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SOUNDS RECORDED FROM BAIRD'S BEAKED WHALE, *BERARDIUS BAIRDII*

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SOUNDS RECORDED FROM BAIRD'S BEAKED WHALE, *BERARDIUS BAIRDII*

The vocal behavior of ziphiid whales is very poorly known. Free-swimming northern bottlenose whales, *Hyperoodon ampullatus*, have been recorded producing 3–16 kHz whistles and chirps (Winn *et al.* 1970; linear equipment frequency response 500 Hz–14 kHz) and 20-30 kHz ultrasonic clicks (Fauchner and Whitehead, unpublished data; equipment response to 35 kHz). A free-swimming mesoplodont beaked whale (probably *Mesoplodon hectori*) produced ultrasonic clicks (Ljungblad, unpublished data; equipment frequency response to 32 kHz). Sounds have been recorded from a stranded Blainville's beaked whale, *Mesoplodon densirostris* (Caldwell and Caldwell 1971; equipment frequency response 40 Hz–20 kHz) and a post-stranding, captive Hubb's beaked whale, *Mesoplodon carlhubbsi* (Lynn and Reiss 1992; equipment frequency response 70 Hz–40 kHz). The latter two species produced low-frequency pulses (mostly < 2 kHz). The Hubb's beaked whale also produced broadband clicks extending beyond the limit of the recording gear (> 40 kHz) and a few weak whistles (< 10.7 kHz). During cetacean survey cruises conducted by the National Marine Fisheries Service off the coasts of Oregon, U.S.A., and Baja California, Mexico, we recently made what we believe to be the first recordings of Baird's beaked whales (*Berardius bairdii*).

On 27 July 1994 the NOAA Ship *Surveyor* encountered a group of 30–35 Baird's beaked whales about 225 nmi west of Hecata Head, Oregon (at 44°10′N, 129°10′W). Two sonobuoys (ex U.S. Navy, type 57B) were deployed. The first was deployed 1.6 nmi away from the animals, before a rigid-hulled inflatable boat (RHIB) was launched. The second was deployed 55 min later from the RHIB, within tens of meters from the animals. To relocate the animals after each dive, a continuous search was maintained by two observers searching the forward quadrants with 25× binoculars and two or more additional observers searching all quadrants with 7× binoculars and unaided eyes. The only other cetacean seen during this time was one large sperm whale 6–10 nmi away. Sounds were recorded using a Nagra IV-SJ analog tape recorder, for a total system response from 20 Hz to 20 kHz. We filtered these recordings at 20 kHz (low pass) and digitized them at 44.1 kHz (16 bit). Spectrograms (4096 pt FFT, 1024 pt frame length, 87.5% overlap, 174.85 Hz analyzing filter bandwidth) were generated using Canary™ signal processing software (v. 1.2.1; Cornell University), running on a Power Macintosh™ 7600/120.

Much of the Oregon recording was corrupted by noise from an outboard motor. Only five short (4–12 sec) sequences of sounds could be analyzed. These sounds were recorded clearly from both bouys, though at lower amplitude on

