Sounds, source levels, and associated behavior of humpback whales, Southeast Alaska

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Humpback whales in Southeast Alaskan waters produced five categories of sounds: moans, grunts, pulse trains, blowhole-associated sounds, and surface impacts. Frequencies (Hz) of moans and grunts were 20–1900. Major energy in low-frequency pulse trains was in a band of 25–80 Hz with pulse duration of 300–400 ms. Blowhole-associated sounds, recorded as transiting whales encountered one another, were of two types: shrieks, 555–2000 Hz, and trumpetlike horn blasts with fundamental at 414 Hz (median). Pulses and spread spectrum noise were associated with gas bubble formation and explosive bursts, respectively, in connection with spiral feeding maneuvers. Surface impacts resulted from fluke or flipper slaps in sequences of 3–21 sounds. Source levels ranged from 162 (low-frequency pulse trains) to 192 dB (surface impacts), *re*: 1 μPa, 1 m. Songs, commonly heard on winter breeding grounds, were absent from our recordings. Feeding and perhaps certain other whale activities can be monitored based on sound production.

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INTRODUCTION

During winter and early spring on the breeding grounds near Hawaii, Mexico, Bermuda, and the West Indies, humpback whales produce repeated patterns of spectacular underwater sounds called whale "song" (e.g., Winn *et al.*, 1981; Payne and McVay, 1971; Payne and Payne, 1985). Little has been published about their sounds at other seasons and places. Schevill and Watkins (1962), Schevill (1964), and Winn *et al.* (1979) reported few sounds and no songs at high latitudes in the North Atlantic. Bioacoustic and related behavior of this species in northern waters recently has been of great interest because of increased human activities in the whale's summer habitats, e.g., Malme *et al.*, 1982. For these reasons, we believe it is important to document our observations and measurements.

The main objective of the work presented here (Thompson *et al.*, 1977) was to record and describe sound production and associated behavior of Pacific humpback whales in Southeast Alaskan waters on their summer feeding grounds. Second, we looked for evidence of song production.

I. METHODS

During August, 1975, we found about 20 humpback whales, *Megaptera novaeangliae*, which fed on krill and herring off Cape Fanshaw, 130 km south of Juneau, Alaska. Others were sighted farther north along the east shore of Stephens Passage to Pt. Astley. Thus the study area consisted of 75 km along the Alaskan archipelago, just south of Juneau.

Up to ten grouped whales were sighted at a time, the small groups being at distances of 10 m–2 km from the ship. Sometimes we could not tell exactly which individual produced a recorded sound. Our Captain determined distances to whales by (1) familiarity with many of the areas, (2) reference to large scale charts, (3) measuring of the distance when the ship moved to the site recorded from, and (4) comparison with fixes on stationary targets judged to be the same distance as whales.

The basic recording instruments included a hydrophone (Wilcoxon MH-90A) outfitted with 100 m of buoyant signal cable and a spar buoy for reducing low-frequency drag and acceleration noise, a sound-pressure calibration network, and a tape recorder (Nagra IVs) operated at 19 or 9.5 cm/s. Overall system frequency response was ± 3 dB, 20–12 000 Hz. A total of 8.5 h of magnetic tape containing whale sounds was studied using a spectrographic analyzer (Kay Elemetrics 7030), sound and vibration analyzer (General Radio 1564-A), graphic level recorder (General Radio 1521-B), and RTA (Spectral Dynamics 301-D with 3-D hardcopy).

II. RESULTS

A. Sounds

Underwater sounds from humpback whales consisted mainly of (1) moans, (2) grunts, (3) pulse trains, (4) blowhole-associated sounds, and (5) surface impacts.

Prolonged vocalizations of at least 400-ms duration were classified as moans (Fig. 1); shorter vocalizations were termed grunts (Fig. 2). The overall frequency range for moans was 20–1800 Hz; grunts were 25–1900 Hz (Table I). Moans had harmonic content; grunts did not.

