# Clicks from Cuvier's beaked whales, *Ziphius cavirostris* (L)


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Recordings of pulsed sounds (clicks) from Cuvier's beaked whales are presented. Such recordings have not been reported in the literature before. Spectrogram analysis of data collected off SW Crete (Greece) from 1998 to 2000 revealed numerous sequences of clicks. Click pulses had durations of about 1 ms and their energy content in the audible spectrum presented a narrow peak between 13 and 17 kHz. Sequences of 35–105 clicks, with duration 15–44 s, were separated by short intersequence pauses of 3–10 s. Interclick intervals appeared fairly constant, primarily oscillating between 0.40 and 0.50 s. Characteristics of Cuvier's beaked whale clicks were consistent with echolocating cetaceans, suggesting that this species do echolocate.



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## I. INTRODUCTION

Since 1947, when the bottlenose dolphin was the first cetacean species suggested to detect objects underwater by echolocation, the list of odontocetes shown to echolocate has expanded greatly (Au, 1993). A wide range of species from all the odontocete families have been demonstrated to produce pulsed sounds (commonly called clicks), and it is generally considered that these are used for echolocation purposes (Au, 1993; Richardson *et al.*, 1995).

The family of beaked whales (Ziphiidae) consists of 20 species that account for 28% of all odontocetes (Rice, 1998). However, encounters with most species in the wild are scarce and recordings of their sound emissions are difficult to collect. As a result, their acoustic repertoire is very poorly known. Opportunistic audio recordings from rare sightings or strandings have been reported for six beaked whale species, and among them, only the northern bottlenose whale has been studied systematically (Hooker, 1999).

The only available sound emissions by the Cuvier's beaked whale (*Ziphius cavirostris*), the most common species of the Ziphiid family (Heyning, 1989), is anecdotal (six whistles by Manghi *et al.*, 1999). This lack of data became a serious concern in respect to recent mass strandings of Cuvier's beaked whales that were spatially and temporally correlated with high-level, anthropogenic noise in the local marine environment (Frantzis, 1998; IWC, 2000). Data on both sound production and hearing of beaked whales are of major importance to the understanding of their life habits and interactions with anthropogenic noise. We report the first recordings of Cuvier's beaked whale clicks, and discuss their time and frequency characteristics in the audible range, with respect to their potential echolocation function.

## II. METHODS

Acoustic recordings of Cuvier's beaked whales were made from a 16-m vessel off Southwest Crete (Greece, Mediterranean Sea) from 1998 to 2000. Beaked whales were detected visually and were gradually approached. Recordings were started while the whales were at the surface and continued after they dove. In two cases, the proximity of beaked whales was detected acoustically (through the hydrophone) and the recording was started while the whales were diving, before the first visual contact that occurred 15 and 24 minutes later, respectively. During all the recordings the sea state was less than 3 and the sea surface was continuously scanned by naked eye and binoculars, 360 degrees around the research vessel. The time of surfacing and the dive start time of each whale were noted, as well as the visual and/or acoustic presence of other cetacean species. Geographic coordinates were recorded with the aid of a GPS. Bottom depths of sightings were determined by plotting the geographical coordinates on a bathymetric map. Photo-identification of individual whales was accomplished by reviewing miniDV videos recorded at the surface.

The hydrophone array contained two omnidirectional Benthos AQ-4 elements with 30-dB gain preamplifiers. The elements were mounted 3 m apart along the axis of a 10-m oil-filled polyurethane tube. The frequency response of the elements was flat ±1.5 dB and flat ±2.0 dB for the 1 Hz to


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TABLE I. Data regarding the tape segments of Cuvier's beaked whale recordings selected for interclick interval (ICI) analysis.

| Date Time | Duration (No. of clicks) | No. of whales | Bottom depth (m) | Context |
|---|---|---|---|---|
| 2 July 2000 13:28:58 | 71.7 s (119) | 2 | 1020 | Middle of a long dive of 68 min started at 12:55:30 |
| 31 July 2000 12:21:47 | 101.8 s (177) | 2 | 500 | Beginning of a long dive started at 12:19:16 |
| 1 August 2000 11:57:53 | 107.3 s (227) | 1 | 1300 | During a dive started at 11:49:50 |

15 kHz and 15–25 kHz bandwidths, respectively. The array was towed 100 m behind the vessel or, when the vessel was not in motion, was left to sink into a vertical position 100 m below the stern. Signals from the array were high-pass filtered (200 Hz filter break, −12 dB per octave roll off) before being recorded with a Sony TCD-D8 digital tape recorder (DAT), at 48 kHz sampling frequency. This DAT recorder has a flat frequency response ±1.0 dB for the bandwidth 20 Hz to 22 kHz, and cuts off above 24 kHz. As a result, possible higher frequency components of the Cuvier's beaked whale clicks could not be recorded. Similarly, it was not possible to obtain the source level and position of the sound-producing animals relative to the hydrophone.

