was produced twice during the recording session. The principal energy of this signal recorded from the captive animal was in a band from 100 to 200 Hz, with a secondary peak around 1.5 kHz (Figure 1A). The duration of the sound was just over 1 sec. There was no obvious movement of the blowholes or expulsion of air associated with this vocalization.

The most common sound was the "metallic-sounding pulsed signal" which consisted of 8 to 14 pulses in bursts lasting up to 2 sec (Figure 1B). The pulses had sharp fronts (fast rise times) with energy extending from below 100 Hz to over 10 kHz, and several resonant peaks, the strongest being at 1.4 kHz. This sound occurred as often as five times a minute, even when not incited by the trainer. Only occasionally did it appear to be correlated with exhalation and movement of the blowholes.

Three times during the recording session, a short (0.2 sec), broadband, "gruntlike" sound (Figure 1C) was emitted, without movement of the blowholes. Its peak energy was centered at 200-400 Hz and 1.6 kHz.

Figure 1D shows the underwater sounds of an exhalation followed by a low-pitched, "blowhole rumble." This combination occurred several times.

Twice, a long "metallic-sounding pulse train" with a repetition rate of about 14 pulses/sec merged into a long, low-frequency "groan" after about 1.5 sec (Figure 1E). Except for the much faster pulse repetition rate, the first part of this vocalization was similar to the sound shown in Figure 1B.

Numerous other sounds produced by Gigi during the 3-hr recording session essentially were variations of one of the five types discussed above.

SOUNDS RECORDED DURING RELEASE OF GIGI

Unfortunately, we did not record again in the presence of Gigi until she was released on 13 March 1972. The recording and analysis system used for these data was the same as used at Sea World. Shortly after Gigi was lowered into the water from the barge that carried her out to sea, long trains of "clicks" were heard. Although at the time there was no way to determine if these sounds, which were unlike any recorded from Gigi at Sea World, actually came from the whale or from another unseen biological source in the area, we now believe they were emitted by Gigi. The clicks were nearly identical to the clicks we have recently recorded in the presence of gray whales in Wickaninnish Bay, Vancouver Island, Canada.

The clicks recorded in the presence of Gigi are shown in Figure 2. Their principal energy occupied a band from about 2 to 6 kHz, centered at 3.4 to 4.0 kHz. Click duration was 1 to 2 msec. Eight minutes and 15 sec after the whale entered the water most boats in the area shut down their engines for our recording. The first burst of 29 clicks was recorded 6 sec later. Three minutes and 49 sec later the boats started their engines and we had to terminate our final recording of Gigi. During the 3 min and 55 sec of quiet-ship conditions we recorded 1,304 clicks. The number of clicks per burst (or train) varied from 1 to 833 and the click repetition rate from 9.5 to 36.0/sec. The longest click train, containing 833 clicks at an average repetition rate of 19/sec, began about 1 min after the boats had shut down their engines. Although the amplitude of the signals varied with time, we could not correlate signal level with the location of Gigi because the animal was not seen during the entire time of the recording.

SOUNDS RECORDED FROM GRAY WHALES OFF VANCOUVER ISLAND

The system used to record sounds in the presence of gray whales in Wickaninnish Bay on the west coast of Vancouver Island, Canada, consisted of a cassette recorder (Sony Model TC-126) and a portable underwater listening set (InterOcean Model 90A Bio-Acustik). The useable frequency range of the system was 100 Hz to 10 kHz. The hydrophone arrangement shown in Figure 3 resulted in good quality recordings with the small boat system.

Since 1967, as many as seven gray whales have been sighted at one time in Wickaninnish Bay. However, all of the recordings described here were from single whales or pairs. At 1725 hr on 10 August 1973, several click trains were recorded from a single feeding gray whale in 10 m of water, 1,200 m from shore. Very little wind and calm seas made recording conditions ideal. The first clicks, shown in Figure 4F, began 1 min after the whale started a 3-min-35-sec-long dive, at a distance of 50 to 70 m from the hydrophone. Additional click trains (Figure 4G) occurred simultaneously with the first exhalation after the dive. Twenty sec later, noise from an unseen boat began and continued for 95 sec. A third click train was emitted 50 sec after the boat noises ceased and 50 sec prior to the next blow. By then, the whale was 80 to 100 m from the hydrophone and the received level of the clicks was 5 to 7 dB lower than the level of the clicks recorded when the whale was half that distance from the hydrophone.