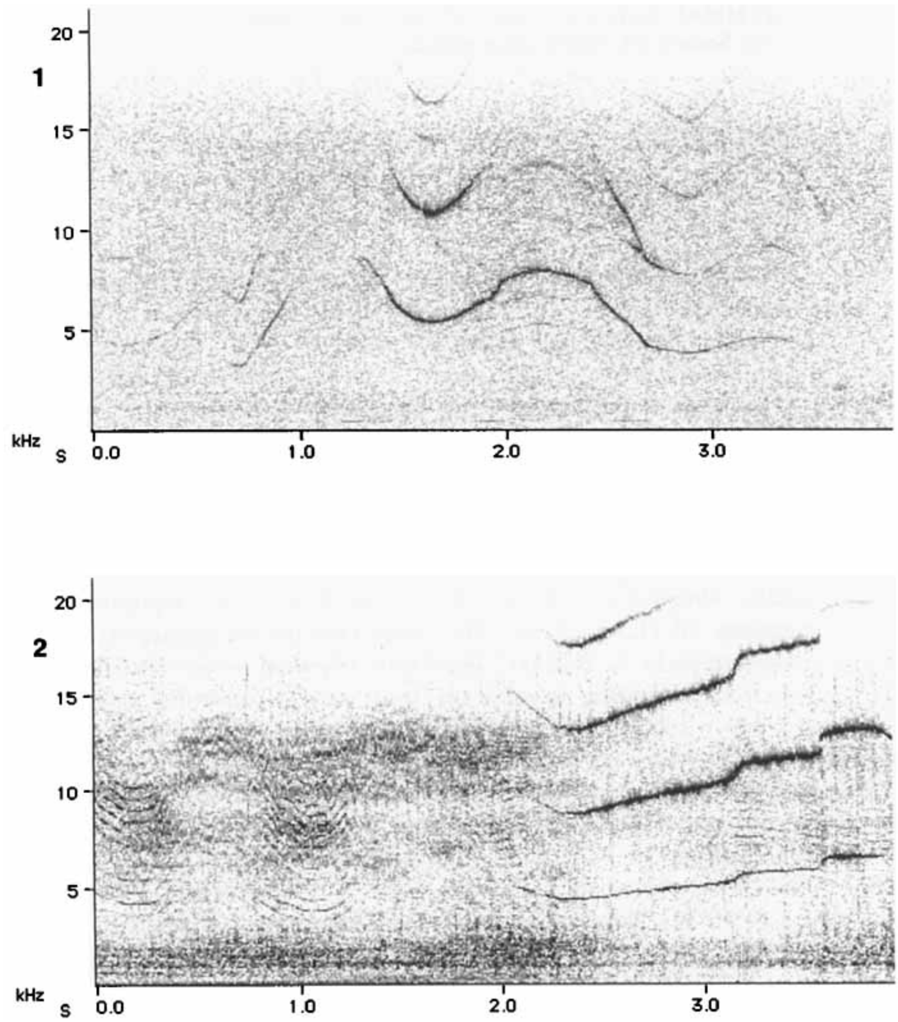

Figure 1. Spectrograms of two sequences containing FM whistles, recorded using a sonobuoy and audio tape recorder. Spectrogram 2 also shows the lower emphases of clicks whose major energy was probably beyond the upper limit of the equipment. The weak, multiharmonic, tonal sounds present at 0.3, 1.0, 2.0, and 3.5 sec in this record probably represent the repetition rate of ultrasonic clicks.

the distant bouy. Four sequences contained frequency-modulated (FM) whistles with fundamental frequencies between 4 and 8 kHz, with 2–3 strong harmonics within the recording bandwidth (Fig. 1). The lower frequency emphases of apparently broadband clicks were associated with all records except one (Fig. 1, spectrogram 1). Tonal sounds, apparently generated by clicks at high repetition rates, were present in two of the sequences (*e.g.*, Fig. 1, spectrogram 2). These sounds were very similar to those occasionally heard from dolphins (*e.g.*, Dawson 1991).

We were able to make more extensive recordings between 1638 and 1800 on 7 September 1995, when the NOAA Ship *McArthur* encountered a group of about 11 Baird's beaked whales approximately 40 nmi west of Isla Cedros on the eastern side of the Baja California Peninsula, Mexico (at 28°10′N, 115°45′W). Observers on the *McArthur* predicted where the whales would surface next from the trend of previous sighting positions displayed *via* a custom-written computer program. Recordings were made from a 5.7-m RHIB positioned according to these predictions. On one occasion the whales surfaced within 100 m of the RHIB. Another group of three Baird's beaked whales was seen ~2 nmi away from the first group. A group of common dolphins was seen moving rapidly through the vicinity at 1745–1800. Whistles were recorded from a sonobuoy while Baird's beaked whales were being recorded from the RHIB, but their timing coincided with the appearance of the common dolphins, and therefore they are not presented here. We recorded no whistles from the RHIB during our encounter with the Baird's beaked whales.