Preliminary waveforms and spectrograms were made using BatSound 1.2 and Sound Forge XP 4.0. Only very short parts of the recordings contained clearly audible Cuvier's beaked whale clicks, although visually clear clicks could be identified in the waveforms and spectrograms for sequences as long as 14 min. In a total of 5 h and 3 min of recordings made in proximity of Cuvier's beaked whales, sound emissions of this species were detected in 59 min. In order to avoid contamination of our data with sounds from other species, we processed only tape segments for which no dolphins or other cetaceans had been sighted or heard for one hour before or after the recordings. Nine tape segments were selected for final analysis because only one whale was recorded and had high signal-to-noise ratio. These segments started 2.5 to 34.0 min after the start of long dives. Three segments contained clicks that could be identified and tracked with no interruption for periods longer than 70 s, and were selected for the interclick interval (ICI) analysis (Table I). These click trains originated from three different individuals (on the basis of photo-identification results), encountered on three different days.

Clicks appeared as narrow spectrogram peaks at around 15 kHz, in most cases followed by a surface echo coming a few tens of milliseconds later. Click intensity was variable over a period of tens of seconds, and only short sections showed high signal level. These sections were used for the frequency and pulse duration analysis. The sound files were imported into MATLAB for detailed inspection of the individual pulse shapes and spectra. Only one channel (the right) was used for the analysis. A digital high-pass filter set at 500 Hz was applied to reduce noise. The onset of each individual click was marked to the nearest sample point, with an accuracy of about 0.02 ms. Similarly, a marker was laid down at the position where the pulse decayed into the background noise. These marker data were subsequently compiled to yield ICIs, defined as the time difference between the onset markers of two successive clicks, and pulse durations, defined as the time difference between onset and decay markers of each click. Onset markers also served as reference points for spectral analysis targeted at the short sections of data containing the click pulses. Each click was centered in a 256-point FFT window (duration 5.3 ms) and the section was modulated with a Hanning window to remove edge effects.

## III. RESULTS

Pulse duration of Cuvier's beaked whale clicks ranged from 0.7 to 1.6 ms, with an average of 1.08 ms (s.d. $=0.26$, $n=142$). The energy of the clicks was concentrated into a narrow peak between 13 and 17 kHz (Fig. 1). Spectral analysis of sequential clicks revealed, repeatedly, a progressive slide of this narrow-band peak, between 13 and 16 kHz, during the course of some 20 clicks, in less than 10 s. However, distortions due to possible off-axis recording cannot be excluded, since the position of the whales relative to the hydrophones was not known.

The analysis of the three segments that contained long series of clicks (Table I) revealed that click production in Cuvier's beaked whales is not continuous. Sequences of 35–105 clicks, with duration 15.5–44.5 s, were separated by short intersequence pauses (periods of silence) of 3.0–10.3 s. This pattern was obvious in all analyzed segments, which contained seven complete, and three incomplete click sequences in total, with eight pauses among them [Figs. 2(a)–(c)]. As complete click sequences we define those that were recorded from their first to their last click and consequently were preceded and followed by a pause. All pauses were

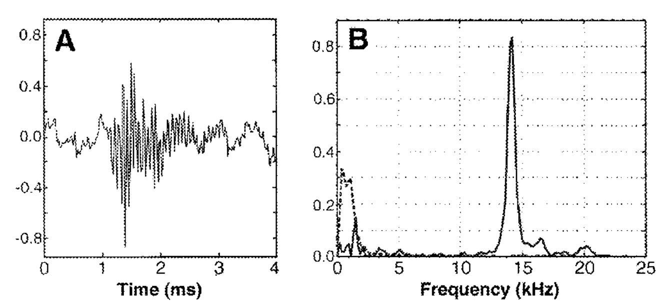


FIG. 1. Typical waveform in background noise (a) and spectral density (b) in the audible frequency range of Cuvier's beaked whale clicks. The dashed line in the spectrogram represents the level of background noise (high-pass filtered at 500 Hz).

