TABLE 2.—*Regression equations for predicting weights of known-age coyote pups and age of wild caught coyote pups, ($\hat{y} = a + bx$).*

n[a]	Age (days)	Weight Prediction equation[b]	r	Age prediction equation[c]	r
4	0–30	[d] $\hat{y} = .2685 + .0197X$	0.999	[d] $\hat{y} = -13.57 + 50.59X$	0.999
15	30–154	$\hat{y} = -0.5049 + 0.0469X$	0.995	$\hat{y} = 11.386 + 21.101X$	0.995

[a] n = number of weight periods used from Fig. 1. [b] $\hat{y}$ = weight (kg); X = age (days). [c] $\hat{y}$ = age (days); X = weight (kg). [d] From Bekoff and Jamieson (1975), data used from 0–30 days.

Regression equations to predict weights of known-age coyote pups and relative age of wild-caught pups have been developed in Table 2. Equations for birth to 30 days are based on data from Bekoff and Jamieson (1975). Equations of weight prediction may allow monitoring of proper gains in pups in a laboratory situation. When used in conjunction with tooth eruption patterns established by Bekoff and Jamieson (1975) and Gier (1975), the equations of prediction for age should yield a reasonably close estimate of age for wild-caught coyote pups.

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VOCALIZATIONS AND FEEDING BEHAVIOR OF THE KILLER WHALE (*ORCINUS ORCA*)

Pods of killer whales, *Orcinus orca*, were observed and their vocalizations recorded on two occasions (August 1968 and August 1972) in the immediate vicinity of St. John's Harbor (47°34′N, 52°39′W), Newfoundland. On the second occasion, the whales were apparently feeding. In this report, we describe the types and variability of the killer whale vocalizations recorded, and apparent cooperative feeding behavior.

On 13 August 1968, a pod of four killer whales (one male and three females or juveniles, as judged by relative fin size—a sexually dimorphic character) was encountered at approximately 0900 h, 2 km off St. John's, Newfoundland, by the R/V TRIDENT. Two of us (H.E.W. and P.J.P.) made sound recordings and behavioral observations of the whales over a 2.25 h period. Twenty minutes of good signal-to-noise ratio recordings were made with a U.S. Navy An/BQR-3a directional hydrophone and a U.S. Navy AN/UNQ-7a tape recorder-reproducer.