Signals were recorded with a Sonatech Model 8178 wideband hydrophone, custom-built wideband amplifier, and Racal Store 4DS analog tape deck. The frequency response of this system was 30 Hz–180 kHz ± 4 dB, and signal-to-noise ratio 40 dB. Signals were recorded onto two channels of the recorder (set 6 dB apart), and monitored using a BatBox II™ bat detector to give us audible indications of ultrasonic sounds. We recorded whenever we could see sounds deflecting the meter of the tape recorder, obtaining 20 min of recordings over the 82-min duration of the encounter. An indication of vocalization rate is available from our recording of 245 sequences of high signal-to-noise ratio in this time. With the bat detector set to ~25 kHz, we could hear irregular pulse series as a "sneeze" or fast scraping sound. Individual clicks and short click sequences were not audible; they seemed too short to trigger the detector.

All tape sections of high signal-to-noise from the Baja encounter ($n = 245$) were digitized at an effective sample rate of 196 kHz (16-bit resolution) and printed. We then sorted the sounds into three categories ("clicks," "irregular pulse series," and "click bursts"), which represent increasing pulse repetition rate, and chose the 10 best (highest s/n ratio) from each category. To avoid missing any high-frequency components, these 30 records were digitized again at an effective sampling rate of 352.8 kHz (⅛ record speed at 44.1 kHz; 16 bit) with a Kemo VBF8 48 dB/octave filter set at 160 kHz (low pass) to avoid aliasing. Hence the combined recording and analysis bandwidth was 300 Hz to 160 kHz. Sounds were digitized and analyzed using Canary™ software.

For "clicks" and "irregular pulse series," individual pulses were evident. We measured peak signal pressure (on a linear scale) of each pulse relative to the background noise in each record and analyzed only those pulses with a signal-to-noise ratio > 5. From these we measured the duration of each pulse from the time of onset to the point at which it decayed to the level of the background noise and computed spectra over the same duration. Linear (quadratic in Canary's jargon) spectra (amplitude *vs.* frequency) were computed as 4,096-

point FFTs (frame length 4,096 pts) with an analysis filter bandwidth of 380.62 Hz. A Hamming window was used in computing all spectra and spectrograms. We noted the frequency of the four largest peaks in the spectrum of each pulse.

"Click bursts" also had a pulsed structure, but pulses were too close together to allow us to measure duration of each. For each record we computed 4,096-pt logarithmic spectrograms (frequency *vs.* time) using Canary (2,048-pt frame length, 93.75 % overlap, 699-Hz analyzing filter bandwidth). We also computed a spectrum for each "click burst" within the record. Spectra of long signals become very "spiky" when analyzed with large frame sizes. To make spectra easier to interpret we also computed quadratic 8,192-pt FFTs with a 512-pt frame size, yielding an analyzing filter bandwidth of 2,797 Hz.

Throughout the Baja recordings, "clicks" were made singly or in short sequences. Our ten best records of click sequences averaged 636 ms long (range 22–2520 ms) and contained one to nine pulses (total = 27). Three of these records contained three or more clicks (3, 5, 9 clicks). Timing of clicks within these records was irregular. Mean interclick intervals in these records were 141.7 ms (CV = 40%), 541.1 ms (CV = 77%) and 98.7 ms (CV = 77%), respectively. The longest click train is shown in Figure 2. Duration of individual clicks ranged from 122 μs to 953 μs (mean = 463 μs, CV = 58%). There was no significant relationship between signal-to-noise ratio and click duration. In most clicks the largest spectral peak was between 22 and 25 kHz (Fig. 3). In one record (Fig. 2), the first eight clicks had much lower frequency (12.1–15.6 kHz) than did the final click of the series (25.2 kHz). For all clicks, duration and dominant frequency were inversely related ($r^2 = 0.459$, $P < 0.001$). The second largest spectral peak was typically between 35 and 45 kHz (Fig. 3). Only four of the 27 clicks had one of their four largest spectral peaks above 80 kHz (80, 80.3, 80.3, 129.5 kHz).