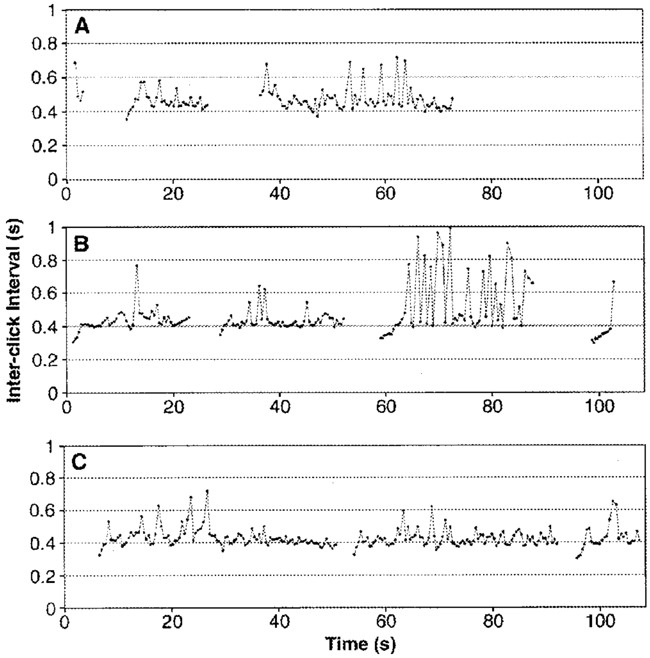


FIG. 2. Variation in interclick interval (ICI) during the dive of three different Cuvier's beaked whales [plots (a)–(c)], recorded on three different days. Plots contain: one incomplete and two complete sequences (a), three complete and one incomplete sequence (b), a single click at time 0 s followed by a pause, two complete, and one incomplete sequence (c).

three to ten times longer than the maximum ICI encountered, and were discarded from any ICI statistical analysis.

The ICI appeared fairly constant, oscillating between 0.40 and 0.50 s for most parts of seven of the eight complete click sequences [Figs. 2(a)–(c)]. Some sharp oscillations were also present. In one click sequence [third in Fig. 2(b)], although the ICI baseline was at about 0.40 s, a sharp oscillation was the dominant pattern, with the highest ICIs ranging between 0.70 and 1.00 s. The changes from the baseline to the next maximum and back to the baseline were not gradual, but occurred from one ICI to the next. In total, the ICI ranged from 0.295 to 0.989 s. Although the differences between average ICIs from the three analyzed segments were significant (single factor ANOVA, $n=512$, $F=11.29$, $p<0.001$), the three ICI distributions had similar modes (0.40–0.45 ms), and more than 75% of ICIs ranged between 0.35 and 0.50 ms in all three cases. The overall average ICI was 0.444 s ($n=512$, s.d.$=0.092$).

All click sequences presented a common starting pattern: very short ICIs increasing progressively [Figs. 2(a)–(c)]. In all but one case, the first ICI of each sequence had the minimum value of the entire click sequence. No obvious trend was observed for the last clicks of click sequences.

## IV. DISCUSSION

Efforts to record Cuvier's beaked whale clicks have been made in the past (Dawson *et al.*, 1998; Manghi *et al.*, 1999). However, their lack of success raised the possibility that Cuvier's beaked whales were substantially less "vocal" than other beaked whales (Dawson *et al.*, 1998). Our repeated recordings of Cuvier's beaked whale sounds indicate that this species produces clicks as often as other odontocetes. These clicks had not been detected up to now, for reasons likely common to most beaked whale species.

While finding free-ranging Cuvier's beaked whales is difficult because of their behavior, we believe that the main reason why no recordings have been previously reported is that Cuvier's beaked whale clicks are rarely audible to most humans when heard or recorded through conventional omnidirectional hydrophones. Both their frequency and short pulse duration make them difficult to detect by ear. In the audible frequency range, their only significant components above background noise were between 13 and 17 kHz, just at, or above the limit of useful sensitivity for most humans. In addition, the sound level of clicks was low in most parts of our recordings, with loud clicks occurring intermittently for only a few seconds. Cuvier's beaked whales may also produce ultrasounds, as is the case with northern bottlenose whales (Hooker, 1999) and Baird's beaked whales (Dawson *et al.*, 1998). However, in this work only frequency components in the audible spectrum could be recorded and analyzed with the available instrumentation.

