Description of sounds recorded from Longman's beaked whale, *Indopacetus pacificus*

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Abstract: Sounds from Longman's beaked whale, *Indopacetus pacificus*, were recorded during shipboard surveys of cetaceans surrounding the Hawaiian Islands archipelago; this represents the first known recording of this species. Sounds included echolocation clicks and burst pulses. Echolocation clicks were grouped into three categories, a 15 kHz click ($n = 106$), a 25 kHz click ($n = 136$), and a 25 kHz pulse with a frequency-modulated upsweep ($n = 70$). The 15 and 25 kHz clicks were relatively short (181 and 144 ms, respectively); the longer 25 kHz upswept pulse was 288 ms. Burst pulses were long (0.5 s) click trains with approximately 240 clicks/s.
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1. Introduction

Longman's beaked whale, *Indopactus pacificus*, is one of the least known cetacean species and has only recently been described (Dalebout *et al.*, 2003). Little is known of its behavior, life history, or its population structure (Pitman *et al.*, 1999). This ziphiid species resembles the northern and southern bottlenose whales (*Hyperoodon ampullatus* and *Hyperoodon planifrons*, respectively) in general body shape and color and is distributed in tropical to subtropical waters, with a $20° - 30°$ latitudinal separation from either of the two bottlenose whales. Individuals of this species often surface in unison, creating sufficient white-water to be visually detected at a distance. This, combined with their pronounced blow, allow them to be detected at greater distances than beaked whales in the genera *Ziphius* and *Mesoplodon*. Nonetheless, because they are only found in offshore tropical oceans, there have been few documented encounters. Vocalizations had never been recorded in the presence of this species prior to this study.

Description of the vocal repertoire of this species will allow for the development of automated detectors for future shipboard surveys and for examination of recordings obtained from seafloor hydrophones, which may provide valuable information on the behavior, population structure and habitat use of the species. This study examines recordings made in the presence of a single-species group of Longman's beaked whales encountered during a cetacean survey.

2. Methods

The recordings were made during a combined visual and acoustic line-transect shipboard survey of cetaceans of the Hawaiian Islands in the fall of 2010. Visual methods consisted of teams of three experienced visual observers searching with "big-eye" 25×150 power binoculars, 7X binoculars, and the unaided eye. Description of group behavior was recorded by an experienced observer (R. Rowlett).

A hydrophone array was towed 300 m behind the vessel at a depth of 8 – 11 m at 10 knots during daylight hours. The five-element hydrophone array included two Reson 4013 hydrophones in an oil-filled section of the array (5 – 150 kHz $\pm$ 2 dB at -171 dB re 1 V/μPa). Signals from the array were sent through a Magrec monitor unit (high pass filter at 1 kHz, http://ecologicuk.co.uk) and were recorded to a computer hard drive (500 kHz sampling rate) using an analog-to-digital conversion card (National Instruments 6251) and Logger 2000 Software (http://www.ifaw.org/sotw).

Signal processing was performed using XBAT (http://xbat.org) and custom routines in MATLAB (The MathWorks, Natick, MA). All pulsed signals were manually detected by inspecting spectrograms in 5 s windows and delineated using XBAT. Precise start times, end times, and duration of each signal were computed using the Teager energy algorithm described by Soldevilla *et al.* (2008). Recordings were digitally filtered with a 10-pole Butterworth band-pass filter (3 – 200 kHz). Spectra of each detected pulsed signal were calculated using 2.05 ms of data and a 1 024 point Hann window centered on the signal. Sounds with a signal-to-noise (SNR) ratio of less than 5 dB were discarded. Peak frequency was extracted as the frequency with the highest amplitude within each signal spectrum. Detections with peak frequencies below 10 and above 40 kHz were not further considered in the analysis overall temporal and spectral properties suggested they were noise. A Gaussian mixture model with two mixtures was fitted to a peak frequency histogram to describe distinct peaks in the distribution. Center frequency and bandwidth were calculated according to the definition by Au (1993). Click trains in which all clicks within a train had been measured were selected for measurement of interclick interval (ICI). The ICI was calculated for a subset of 32 click trains by measuring the time between subsequent pulsed signals within a train using the spectrographic display.