Moans were subclassified as simple or complex, the former having simple harmonic structure, including a strong fundamental component from about 25–30 Hz (e.g., first

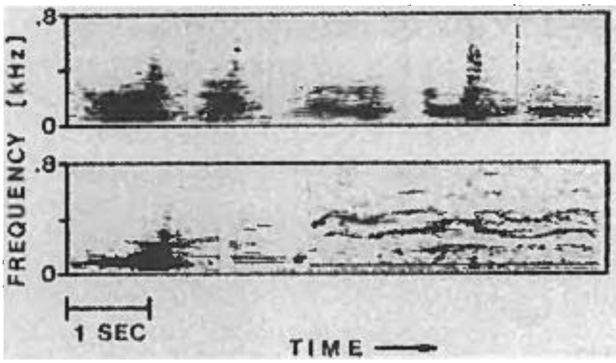

FIG. 1. Sonograms of simple moans (first three, upper) and pulsive complex moans (last two, upper, all in lower). Analysis bandwidth, 11.2 Hz.

three moans, Fig. 1). Simple moans of high signal-to-noise level typically had up to nine harmonics, to a maximum of 385 Hz. Complex moans did not exhibit strong fundamentals, and they often were pulse modulated in a band from 35–360 Hz (e.g., last five moans of Figs. 1 and 3).

Median duration for simple and complex moans was 800 ms. Most moans had little frequency modulation, but some slightly increased at onset to a plateau, ending in a sudden upshift. Most grunts were pulse and upward frequency modulated (Fig. 2). Of 850 moans and grunts, the mean vocalization rate was 1.8–3.2 sounds/min (median, 1.3).

The highest amplitudes of low-frequency pulse trains (Figs. 4 and 5) were between 25 and 80 Hz. Single pulse duration was 300–400 ms with a bandwidth of about 50 Hz. Some of these pulse trains had tonal characteristics, sometimes with harmonics (Fig. 4, lower half). In one series of 26 trains, the pulse repetition rate was 1.1/s with an average of 15 pulses/train. In another of 43 trains, it was 1/s with 5.7 pulses/train. We recorded 183 of these pulse trains with a median frequency of occurrence of 5 pulses/min in 8.5 h.

Associated with all low-frequency pulse trains was an unusual spread spectrum noise (40–1250 Hz) which typically decreased in intensity over the duration (Fig. 5).

We recorded a *broadband* pulse train of irregular interpulse interval (median, 300 ms, Fig. 6). Its 85, 1-ms pulses lasted 32 s. The frequency content was mainly between 0.4 and 5 kHz, extending above 16 kHz.

Humpback whales sometimes made distinct sounds while blowing at the surface, namely, shrieks or trumpetlike horn blasts (Fig. 7). The median frequency range of 12 shrieks was 555–2000 Hz, their main components modulating from 1800–750 Hz over 420 ms (median). Trumpetlike horn blasts had a simple harmonic structure with a median fundamental at 414 Hz (range, 410–420 Hz) and a median duration of 550 ms (range, 400–600 ms). All showed a downward frequency modulation of 7 Hz, median (range, 5–10 Hz), and a harmonic structure of 8–16 components.

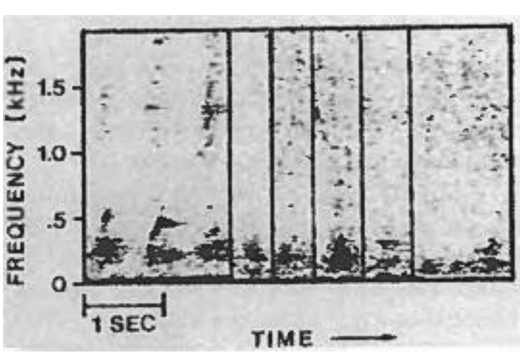

FIG. 2. Sonograms of grunts showing some components up to 1900 Hz. Analysis bandwidth, 11.2 Hz.

