Low frequency, ca. 40 Hz, pulse trains recorded in the humpback whale assembly in Hawaii

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Abstract: During studies of humpback whale song and social sounds in Hawaii, bouts of low frequency (ca. 40 Hz) pulses were periodically recorded. One example was made near an active group of eight adults (included 22 bouts, 2–13 s long, over 90 min); another close to an adult male-female pair (12 bouts, 9–93 s long, over 22 min). The mean peak and center frequencies (39 to 40 Hz) and bandwidth (13 Hz) were similar in both, but the organization of the pulses differed. Song components, social sounds, bubble trains, or other species do not provide a ready explanation for this sound.

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1. Introduction

Humpback whales are as active acoustically as any species of whale, and possibly any animal. Known span of sound-use includes the long, complex, and changing songs (Payne and McVay, 1971; Au *et al.*, 2006), a wide array of brief signal or contact phonations collectively known as social sounds (Silber 1986; Dunlop *et al.*, 2007; Stimpert *et al.*, 2011), high energy, group-specific, feeding calls (Cerchio and Dalheim, 2001), sounds from bubble streams and blasts and fluke and flipper slaps (Thompson and Cummings, 1986; Dunlop *et al.*, 2010), and enigmatic nighttime click trains recorded during foraging (Stimpert *et al.*, 2007).

In the course of decade-long studies of humpback whale song and social sounds in Hawaii very low frequency pulse trains were recorded that appeared categorically different from these other reported sounds. The source of these sounds was not verified, although all were recorded in the close presence of humpback whales. The purpose of this report is to introduce and describe the sounds, and encourage further exploration and assessment.

2. Methods

The collection of these sounds was coincidental to recording songs and social sounds. All recordings were made by dipping hydrophones directly from small craft with recording gear consistent throughout the 2005–2013 time-period. Marantz PMD 670 digital recorders (sampling rate: 44.10 kHz), and High Tech HDI 96 min hydrophones (frequency response of 2 Hz to 30 kHz; sensitivity −164.4 dB re: 1 V/uPa) were used. The recorded sounds were analyzed using RAVEN 1.5 software. In this paper, a "pulse" is the most fundamental utterance; a series of pulses is a "bout." Within a bout, the pulses are not evenly spaced but produced in groups termed "packets."

3. Results

3.1 Context of recordings

The recordings were made at the peak of winter assembly of humpback whales in Hawaii, with a high density of whales numbering in the hundreds to thousands in the Auau Channel region between Maui and Lanai. Figures 1(A) and 1(B) illustrate two examples of the low frequency pulse trains, with audio examples Mm. 1 [Fig. 1(A), Track 22, 1–1:20] and Mm. 2 [Fig. 1(B), 2:30–4:00]. The details of the recordings are provided in Table 1; photographs of the whales are in Fig. 2.

Mm. 1. Example audio Fig. 1(A), Feb 12, 2005, Track 22, 0–1:20. File type "wav" (7.5 MB).

Mm. 2. Example audio Fig. 1(B), Mar 8, 2013, 2:30–4:00. File type "wav" (8.6 MB).

Example A: February 12, 2005. Over a 70-min period from 13:10 to 14:20, recordings were made close to a surface-active group of eight adult whales [Fig. 2(A)]. They were involved in high-energy behavior common in this social group typically consisting of one female leading multiple males, travelling at speed, generally in a consistent direction.