3. Results

A single-species encounter with Longman's beaked whales on August 31, 2010 (28.0792° N, -173.40° W) provided recordings used for description and characterization of vocalizations. Confirmation that the detected group consisted of only Longman's beaked whale was made by experienced visual observers during the 2.5 h spent in the immediate area; no other sightings were made within 100 km of this detection. Group size was estimated to be 88 individuals, including ~3 – 5 calves. This group showed a relatively high level of surface activity, and although they did exhibit evasive behavior relative to the ship, including splitting into subgroups, this behavior was less dramatic than is typically observed with this species (R. Rowlett, personal communication). Animals within this group were noted to dive synchronously; however, dive intervals were described as "short" by an observer familiar with Longman's beaked whale (R. Rowlett, personal communication), suggesting that these may have been shallow dives.

A total of 312 echolocation clicks were detected. Of those, 69 pulses contained frequency modulation (FM) and 243 short clicks showed no indication of a FM structure. We use of the term "clicks" to describe short-duration sounds devoid of FM structure and "pulses" to describe longer-duration sounds with a FM sweep. Two categories of short clicks (15 and 25 kHz) were based on the two mixtures of the Gaussian mixture model over the peak-frequency distribution, with a split at 19 kHz. The 15 kHz click showed a strong peak at 15.5 kHz, and median Teager-energy duration of 181 μs [$n = 107$, Fig. 1(a), Table 1]. The peak for the 25 kHz click was at 25.3 kHz,