On 18 August 1973, the click train shown in Figure 4H was recorded from a single feeding gray whale at 0900 hr. The whale was about 600 m from shore in 4 m of water. The surface was calm with about a 1m swell. At the time the click train was emitted, the whale was 100 to 150 m from the hydrophone. Twenty min later a single harbor porpoise, *Phocoena phocoena*, was observed in the area.

About 5 hr of recordings were made in the presence of the gray whales in Wickaninnish Bay and much additional monitoring was done without recording. Although at times nearly continuous very faint clicking could be heard, only about 250 of the recorded clicks had good signal-to-noise ratios. The number of clicks per train varied from 1 to 96 with repetition rates of 8 to 40/sec. The principal energy of these clicks occupied a band from about 2 to 6 kHz, centered at 3.5 to 4.0 kHz. The average click duration was a little under 2 msec.

DISCUSSION

We do not know how any of the sounds discussed in this paper were actually produced by the gray whales. The "metallic-sounding pulsed signal" produced by Gigi at Sea World sounded like air bubbles escaping from an area of high pressure through a constriction (similar to the sound of air escaping from a scuba regulator underwater). Since this whale sound generally was not associated with exhalation or blowhole movement, if it were, in fact, generated by escaping air, the air must have passed from one internal chamber to another. No bubbles were observed coming from the mouth or blowholes.

Although the possibility exists that another species of marine mammal could have produced the clicks recorded when Gigi was released off San Diego and the clicks recorded in the presence of gray whales in Wickaninnish Bay, we think the evidence indicates that the clicks did come from the gray whales. The acoustic parameters of the clicks recorded from the geographic areas are nearly identical. The only marine mammals, other than gray whales, observed in either recording area was the single *Phocoena phocoena* observed a half hour after the recording was made on 18 August 1973 in Wickaninnish Bay and a small group of *Delphinus delphis*, about 2 km away from the site of Gigi's release a half hour before she was released. *Phocoena phocoena*, however, has not been observed off San Diego, and clicks of *Delphinus* have a much higher frequency content than described in this report. Also, the level of the clicks recorded in the presence of Gigi was too high for the sounds to have come from the *Delphinus* as the clicks appeared to originate from a single source rather than from a group of animals.

We have no evidence that the clicks recorded in the presence of gray whales have an echolocation function, but if they do, their frequency range (2 to 6 kHz) probably would be too low for the sounds to be useful for locating small individual food organisms. However, they could be helpful for finding dense concentrations of organisms or for ranging off the bottom to feed or navigate. Despite four seasons of recording in the presence of hundreds of migrating gray whales off San Diego, Naval Undersea Center personnel have never recorded similar clicks from the whales. But, according to most authorities, gray whales do not feed on their long migrations (Rice and Wolman, 1971). If the clicks were associated with feeding, we consequently should not expect to