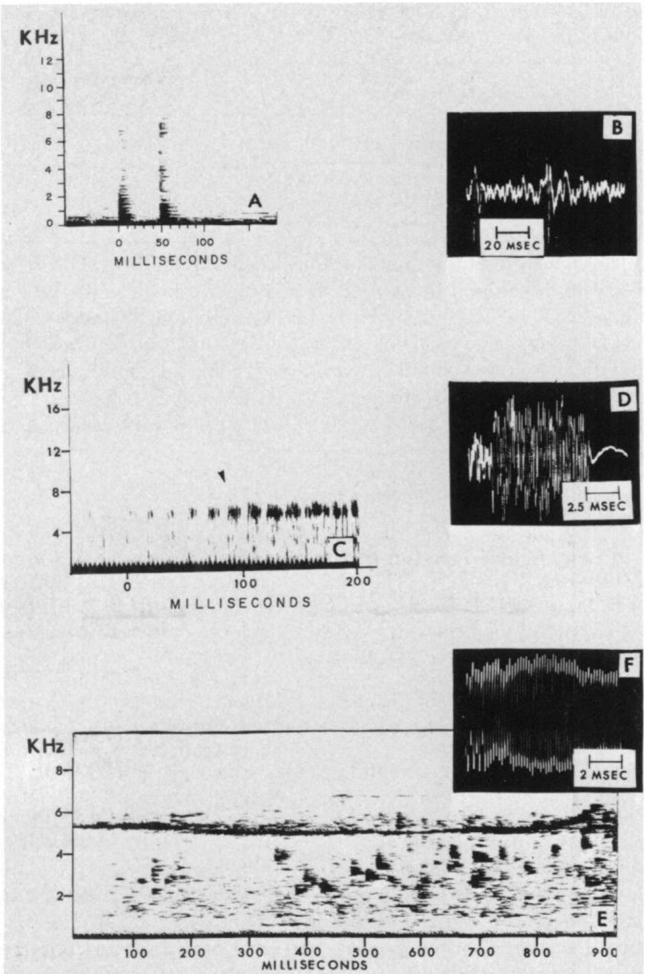

FIG. 1.—A) Spectrographic representation of two broad band clicks; filter bandwidth of 60 Hz. B) Oscilloscope representation of the same two clicks. C) Spectrographic representation of a series of narrow frequency emphasis clicks; filter bandwidth of 800 Hz. D) Oscilloscope representation of a single narrow-frequency emphasis click, as marked by arrow, from Fig. 1C. E) Spectrographic representation of a tonal vocalization (single line just below 6 kHz); filter bandwidth of 40 Hz. F) Oscilloscope representation of same tonal vocalization.

On 4 August 1976, at 0600 h, at almost the identical position of the previous encounter, personnel aboard the R/V WESTWARD sighted a pod containing one male and three female or juvenile killer whales (as judged by relative fin size). The whales were followed for approximately 3 h at a range of 0.5 to 1.0 km, during which time one of us (J.H.H.) made recordings and behavioral observations. Over 30 min of recordings were obtained with a Research Mfg. Corp. R-130 omnidirectional hydrophone, and a Uher 4400 Report Stereo tape recorder.

Our analysis used a Kay Electric 675 sound spectrograph, Hewlett Packard 1201A/B Dual Trace oscilloscope, and a Tektronix C-12 oscilloscope camera.

During both encounters, each lasting 2 to 3 h, no other cetaceans were seen, and signal levels varied appropriately with distance to the whales. Consequently, we are confident that all sounds recorded were made by the killer whales.

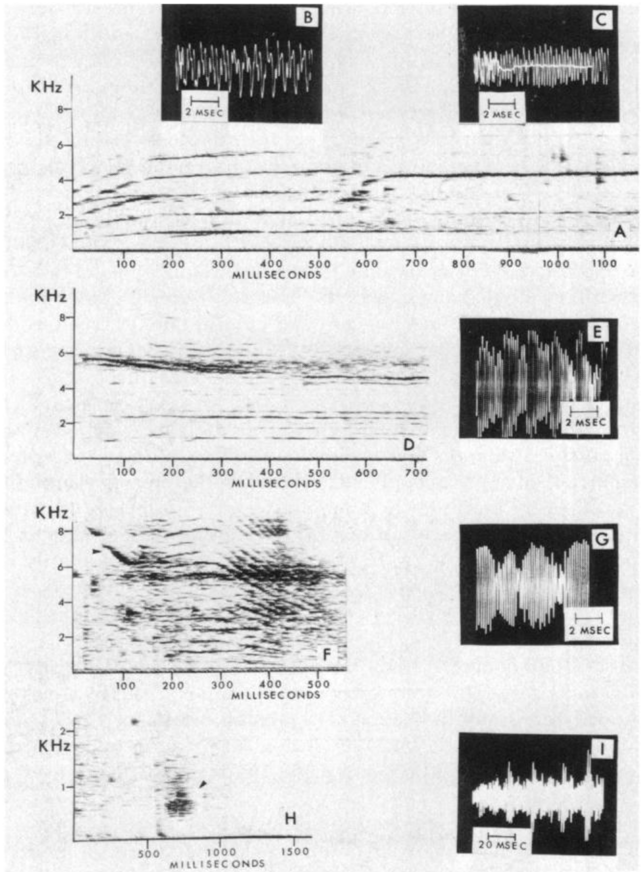

FIG. 2.—A) Spectrographic representation of a two-part pulsed "scream." Part 1 lasts from 0–600 msec; part 2 lasts from 600–1,200 msec; filter bandwidth of 40 Hz. B, C) Oscilloscope representations of parts 1 and 2 of the pulsed "scream." D) Spectrographic representation of a pulsed "shrill scream," filter bandwidth of 40 Hz. E) Oscilloscope representation of a pulsed "shrill scream." F) Spectrographic representation of a pulsed "creak"; filter bandwidth of 40 Hz. Note the presence of a short, modulated, tonal vocalization marked by arrow immediately preceding the pulsed sound. G) Oscilloscope representation of pulsed "creak." H) Spectrographic representation of a pulsed "croak"; filter bandwidth of 12 Hz. I) Oscilliscope representation of pulsed "croak."