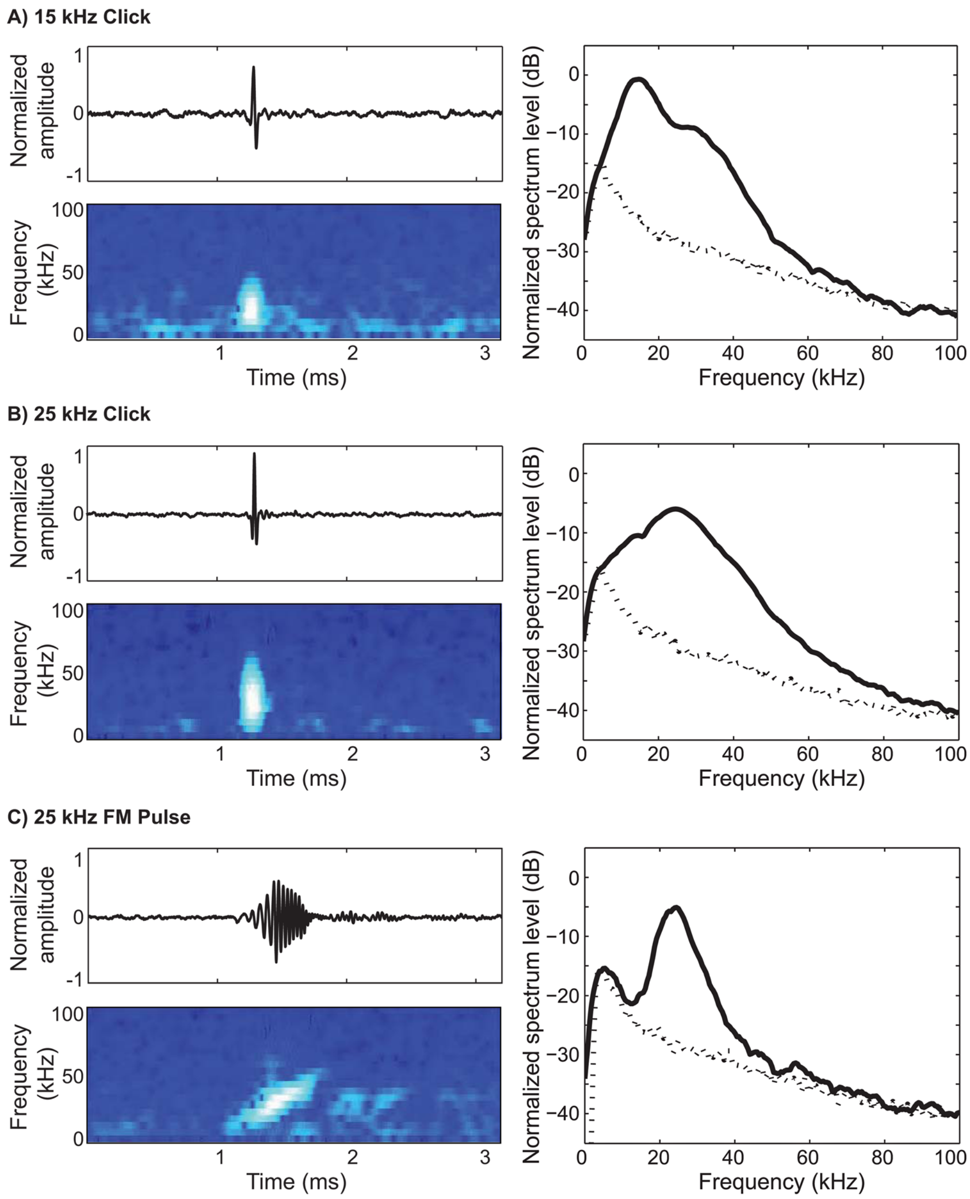

Fig. 1. (Color online) Sounds attributed to Longman's beaked whale, including: (a) 15 kHz click, (b) 25 kHz click, and (c) 25 kHz frequency-modulated (FM) pulse. For each type, waveform (with normalized amplitude versus time), spectrogram (100 points FFT, 99% overlap), and normalized mean spectra (solid line is click amplitude, dashed line is normalized ambient amplitude; 10-pole Butterworth bandpass filter 3–200 kHz) are given.

with median Teager-energy duration of 144 μs [$n = 136$; Fig. 1(b), Table 1]. The 15 and 25 kHz clicks were the extreme ends of a continuous spectrum where clicks could have one or both peaks in varying degrees of intensity. An upswept FM pulse was identified that was centered around 25 kHz with a median sweep rate of 19.8 kHz/s and a median duration of 288 μs [$n = 69$; Fig. 1(c), Table 1]. Both of the shorter click types could appear within one click train, whereas FM pulses were not observed mixed with either short click type. Echolocation trains ($n = 32$) were measured for ICI; each click train included between 3 and 17 clicks or FM pulses. Interclick intervals varied

Table 1. Signal characteristics (median values and 80% confidence intervals) for three types of Longman's beaked whale clicks and pulses.

Parameter	Unit	15 kHz Click ($n = 107$)		25 kHz Click ($n = 136$)		25 kHz FM[a] pulse ($n = 69$)	
		Median	(10%–90%)	Median	(10%–90%)	Median	(10%–90%)
Peak frequency	kHz	15.1	(12.7–18.0)	25.4	(20.1–37.7)	24.7	(20.8–29.8)
Center frequency	kHz	18.6	(15.3–23.8)	24.6	(19.5–30.6)	23.9	(21.2–27.3)
−3 dB bandwidth	kHz	9.8	(6.8–18.0)	13.2	(7.8-–22.9)	6.9	(4.4–8.8)
−10 dB bandwidth	kHz	19.3	(11.8–34.2)	28.1	(16.1–46.9)	12.2	(9.8–19.3)
Teager-energy duration	μs	181	(112–336)	144	(86–314)	288	(178–511)
Sweep rate	kHz/ms	—	—	—	—	19.8	(4.1–43.2)
ICI[b]	s	0.44	(0.25–0.9)	0.51	(0.11–0.93)	0.36	(0.27–0.40)

[a]Frequency modulated.

[b]Interclick intervals.

between 0.1 and 0.9 s, with median ICI of 0.44 s for 15 kHz clicks, 0.51 s for 25 kHz clicks, and 0.36 s for 25 kHz FM pulses (Table 1).