"Irregular pulse series," composed of several pulses at high repetition rates, were common in the Baja recordings (Fig. 4). Our ten best records averaged 320 ms long (range 33–580 ms) and contained a total of 119 individual pulses of high signal-to-noise ratio. Six records contained one or two pulses at the beginning or end of the record, separated by 100 ms or more from a pulse series containing 4–31 pulses within a few milliseconds of one another. Mean interpulse interval within irregular pulse series was 6.8 ms ($n = 102$ measured intervals; CV range = 44%–282%). Pulse duration ranged from 122.6 to 549 μs (mean = 310 μs, CV = 30.6%) and, not surprisingly, was significantly related to signal-to-noise ratio ($r^2 = 0.312$, $P < 0.0001$); louder pulses being longer. Most of the pulses had a strong spectral peak around 23 kHz (Fig. 5) with a second harmonically unrelated peak at around 42 kHz. All but eight of the 119 individual pulses contained a strong spectral peak at around 23 kHz (*i.e.*, one of three strongest spectral peaks). Dominant frequency and pulse duration were inversely related ($r^2 = 0.179$, $P < 0.001$). Thirteen pulses had one of their largest spectral peaks above 80 kHz (maximum = 134 kHz).

Our ten best records of "click bursts" averaged 269 ms long (range 94.2–623 ms) and contained 17 individual click bursts (mean duration = 44.7 ms,

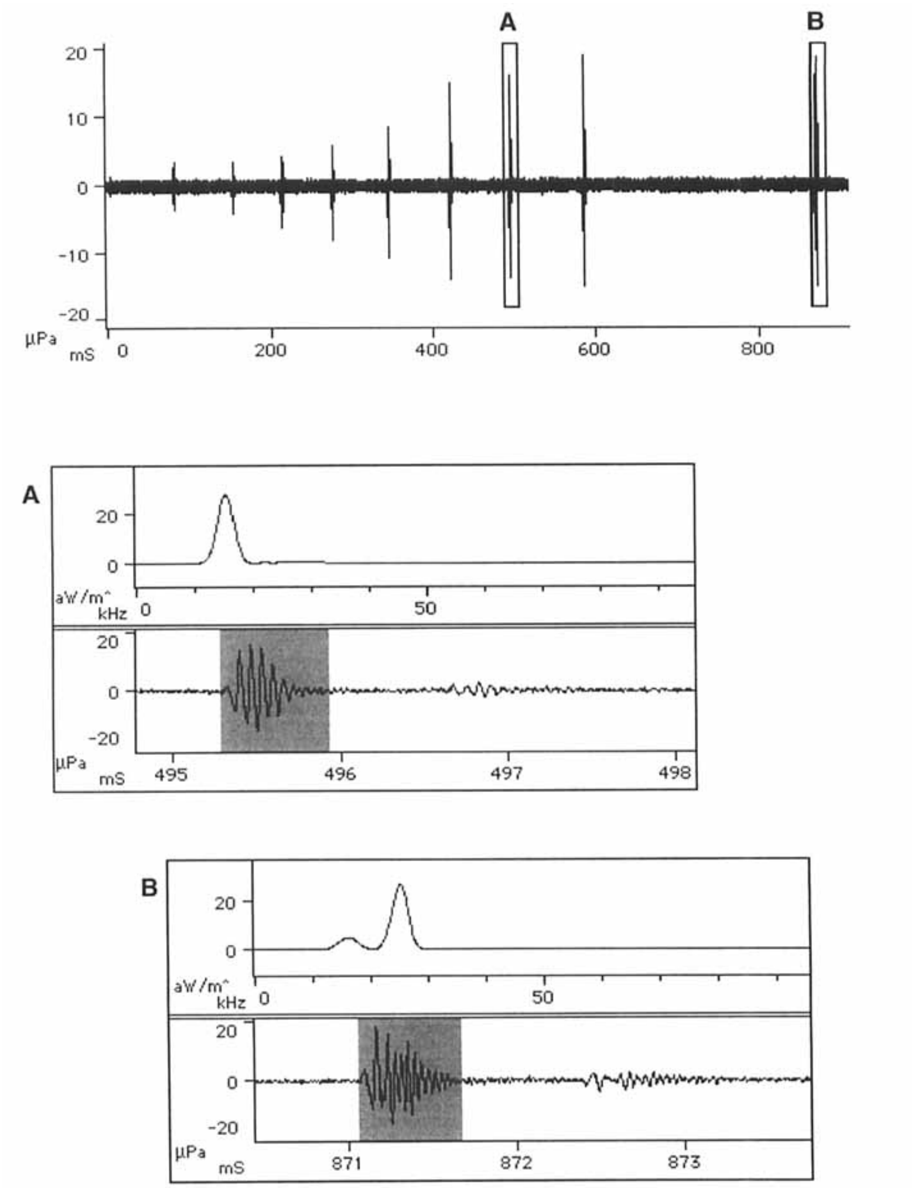

Figure 2. The longest click train recorded. Waveform and spectra are shown for two pulses (*y* axes are linear, but uncalibrated; see text for analysis details). Shading indicates the duration over which spectra are calculated. Note the shift in frequency of peak amplitude between pulses A (15.3 kHz) and B (25.3 kHz). Most other clicks recorded were more similar in structure and frequency to pulse B.