Other sounds from surfaced humpback whales were powerful impulses from flipper or fluke slaps on the water's surface. Aurally, these resembled underwater explosions. They were very similar to southern right whale sounds produced by the same mechanisms (Cummings *et al.*, 1972). Surface impact sounds from humpback whales were extremely broadband (30–12 000 Hz), and each was followed by reverberation that sometimes lasted several seconds. Although many single impulses were noted, we recorded a series of 5 and another of 3 flipper slaps, and series of 21, 17, and 9 fluke slaps with interseries intervals of 18 and 21 s. The median flipper slap repetition interval was 7 s (range, 4–10), and the median tail slap repetition interval was 4 s (range, 2–6).

Humpback whale sounds often were in groups; e.g., grunts rarely occurred alone and were in long series with other grunts, moans, pulses, and occasionally blowhole-associated sounds (Fig. 8).

B. Source levels

Peak source levels (*re*: 1 μPa, 1 m) were backcalculated from measured received levels over the effective bandwidths and durations of the recorded sounds, based on 20 log R (yds) spreading loss and negligible attenuation. For cases in which the responsible whale could be identified with certainty, source levels were: 192 dB, the most powerful fluke slap; 183–192 dB, flipper slaps; 162–171 dB, low-frequency pulse trains from a visible feeding whale; 179–181 dB, blowhole shrieks; and 181–185 dB, trumpetlike horn blasts.

Assuming that the closest observed whale was the source among other whales in small groups, source levels were: 190 dB, grunt; 175 dB, moan; and 176 dB (median), low-frequency pulsing. Thus, for 53 measured humpback whale sounds in Southeast Alaska, source levels were 162–192 dB *re*: 1 μPa, 1 m (summary including No. observations, Table II).

C. Behavior during sound production

Low-frequency pulse trains and accompanying spread spectrum noise were recorded from a nearby submerged whale as it made a circle of bubbles in a spiral feeding maneuver (sometimes called "bubble net") next to the ship (Fig. 9). We clearly saw the whale; it emerged from the center of the bubble ring. By observing and listening, we determined that the pulses were associated with bubble generation, and the accompanying spread spectrum (40–1250 Hz) noise was associated with explosive bursts as the bubbles rose toward the surface. Sometimes pulse trains were interspersed with 140- to 600-Hz grunts, resulting in an alternating rhythmic effect. These trains and the accompanying noise also were

TABLE I. Frequency, harmonic, and temporal characteristics of underwater humpback whale sounds.

	Simple moans	Complex moans	Grunts
No. Observations	36	73	48
Frequency (Hz, lower limits)			
Median	25	40	90
Fundamental only	25		
Range	20–280	10–280	25–400
Fundamental only	20–280		
Frequency (Hz, higher limits)			
Median	385	360	510
Fundamental only	30		
Range	240–1800	100–1900	100–1900 +
Fundamental only	25–460		
Harmonic structure	present	present	absent
Duration (s)			
Median	0.8	0.8	0.2
Range	0.5–1.5	0.4–9.1	0.1–0.3

recorded from more distant whales that appeared to be feeding in this manner. Payne (1979) and McSweeney and Lawton (1979) reported that noise was recorded in conjunction with this type of feeding.

Bubble formation, which we and others associated with spiral feeding (or "bubble-net") maneuvers, has been interpreted as a method of concentrating krill and small fishes (Ingebrightsen, 1929; Wolman, 1978; Jurasz and Jurasz, 1979).

The broadband pulse train possibly may have been associated with baleen rattle, such as Watkins and Schevill (1976) observed from northern right whales feeding in the Atlantic.