A total of six burst pulses was detected during the single-species encounter on August 31, 2010 (Fig. 2). Burst pulses are pulsed signals with high repetition rates. All burst pulses had a low SNR. Burst pulses ranged from a median low frequency of 10.1 kHz (range 9.2 – 12.3 kHz) to a median high frequency of 18.6 kHz (range 15.2 – 24.2 kHz). Mean peak frequency was 11.7 kHz (range 11.2 – 13.3 kHz). Burst pulses were ∼0.5 s and had a pulse repetition rate of ∼240 s^{-1}. A relatively brief series of low-frequency clicks, with energy ranging approximately from 2 to 6 kHz, was detected during this encounter (Fig. 3). Excessive ship noise associated with

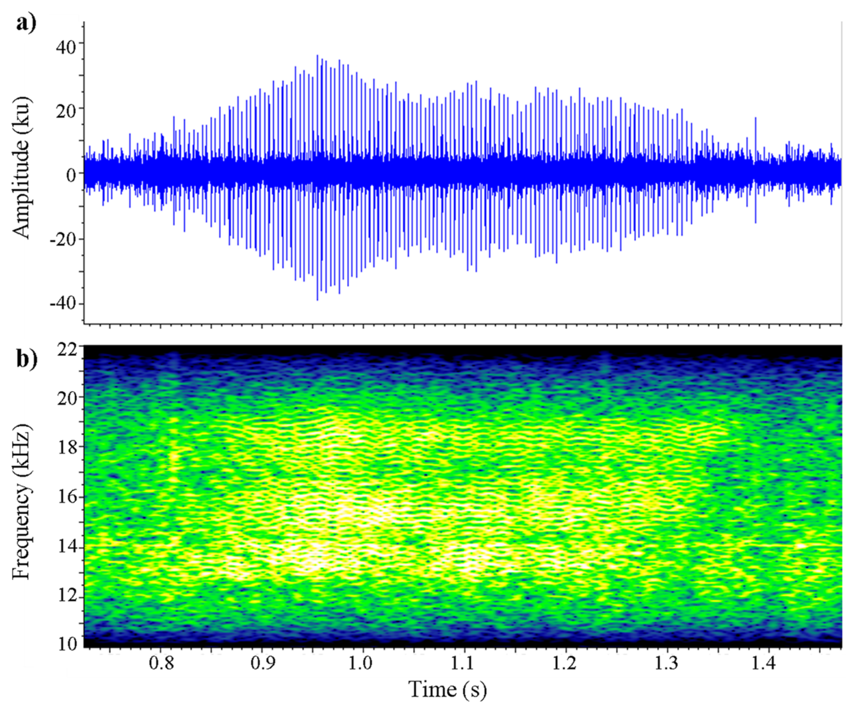

Fig. 2. (Color online) Burst pulse sound recorded in the presence of Longman's beaked whale. Clicks are apparent in the (a) waveform; (b) banding in spectrogram represents click intervals (192 kHz sample rate, 4 096 FFT, Hann window).