Vocalizations.—The killer whales emitted three physically distinct types of sounds. (1) *Clicks* and *click trains* of variable length were heard during both encounters. They were relatively broad-band emissions of sound, characterized by short durations.

We performed detailed spectrograph and oscilloscope analyses on over 60 individual clicks. Durations ranged from 0.8 to 13 milliseconds (msec) with the majority measuring greater than 4 msec. Although all clicks contained energy within a broad frequency range, they often had a major narrow band frequency emphasis. Most often this emphasis was below 2,000 Hz, but we also analyzed clicks with a major frequency emphasis as high as 6,000 Hz (see Fig. 1A, 1C). Because of our limited recording bandwidths, we were unable to perform detailed analyses of ultrasonics, but we did note click energies as high as 22,000 Hz.

Long click trains were infrequent. Typically, they were short, usually containing less than 20 separate clicks. The average interval between clicks in a train was 63 msec, corresponding to a repetition rate of 16 per sec. We note that the most frequently observed click series had only two or three separate clicks. In these click "doublets," the first click was rich in low frequency energies, 200 to 900 Hz, while the second click consistently had additional higher frequencies to 7,000 Hz. In addition, we recorded a few rapid click trains, the "rusty hinge" or "rasp" series typical of other odontocetes. These trains contained click repetition rates as high as 200/s.

(2) *Pulsed vocalizations* were characterized by a fundamental tone frequency, which was pulsed at variable rates (Watkins, 1967). They were recorded only during the second encounter.

Pulsed sounds were rich in harmonics, and often the aural impression was "harsh," "strident," or "metallic" in quality. The combinations of fundamental tone frequency and concomitant pulsing rates varied widely, producing a broad spectrum of aurally and physically different sounds (Fig. 2). Fundamental tone frequencies ranged from 600 Hz to 6,000 Hz. The pulsing rates ranged from 60 Hz to 2,200 Hz. In some instances the fundamental tone frequency and the pulse rate varied within a single sound, as in the two-part "scream" illustrated in Fig. 2A. Main energies were most often found at the fundamental tone frequency, such as the second half of a two-part scream in Fig. 2A, 2D, 2F, and 2H; but, in other instances, the main energies were found at the harmonic intervals corresponding to the pulse rates (first half of a two-part scream—Fig. 2A).

The relative strength of the fundamental tone versus the side harmonics was dependent on the strength of the pulsing structure. The oscillograms in Figs. 2B and 2C represent nearly equal fundamental frequencies (of approximately 4,000 Hz), but the pulsing emphasis is much greater in Fig. 2B. In Fig. 2B every fourth cycle is emphasized (the intervening cycles are detectable as small inflections on the signal wave); in Fig. 2C every other cycle is slightly emphasized. The corresponding spectrograph (Fig. 2A) indicates energy distributed primarily in the side bands for the first part of the "scream" and subsequent energy centered primarily on the fundamental tone for the second part of the "scream." A complete description of various pulsing mechanisms is found in Watkins (1967).

Durations of pulsed sounds ranged from 0.2 to 3.0 s in the longer two-part "screams."

(3) *Tonal vocalizations* were pure frequency sounds characterized by a lack of side harmonics in spectrographic analysis or any indication of a pulsing mechanism in oscilloscopic analysis. Over 50 tonal sounds were recorded, but only during the 1976 encounter. Minimum and maximum frequencies recorded were 500 Hz and 8,900 Hz, respectively, with durations of 0.05 to 1.85 s (Figs. 1E, 1F, and 2F).