The oscillating signal levels, as well as the progressive slide of the recorded peak frequency, suggest that Cuvier's beaked whale clicks are directional, and that the hydrophone may be picking up different parts of the beam as the whale changes orientation underwater. If this is the case, the energy peaks of clicks recorded off-axis are biased towards lower frequencies, since the latter give rise to a broader beam pattern. We have observed and recorded on video one Cuvier's beaked whale just under the surface, changing the direction of its head (right–left–right, etc.) nine times, as if "scanning" the vessel, while coming towards it. The mean scanning angle was about 50° and the mean rate of four complete scans was one scan per 2.2 s. Unfortunately, no audio recording was made during this "scanning" behavior.

The average interclick interval of diving Cuvier's beaked whales (0.44 s) is almost identical to that reported by Hooker (1999) for "distant clicks" of diving northern bottlenose whales (0.4 s). ICIs of regular clicks from foraging sperm whale oscillate around 1 s (Gordon, 1987; Goold and Jones, 1995; Douglas, 2000). For both sperm whales and northern bottlenose whales there is evidence that they produce clicks for echolocation purposes (Gordon, 1987; Hooker, 1999; Møhl *et al.*, 2000; Jaquet *et al.*, 2001). Both species are mainly teuthivorous deep divers (Rice, 1989; Mead, 1989; Hooker and Baird, 1999) with diets very similar to Cuvier's beaked whales (Heyning, 1989).

On the basis of the above similarities it appears that the clicks recorded from Cuvier's beaked whales are also used for echolocation as has been assumed or demonstrated for most odontocetes (Au, 1993; Richardson *et al.*, 1995). If this is the case, the ICI should approximate the two-way transit time to the target that the whale is echolocating on, or the maximum detection range at which searching is taking place (Au, 1993). An ICI of 0.44 s implies a searching range of about 310 m ($c_{\text{water}}=1500\ \text{m}\,\text{s}^{-1}$). This is practically equal to what has been estimated for northern bottlenose whales (Hooker, 1999), but about half that estimated for sperm whales (Goold and Jones, 1995). Furthermore, the increasing ICIs in the beginning of all analyzed click sequences indicate that echo-searching in Cuvier's beaked whales commences from about 210 m to expand to about 310 m in the next 1–3 s. A similar pattern was recently observed in click sequences from deep diving sperm whales; 60% of click sequences begin with increasing ICIs and only 3% with decreasing ICIs (Frantzis *et al.*, in preparation).

Small and moderate ICI oscillations, such as those in most click sequences of Fig. 2, have already been reported for echolocating bottlenose dolphins, and were characterized as "typical" of all click trains examined in the presence as well as in the absence of a target (Au, 1993). Similar oscillations have been observed in the ICIs of diving sperm whales and various explanations have been proposed (Goold and Jones, 1995; Douglas, 2000). The sharp oscillations observed in the last complete click sequence of Fig. 2(b) seem unusual and their potential function is unclear.

The detected intersequence pauses (short periods of silence) in Cuvier's beaked whale recordings present an astonishing similarity with sperm whale acoustic behavior during deep dives (Gordon 1987; Douglas, 2000), although at a slightly different time scale. Sperm whale pauses last 2.5 to 58 s, and occur after creaks, or after regular click sequences of 0.5 to 4.4 min (Frantzis *et al.*, in preparation). Both pauses and click sequences from Cuvier's beaked whales (respective durations 3.0–10.3 s and 15.5–44.5 s) were many times shorter than those of sperm whales. The number of clicks between two pauses varies twice as much in sperm whales as in Cuvier's beaked whales (ranges 18–215 and 35–105, respectively). The purpose of regular intersequence pauses between click trains is not yet understood. They may represent the result of feeding after the capture of a prey, a period with no need for sound production, or a necessary, short resting period for the click-producing organ(s). In any case, their detection in Cuvier's beaked whales shows that they are not a sperm whale peculiarity. We detected no sounds similar to sperm whale creaks (rapid bursts of clicks with repetition rates of up to 200 $s^{-1}$) in Cuvier's beaked whales. Constant ICIs and absence of creaks were also reported for northern bottlenose whales and led to the hypothesis that this species could use vision in the final stages of a fairly passive prey capture (Hooker, 1999; Hooker and Baird, 1999). This hypothesis may also apply to Cuvier's beaked whales, since all three prey species found in the stomachs of eight specimens stranded in Greece have photophores (Lefkaditou and Poulopoulos, 1998; Frantzis *et al.*, in preparation). However, more data are needed before concluding that creaks are absent in this species.

Given our limited data, we can do little more than speculate about the precise function of the recorded clicks. However, the fact that diving Cuvier's beaked whales emit clicks with characteristics that are consistent with echolocating cetaceans suggests that Cuvier's beaked whales also echolocate.

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