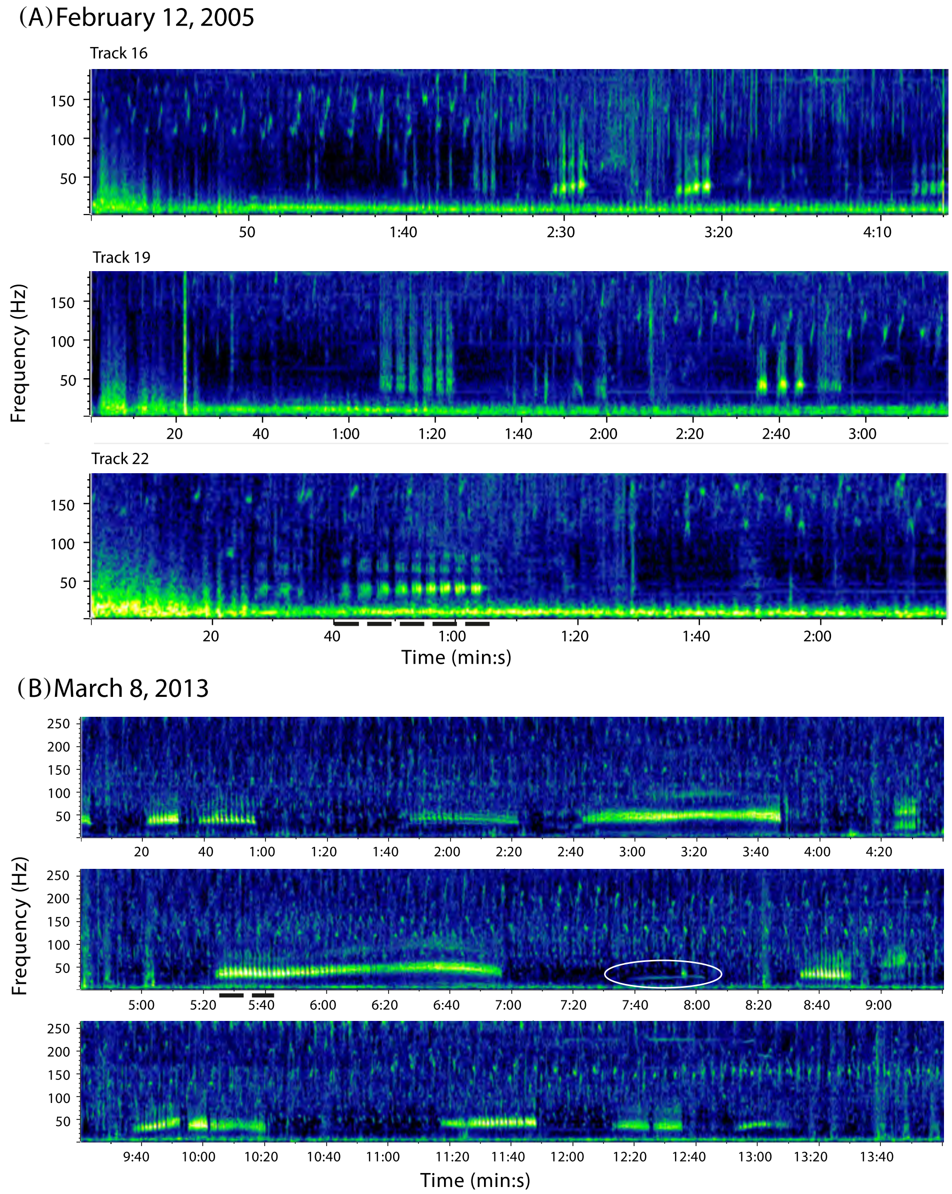

Fig. 1. (Color online) Spectrographs of two examples of low frequency (ca. 40 Hz) pulse trains recorded off West Maui, Hawaii. Example A, 12 February 2005, shows three of nine tracks of recordings made during an encounter with an active group of eight adult humpbacks. Example B, 8 March 2013, is a continuous recording made with a humpback male-female pair circling and passing under the boat. The oval indicates a low frequency (26–27 Hz) sound different from the pulses. The dashed black lines indicate the regions enlarged in Fig. 3. [Spectrograph: Hann window, discrete Fourier transform/fast Fourier transform (DFT/FFT) 32 768, 50% overlap.]

The boat was stationed 500–800 m ahead, engine stopped, hydrophone lowered, and a recording made until the group passed by—generally within 100 m. During the encounter the low frequency pulses were recorded on eight of the nine passes, with recordings ranging from 1 min to 4 min 30 s for a total time of 23 min 23 s (Table 1). All tracks also recorded typical social sounds and song, and on most, the physical slap sounds as whales hit each other.