Feeding behavior.—Apparent cooperative feeding behavior was observed during the 1976 encounter. When the four whales were first approached, they were seen circling together. We interpreted this circling, which was accompanied by vigorous splashing, lunging, and fluking, as a corralling behavior. Sounds from the group were heard simultaneously, including clicks, pulsed sounds, and tonal vocalizations. Periodically, one of the killer whales lunged through the circle created by the joint effort. Usually only one whale lunged through the circle at a time. The male, distinguishable by his large dorsal fin, was sometimes seen swimming on his side, his dorsal fin nearly horizontal. No fish were visible within the circle, but many gulls were working the circled area simultaneously. Nearby fishermen reported herring schools in the area. Subsequently, the behavior decreased in intensity and became less orderly. The male moved away from the others and remained at the surface, with little activity.

There are several previous reports of killer whale clicks. Schevill and Watkins (1966), based on recordings of a newly captured male *O. orca*, reported the fundamental frequency of click pulses at 250 to 500 Hz. Their durations ranged from 10 to 25 msec. They further noted a characteristically slow repetition rate, typically 18 clicks/s, in normally short bursts of 10 to 15 clicks. Diercks et al. (1971), after studying clicks of *O. orca* from an animal trained in discrimination trials, reported main energy at much higher frequencies (approximately 25 kHz). Evans (1973) listed main energy peaks at 16 to 20 kHz, but Diercks et al. (1973) indicated that main energy peaks fell between 10 and 15 kHz. Click durations ranged from 0.5 to 1.5 msec (Evans, 1973). These reports were on animals captured in the Pacific Ocean.

The click durations from our recordings, 0.8 to 13 msec, were comparable at either extreme to those reported by previous workers. The longest durations occurred in clicks with predominant low frequency energy, comparable to those clicks reported by Schevill and Watkins (1966). Clicks with predominantly high frequency energy had the shortest durations, a situation comparable to that reported by Evans (1973). We cannot make quantitative energy level comparisons because of our limited recording responses (not flat), but we did note substantial energies at low frequencies in most clicks (2,000 Hz or less), which agrees with the results of Schevill and

Watkins (1966). We also confirmed their findings of major narrow band frequency emphases, although in our recordings these narrow band emphases were found not only at low frequencies, but also as high as 6,000 Hz.

Many of the pulsed sounds recorded in these two encounters are consistent with those "screams" reported by Schevill and Watkins (1966) and Singleton and Poulter (1967). However, in addition to the standard "screams" reported previously, we recorded a greater variety of pulsed sounds. Killer whales are able to vary their combinations of fundamental tones and pulsing rates to an extent not previously reported.

The tonal vocalizations recorded from *O. orca* were not pulsed sounds, and were often similar aurally to the "whistles" commonly emitted by smaller delphinids. Schevill and Watkins (1966) commented on the lack of whistle vocalizations from their killer whale recordings. However, the whale studied by Schevill and Watkins was a newly captured animal held in a temporary pen in a bay at Vancouver, British Columbia. The animal was isolated from all other killer whales. Our recordings were taken from field situations involving several whales in close proximity to one another, apparently engaged in cooperative behavior. High frequency, pure tonal sounds with relatively low intensities and consequent high attenuation factors are suitable for communication in the latter situation.

As a matter of speculation, we suggest that the sound-producing mechanism associated with the tonal vocalizations may be the same basic mechanism that produces the fundamental tone frequency associated with the pulsed sounds. In some instances the concomitant pulsing mechanism may be absent and only the fundamental tone frequency is apparent, hence a "tonal" sound.

The apparent cooperative feeding behavior observed in the second encounter is consistent with other reports of cooperative feeding behavior by killer whales. Brown and Norris (1956), Leatherwood (1975), and Balcomb (in Rice, 1968) have all described similar behaviors used by killer whales for capturing small cetaceans and pinnipeds.

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