Two fast swimming humpback whales passed close to the ship, moving in a NNE direction (Table II). As they met and were joined by a whale headed north, we heard in air, as well as from the hydrophone, a powerful shriek from one of the pair as it blew. A minute later, a similar sound was heard. After another 2 min, we heard a third shriek and three trumpetlike horn blasts in quick succession as the three grouped whales met another northbound whale. Finally, 12 min later, there was a distant horn sound as the four NNE-bound whales met yet another converging whale which also joined the group.

Humpback whales intentionally slapped the water's surface with the upper flipper while lying on their sides. They also slapped the water with their flukes. Both movements produced the powerful impact sounds, and both were displayed in series.

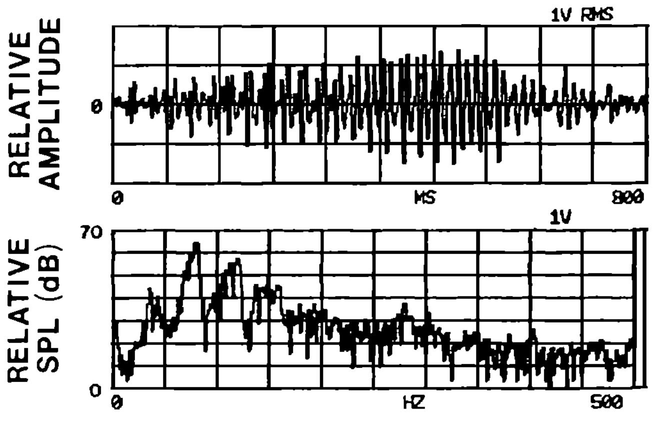

FIG. 3. Waveform (upper) and spectrum (/Hz, lower) of a complex moan having a weak 35-Hz fundamental and pulsive AM. Analysis bandwidth, 1.9 Hz.

III. DISCUSSION

Regional *song* dialects among humpback whales have been described (Winn and Winn, 1978; Winn *et al.*, 1981; Thompson and Cummings, unpublished report). Because they may be useful in discerning separate stocks (Winn *et al.*, 1981; Payne and Guinee, 1983), among other reasons, whale dialects of any kind are of great interest. We have attempted to present descriptions of *nonsong* elements from humpback whales for others to compare future studies of sound production.

We found a variety of humpback whale sounds in these Alaskan waters, but no recurring patterns resembling songs that are commonly encountered in the winter breeding grounds. Although rare, humpback whale song has been reported from northern waters, far removed from wintering areas, i.e., off eastern Canada, in December 1965 (Cummings and Philipi, 1970; Cummings, 1985), during migra-

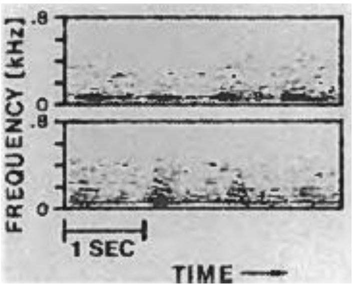

FIG. 4. Sonograms of low-frequency pulse trains, the lower group of 4 pulses with harmonic structure. Analysis bandwidth, 11.2 Hz.