Example B: March 8, 2013. At approximately 10:30, a pair of adult whales (male and female) approached and circled the 60-ft. vessel [Fig. 2(B)]. (The female lighter-colored and unscarred versus the male darker and scarred; underwater video of genital area clearly showed the lobe characteristic of female.) Underwater observation also revealed a third whale on the periphery that was, at one point, chased off by the male in the pair. The whales oriented to the boat, approached and swam under, then circled again and re-approached, at times the female ventral side up.

The recording was 22 min 17 s long; 13 bouts of the low frequency pulses, ranging from 9 to 93 s in length occurred during the first 13 min 11 s of the recording. No sounds were heard in the remaining time.

Fig. 2. (Color online) Photographs of the whales closest to the hydrophone during the recordings. (A) 12 February 2005, shows some of the whales (others underwater) in the active group. (B) 8 March 2013, shows the male-female pair (female below). The hydrophone is hanging from the corner of the boat (photo: J. Sturgis).

Underwater video was taken during this recording session. The 27 min 38 s video (with 23 clips ranging from 17 s to 2 min 35 s in length) overlapped the recording time of 22 min 17 s. While the video had no sound, it allowed a view of whale activity as sounds were being recorded, and importantly, a record of any bubble production that could, conceivably, have accounted for the sounds. During the 27 min 38 s both animals were in the video frame for all but 3 min. There was no external bubble evidence of the 9–93 s sound bouts.

3.2 Change in intensity of the bouts

The change in relative sound intensity, depicted by the boldness of the signal in the spectrograms (Fig. 1), largely match the behavior of the whales in relation to the hydrophone. In example A the recordings started with the whales more distant, with the change in intensity of the sounds in tracks 16, 19, and 22 reflecting their approach and, in the case of track 16 departure, as they passed by the hydrophone. In example B the whales approached, swam directly underneath and past the hydrophone before circling back for another pass. In this recording, the range of intensity was consistent with the whales making these repeat passes.

3.3 Characteristics of sounds

The sounds are produced in bouts or pulse trains of variable length, with gaps of quiet between them (Fig. 1, Table 1). In example A, on the eight tracks of recording, there were 22 bouts of sound ranging from 2 to 23 s in length [$n = 22$, $M = 10 \pm 2$ (95%), $MD = 9$] with inter-bout interval of 3–71 s ($n = 14$, $M = 23 \pm 12$ (95%), $MD = 15.5$). On one recording track 130 s long, no bouts were recorded. In example B, in the continuous recording of 1337 s (22 min 17 s) there were 12 full bouts and one partial (recording started mid-bout lasting 3 more seconds) ranging from 9 to 93 s [$n = 12$, $M = 32 \pm 16$ (95%), $MD = 21$] with gaps 6 to 96 s [$n = 12$, $M = 34 \pm 16$ (95%), $MD = 22$]. In this example, after the last sound bout the recording continued for 586 s (9 min 46 s) without further sounds.

The signal parameters (mean Hz $\pm$ 95% CL) of the two examples are given in Table 2. The values are strikingly similar between the February 12, 2005 and March 8, 2013 examples, with center frequencies of 40 ± 3.3 Hz and 39 ± 4.0 Hz, and peak frequencies of 40 ± 3.9 Hz and 39 ± 4.3 Hz, respectively.

In both examples a bout of sound was composed of "packets" of pulses, as illustrated in Fig. 3. However, the organization of the packets and number of pulses in each appears different between the two.

Table 1. Recording details of low frequency pulse bouts in the February 12, 2005 and March 8, 2013 examples (see Fig. 1).

			Bout timing (s)		
Track No.	Rec. length (min:s)	Bout No.	Begin–end	Duration	Time to next
Example A: February 12, 2005					
15	1:00	1	28–34	6	
16	4:30	1	120–128	8	18
		2	146–157	12	28
		3	185–196	11	64
17	2:18	1	45–53	8	23
		2	76–78	2	32
		3	110–121	11	
19	3:20	1	67–84	17	71
		2	155–166	11	3
		3	169–174	5	
21	1:45	1	76–82	7	13
		2	95–101	6	
22	2:20	1	27–35	8	6
		2	41–64	23	
23	3:05	1	36–48	12	22
		2	70–89	19	11
		3	100–107	7	
25	3:05	1	72–86	14	13
		2	98–110	12	7
		3	127–133	6	5
		4	138–144	6	
26	2:10	0	112–131	19	
Example B: March 8, 2013					
03	22:17	1	0–3	3	18
		2	21–32	11	6
		3	38–57	19	50
		4	107–142	35	20
		5	162–227	65	36
		6	263–272	9	52
		7	324–417	93	96
		8	513–530	17	9
		9	539–557	18	20
		10	577–622	45	55
		11	677–708	31	24
		12	732–755	23	18
		13	773–791	18	586 +