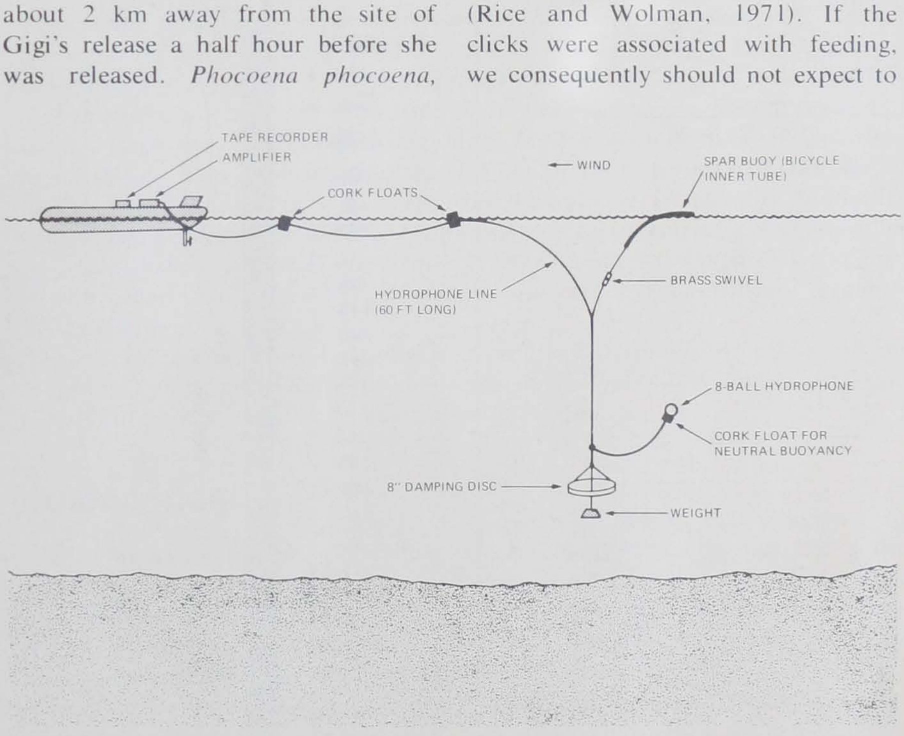

Figure 3.—Hydrophone suspension system used to record underwater sounds in Wickaninnish Bay, Vancouver Island, Canada.