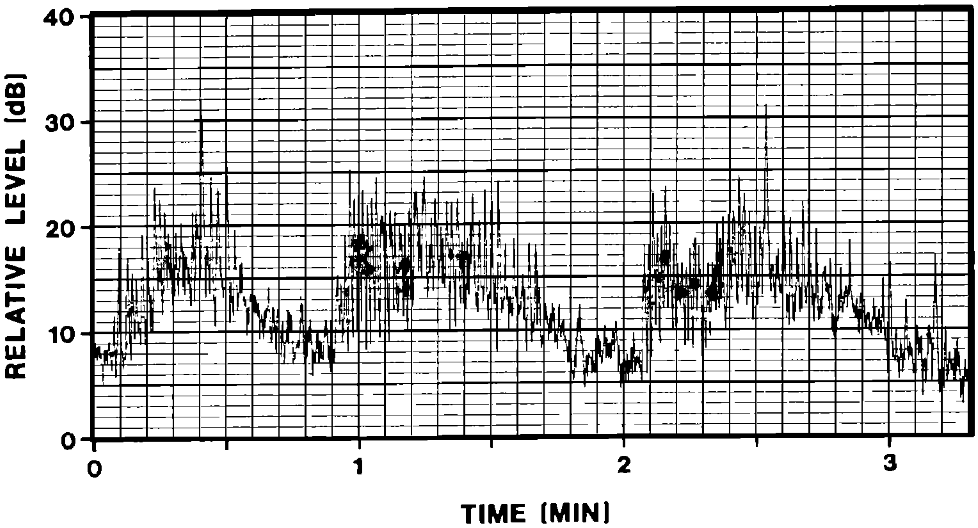

FIG. 5. Sound levels of three low-frequency pulse trains from a feeding whale. Except for four of the strongest peaks caused by unrelated background vocalizations, each peak was a pulse. The background level of each train was raised by spread spectrum noise from bursts of rising bubbles generated by the whale. Analysis bandwidth, 31.5–250 Hz.

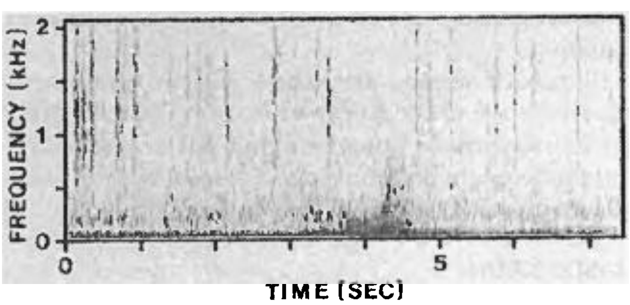

FIG. 6. Sonogram of broadband pulse train. Analysis bandwidth, 19 Hz.

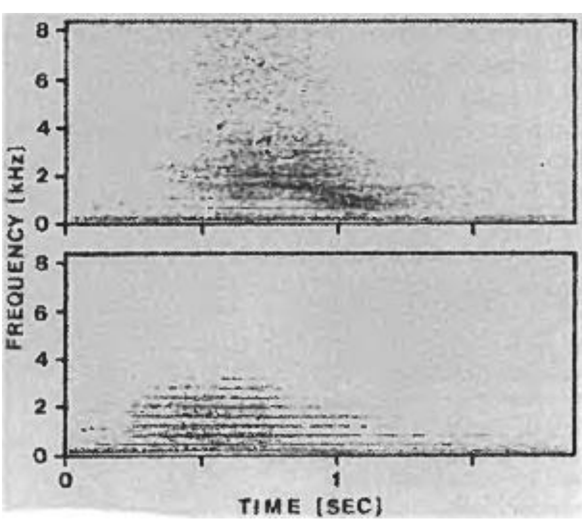

FIG. 7. Sonograms of blowhole-associated sounds received by hydrophone: shriek with narrow-band components (upper); trumpetlike horn sound (lower). Analysis bandwidth, 45 Hz.

tion (Levenson and Leapley, 1976), and in the presently described study area (McSweeney and Lawton, 1979).

Although we found no songs, sound production on the summer feeding grounds of Southeast Alaska was substantially frequent (> 5 sounds/min) compared to previous reports from northern Atlantic regions.

Levenson (1972) reported the average source level of 64 Atlantic humpback whale *song* components to be 155 dB *re:* 1 μPa, 1 m (range, 144–175). Without exception, all of the presently reported source levels of *nonsong* components were higher than Levenson's measurements. The first two authors of the present paper measured source levels of song components off Hawaii, in the same manner described for this Southeast Alaskan work (Thompson and Cummings, unpublished report). As reported here, our measured source levels of songs off Hawaii were about 15 dB higher than those reported by Levenson from the Atlantic.