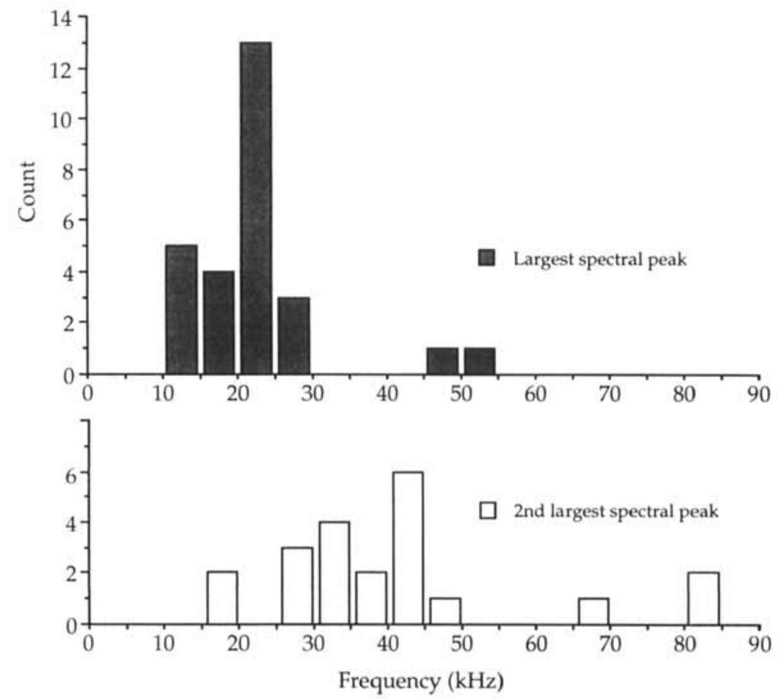

Figure 3. Histogram showing frequencies of the largest and second largest spectral peaks in 27 clicks.

CV = 42%). Sixteen (94%) of the click bursts had a dominant frequency between 23 and 24.6 kHz; the only exception had a dominant frequency of 45.1 kHz (its second largest frequency peak was 23 kHz). No click burst had appreciable energy over 90 kHz. Isolated clicks were often seen within records containing click bursts (Fig. 6).

Although whistle sounds were formerly commonly associated only with delphinid cetaceans (Herman and Tavolga 1980), it appears that they are also produced by a variety of beaked whales. In addition to our observations, whistles were also recorded during an encounter with a group of *Berardius arnuxii* in Antarctica (T. L. Rogers and S. M. Brown, unpublished manuscript). Almost all pulsed sounds we recorded had a dominant frequency around 23 kHz, with a second frequency peak around 42 kHz. Our experience with sounds made by dolphins and sperm whales led us to expect that clicks would be made in sequences (click trains), in which click rate changed gradually. This feature seems broadly characteristic of animals using sonar (*e.g.*, Watkins 1980). The clicks we recorded from *Berardius* were most often emitted in irregular series of very few clicks. We do not suggest that this indicates Baird's beaked whale does not echolocate, merely that its acoustic behavior appears unlike that of many species which do. Irregular click production by transient killer whales (Barrett-Lennard *et al.* 1996) seems strikingly similar. These authors' explanation for this (avoidance of acoustic detection by marine mam-