In the February 12, 2005 example [Fig. 3(A)], the 23 s bout included nine packets of sound (length 1.5–2 s) and each packet had a variable number of pulses ranging from 2 to 5 (each 0.4 s in length). So, this bout had nine packets of sound each with 4, 5, 4, 4, 3, 3, 3, 3, 3 pulses, respectively, for a total of 32 pulses. Other bouts from this example indicate that the number of packets and pulses in a bout may vary [see Fig. 1(A)].

Table 2. Signal parameters (mean ± 95% CL) for pulse bouts recorded in the humpback winter assembly in Hawaii, February 12, 2005 and March 8, 2013.

	A: Feb. 9, 2005	B: Mar. 8, 2013
	n = 22	n = 13
Center frequency (Hz)	40 ± 3.3	39 ± 4.0
Bandwidth (Hz)	13 ± 2.5	13 ± 4.3
Frequency 5% (Hz)	34 ± 2.1	32 ± 2.6
Frequency 95% (Hz)	47 ± 4.1	45 ± 4.5
Peak frequency (Hz)	40 ± 3.9	39 ± 4.3

The March 8, 2013 example [Fig. 3(B)] is different, in that the 28 s bout contained 13 packets of sound (1.3 s length) each with two pulses (each 0.6 s long) equaling 26 pulses. In another segment from this recording, similarly a 20 s bout had 14 packets (1.3 s length) each with two pulses (0.6 s long) for 28 pulses total. Each bout in the March 8 example was continuous and contained a number of packets of consistent duration, each composed of two pulses, while in the February 12 example a bout was broken into packets of different length and number of pulses.

3.4 Other low frequency sounds

Another "type" of low frequency sound was present in the 8 March 2013 recording, from the 7 min 40 s to 8 min points, designated by the oval [Fig. 1(B)]. This sound was continuous for 25 s with a peak frequency of 26–27 Hz, well below the peak frequency of the pulse trains described above.

4. Discussion

While there are a myriad of sound sources in the region, the simplest explanation is that these were sounds generated by the humpback whales closest to the recorder and involved in breeding behavior patterns. The strongest support for this view is that the whales were within tens of meters from the recording boat, and the patterns of changing intensity of sound in both examples matched the observed approach or departure