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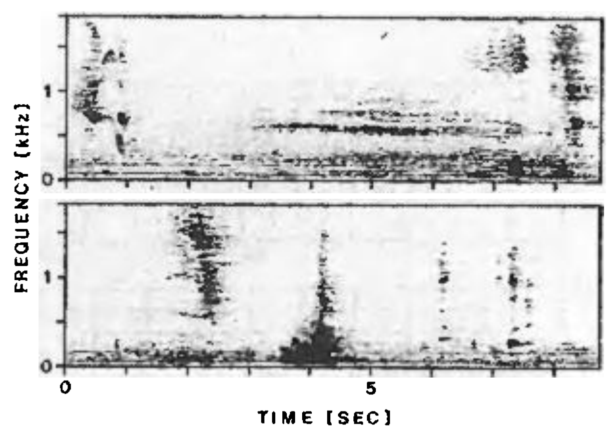

FIG. 8. Sonograms of sound sequences: highly FM vocalization, a 1.5-s quiet interval; a 4-s, abruptly ended complex moan, and then a blowhole-associated shriek, the sequence underlain with 5 pulses of a low-frequency pulse train (upper). Blowhole-associated shriek, followed by a short moan and four grunts (lower). Analysis bandwidth, 11.2 Hz.

TABLE II. Summary of peak sound source levels of humpback whales in Southeast Alaska.

Surface sounds	Other sounds
Fluke slap 192[a] (1)[b]	Low-frequency pulse trains 162–171 (10)
Flipper slaps 183–192 (9)	Grunt[c] 190 (1)
Blowhole shrieks 179–181 (7)	Moan 175 (1)
Trumpeting 181–185 (4)	Low-frequency pulse trains 165–181 (20)

[a] dB *re*: 1 μPa, 1 m.
[b] No. observations in parentheses.
[c] For grunt, moan, 20-pulse trains (median 176), sound assumed to be from closest animal in a small group.

U. S. National Marine Fisheries Service (personal communication to W. C. C.), there is a need to monitor feeding activity of humpback whales in Southeast Alaska. Based in our present and other experiences there, we suggest such monitoring may be done remotely using sonobuoys to record low-frequency pulse trains and associated spread spectrum noise in the feeding grounds. For example, we noted that pulse trains were equally common in the Cape Fanshaw and Point Walpole areas, which appeared to have about the same number of whales.

A network of sonobuoys, such as we set up off Maui, Hawaii (Thompson and Cummings, unpublished report), and that used by Cummings and Holliday (1985), with microwave relays, would also yield valuable information on movements of humpback whales in Southeast Alaska.

Our recorded blowhole-associated sounds from surfacing whales only partially resembled the Atlantic humpback wheezing blows reported by Watkins (1967). Our recorded shrieks and trumpetlike horn blasts averaged one-third the duration of sounds recorded by Watkins, seemingly truncating the first two-thirds. Watkins' findings apparently included no sounds similar to our recorded trumpetlike horn blasts. We found the waterborne components of blowhole-associated sounds to be about as intense as vocalizations produced entirely underwater. The water-propagated shrieks and trumpetlike horn blasts in Southeast Alaska were as high as 185 dB, with airborne components producing strong airborne echoes from nearby mountainous terrain.

The sequences of shrieks and trumpetlike horn blasts, in the context of the described "whale meeting" behavior, suggest animal signals of social significance, e.g., territoriality, recognition, or dominance. Although speculative in this case, such behavioral significance has been ascribed to sounds of numerous other mammals, and birds.

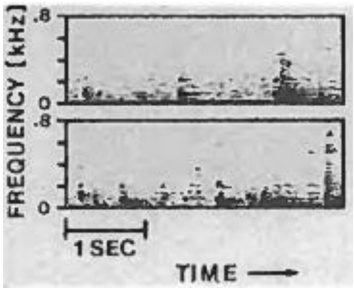

FIG. 9. Sonograms of a low-frequency pulse train during spiral prey-concentrating maneuvers by a whale close aboard. Analysis bandwidth, 11.2 Hz.

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