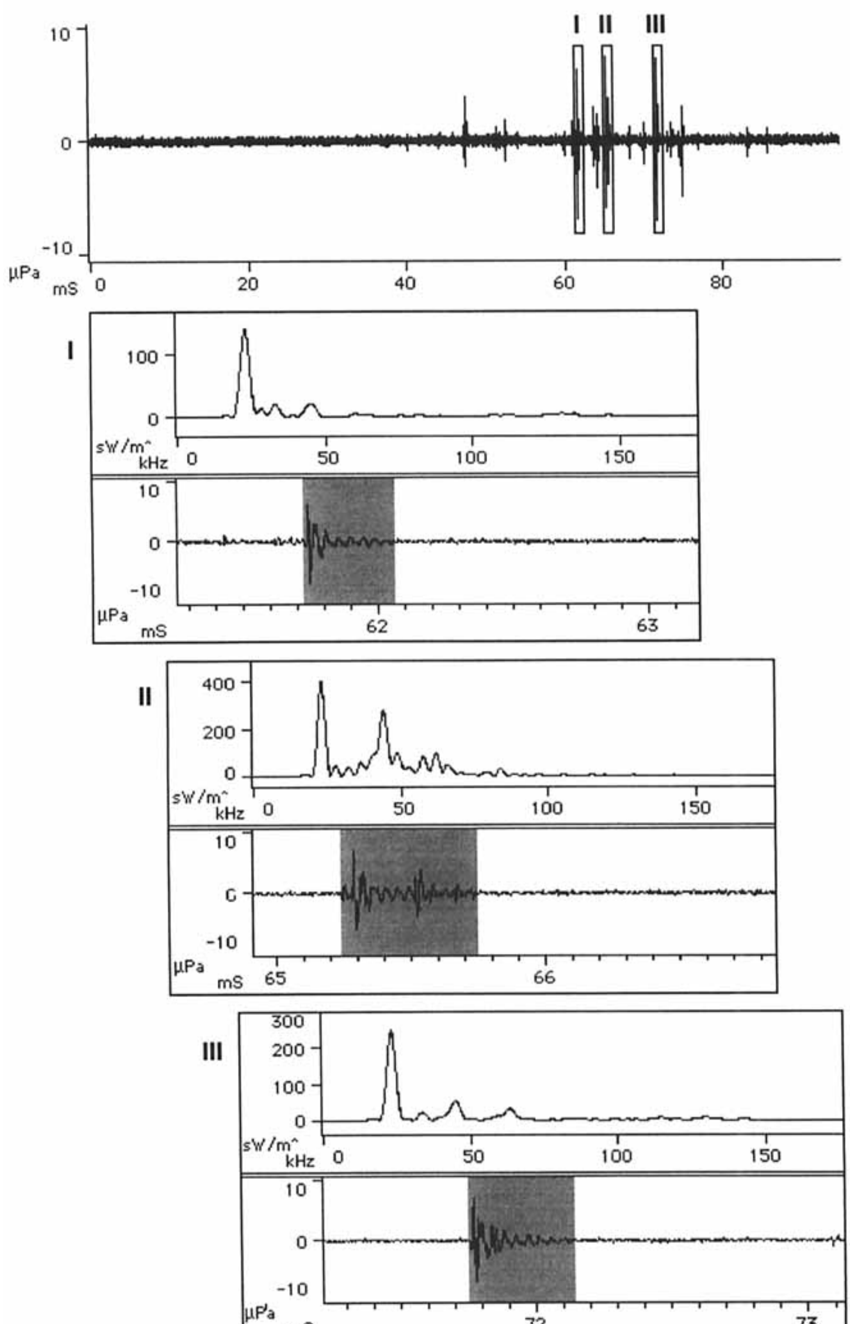

Figure 4. A typical irregular pulse series, with spectra and waveforms for three pulses. Frequencies of peak amplitude are pulse I, 23.0 kHz; pulse II, 23.3 kHz; pulse III, 23.2 kHz.