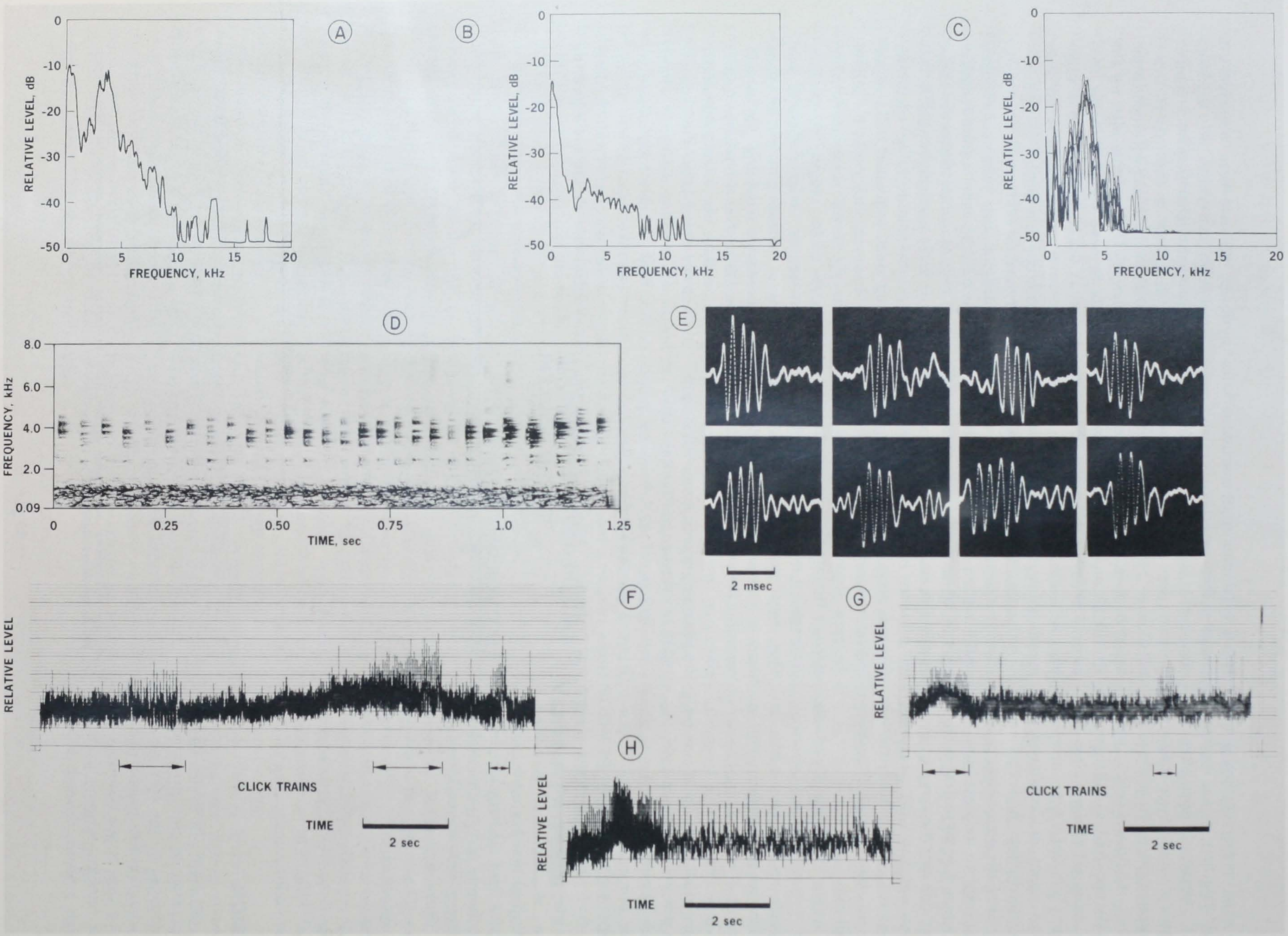

Figure 4.—A. Spectral display of clicks recorded in the presence of a gray whale in Wickaninnish Bay. Spectrum analyzer set in Peak Hold mode for a 6-sec sample of clicks (about 90 clicks). B. Spectrum of ambient noise during preceding 6 sec. For A and B, data in each of 250 filter locations updated, but only in a positive direction, every 0.0125 sec. Analyzing bandwidth 120 Hz. C. Overlapping spectra of the eight individual clicks shown in E below. Spectrum analyzer set in Transient Capture mode. D. Spectrogram of a typical click train. E. Oscilloscope photographs of typical clicks. F, G, and H. Brüel and Kjaer level recordings of several click trains. Note changing repetition rate in H.

encounter them in this area of migrating whales. When the clicks were recorded in Wickaninnish Bay, the gray whales were feeding. Why Gigi emitted clicks when released is unknown. In this case, their function could have been orientation since it is unlikely that she was looking for food so soon after being placed in a new environment. The clicks discussed here are only slightly like those recorded by Asa-Dorian in 1955 (see Wenz, 1964). They are not similar to any other reported gray whale sounds.

Other recent evidence for mysticetes producing click-type sounds has been reported by Beamish and Mitchell (1971). Their recordings in the presence of blue whales included clicks with peak energy in a band from 21 to 31 kHz.

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MFR PAPER 1055

Aerial Observations of Migrating Gray Whales, *Eschrichtius robustus*, off Southern California, 1969-72

J. S. LEATHERWOOD

ABSTRACT

Migrating gray whales were observed from helicopter and fixed-wing aircraft from central California south to Cedros and Guadalupe Islands, Baja California, Mexico, with the primary sighting effort off southern California. Peak numbers were observed off southern California in January for the southward migration and in March for the northward migration. Individuals were observed with the same relative frequency 80-160 km offshore as they were within 80 km of shore. Cows with calves were seen from February through May, primarily inshore, and tended to be alone or with other cows with calves. Yearling whales were seen inshore from February through April and also tended to be solitary or with other yearlings. Average speed of movement for northward migrants was 2.8 km/hour.

Results of aerial surveys compare favorably with published summaries of the timing of migration based on shore and ship samples and support the value of aerial surveys as a tool in cetacean population studies.

INTRODUCTION

Since shortly after its population began to recover from a second near-extermination by man in the 1920's and 1930's (Gilmore, 1955), the California gray whale, *Eschrichtius robustus*, has been the subject of more public interest and more scientific research than perhaps any other species of large whale. Because of their spectacular nature and proximity to shore along much of the route, the migrations of the species have been rather exhaustively described by Scammon (1874), Hubbs (1959), Gilmore (1960a and 1960b), Rice (1961), Pike (1962), Hubbs and Hubbs (1967), Adams (1968), and Rice and Wolman (1971). Observations from shore stations (primarily at Point Loma in