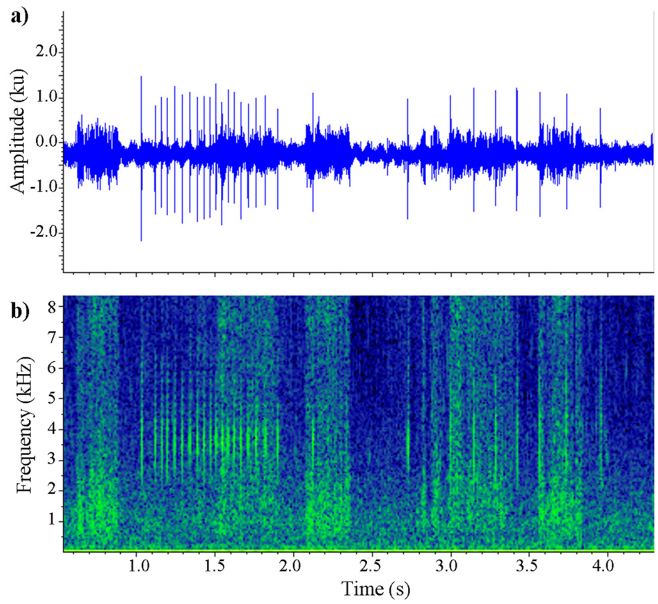

Fig. 3. (Color online) Low-frequency clicks recorded in the presence of Longman's beaked whale. Clicks are apparent in the (a) waveform and (b) spectrogram (192 kHz sample rate, 4 096 FFT, Hann window).

maneuvering precluded measurement of the duration of the signal; the interclick interval was variable, with ICIs ranging between 0.03 and 0.08 s.

4. Discussion

These results show that Longman's beaked whales produce several types of pulsed sounds, including short-duration clicks, long-duration FM pulses, and clicks produced in rapid succession (burst pulses). FM pulses have been described for other beaked whale species and are presumed to be used for echolocation (Johnson *et al.*, 2006). The presence of multiple click and pulse types is similar to what was found for the "Palmyra beaked whale" (Baumann-Pickering *et al.*, 2010), Blainville's beaked whale, *Mesoplodon densirostris* (Johnson *et al.*, 2006), Baird's beaked whale, *Berardius bairdii* (Dawson *et al.*, 1998) and northern bottlenose whale (Hooker and Whitehead, 2002).

Although the frequency structure of click and pulse sounds for Longman's beaked whale overlap with those of other species of beaked whale (e.g., Baird's beaked whale, northern bottlenose whale); they are distinct from the known signals for species with an overlapping distribution in their spectral properties [specifically, Blainville's beaked whales and Cuvier's beaked whale (*Ziphius cavirostris*)]. Likewise, the FM pulses presented here are spectrally and temporally distinct from the FM pulses attributed to beaked whale sounds at Palmyra Atoll (Baumann-Pickering *et al.*, 2010) and Cross Seamount (McDonald *et al.*, 2009). The short 15 and 25 kHz click sounds overlap in peak frequency with click sounds produced by delphinids in the region, such as false killer whales and short-finned pilot whales (S. Baumann-Pickering, personal communication) and may not be useful for species identification. The 25 kHz FM pulses appear to be unique to Longman's beaked whale and may be diagnostic of this species.

Many of the click trains detected were irregular, often containing only a few clicks. A few of the click trains contained both 15 and 25 kHz clicks; some clicks showed bimodal peaks. Peak frequency of directional echolocation clicks has been found to vary according to the angle of orientation (Au, 1993). The frequency spectrum of on-axis echolocation clicks of wild pygmy killer whales (*Feresa attenuata*) was found to be broadband, whereas some off-axis clicks contained one or more frequency peaks (Madsen *et al.*, 2004). Here, the orientation of the animal to the hydrophone is unknown and assumed to be random. It has been argued that the variation based on aspect may be critical in acoustic species identification as off-axis clicks seem to carry species-specific information (Soldevilla *et al.*, 2008). Knowledge about the full spectrum of variability is therefore important. Additional recordings of Longman's beaked whales should verify if these observations are valid for a larger set of data and are specific to this species.

The burst pulses had a low SNR and a lower peak and median frequency than the echolocation clicks. The ICI was consistent throughout the burst pulse, unlike the decreasing ICI found in terminal buzzes in Blainville's beaked whales and the Palmyra beaked whale (Johnson *et al.*, 2006; Baumann-Pickering *et al.*, 2010). These burst pulses had energy in frequency ranges similar to that found in Blainville's beaked whale (Rankin and Barlow, 2007) and Baird's beaked whale (Dawson *et al.*, 1998).

The vocalizations of Longman's beaked whale presented here represent a single encounter, and additional recordings may be needed to fully characterize their sounds. Nonetheless, vocal descriptions of these and other rare species allows for studies of their distribution and abundance in remote regions using autonomous seafloor recordings.

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