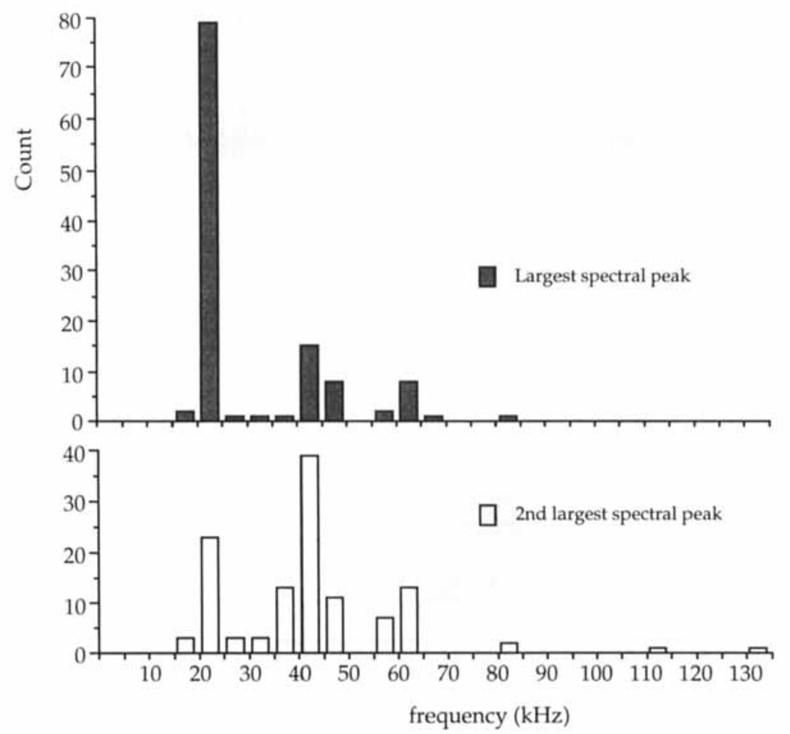

Figure 5. Histogram showing frequencies of the largest and second largest spectral peaks in 119 pulses within irregular pulse series.

mal prey) does not fit Baird's beaked whales, which eat cephalopods and fish (Balcomb 1989).

During the Baja cruise we also had an excellent opportunity to record a group of four Cuvier's beaked whales, *Ziphius cavirostris*. We positioned ourselves where the observer team thought the group might surface, and recorded for 15 min. During the encounter the group surfaced 200 m away, swam towards us and dived within 100 m of our stern. Yet we recorded no vocalizations. Though our sample of observations is very small, this raises the possibility that this species is substantially less vocal than is Baird's beaked whale. We are unaware of any recorded sounds from Cuvier's beaked whales.

Acknowledgments

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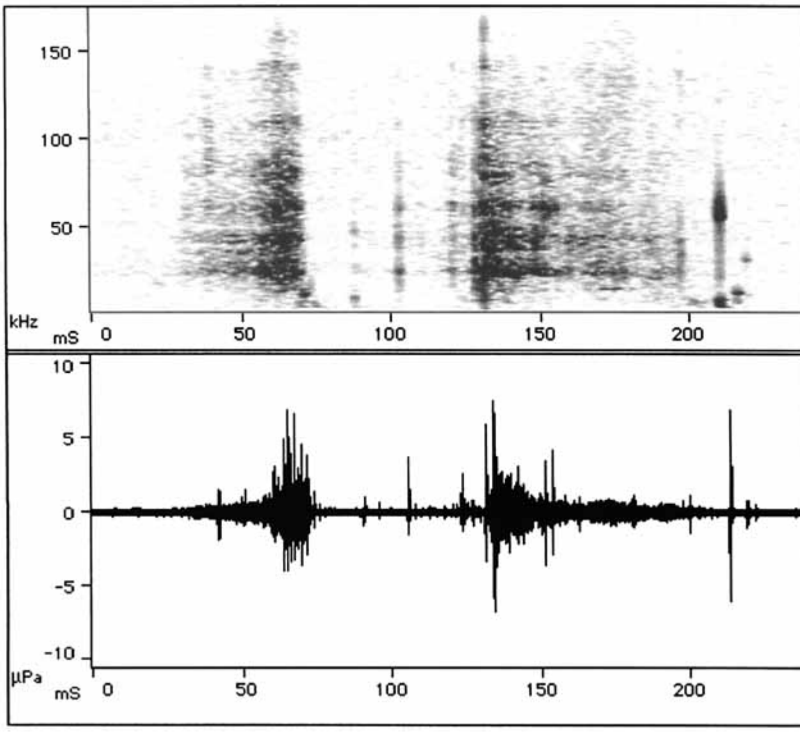

Figure 6. Spectrogram and waveform of a record containing two typical "click bursts." Note the isolated clicks within the record.

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