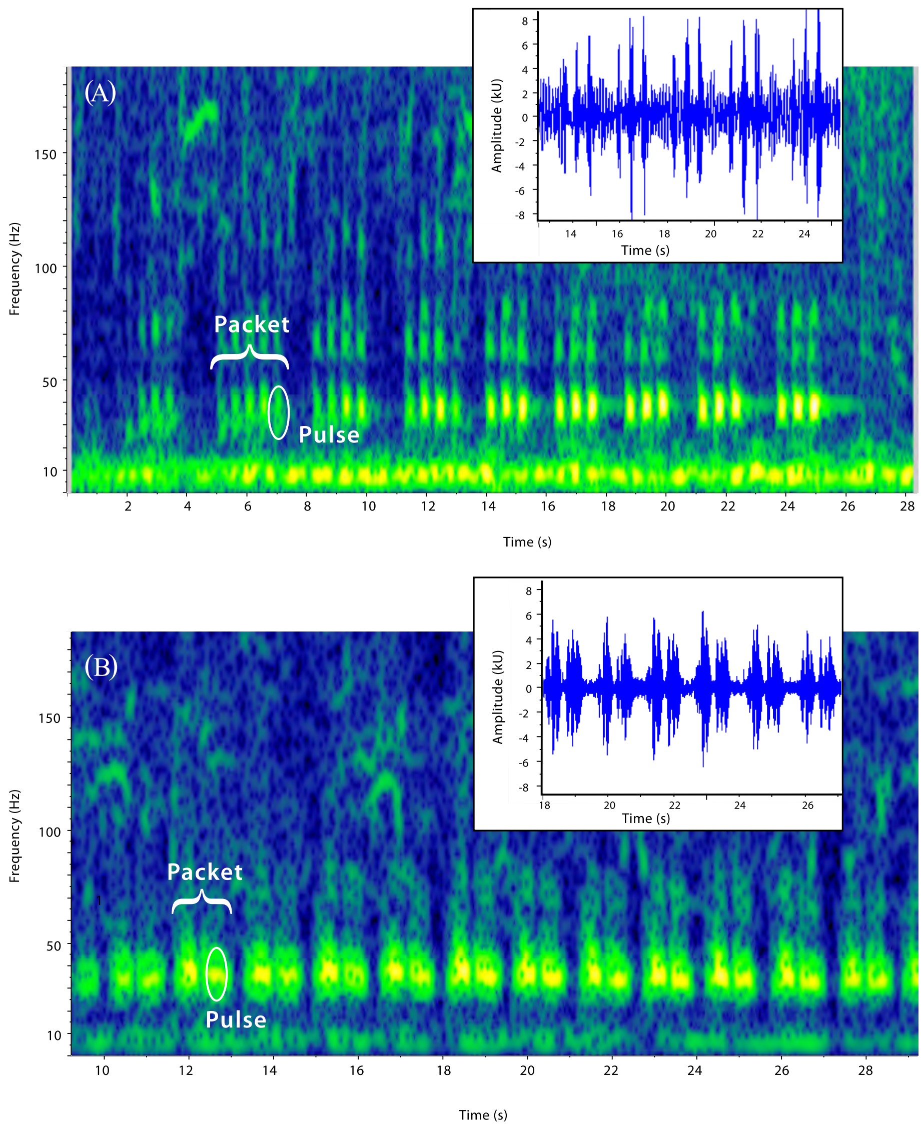

Fig. 3. (Color online) Enlarged portions of the pulses and sample waveforms (insets): (A) from tract 22, 12 February 2005 [Fig. 1(A)] and (B) from beginning of bout at 5 min 25 s of the 8 March 2013 recording [Fig. 1(B)]. These locations are marked with black dashes in Fig. 1. The "packets" of sound and pulses are indicated. (Spectrograph: Hann window, DFT/FTT 16 386, 50% overlap.)

movements of the whales in relation to the stationary hydrophone. Other cetacean species were not known to be present during the recordings.

Potentially similar low frequency pulse sounds were recorded from hydrophones moored off Oahu, Hawaii in 1979–1981 (Thompson and Friedl, 1982). In this study the second of two sounds tentatively attributed to finback whales were described as "trains of short pulses in the 30–90 Hz band range." The authors noted the source could be another species. From the available spectrograph and recording date information the similarity between these and the pulses reported here is intriguing.

The question arises as to whether the low frequency (ca. 40 Hz) pulses are a part of the humpback whale's song and social sound repertoire, or if they are a different "genre" entirely. Most currently described social sounds and song units are discrete phonations rather than pulse trains, and occur at a frequency double or more (80 Hz–4 kHz) that of the sounds in question (Silber, 1986; Dunlop *et al.*, 2007; Tyack and Clark, 2000; Au *et al.*, 2006, Stimpert *et al.*, 2010). Even the "megapclicks," the pulses of broadband sound recorded during humpback foraging, ranged from 800–1700 Hz (Stimpert *et al.*, 2007). However, a few social sounds, song phrases, and bubble stream sounds do approach some of the parameters and general patterns of these pulses, potentially confounding this question.

On review, these other sources do not provide a ready explanation for the pulses. Some song units and social sounds are reported to dip to 30 Hz and may occur in series (Payne and Payne, 1985; Dunlop *et al.*, 2007). In order to be confused with these pulse trains, they would have to occur outside of the song context and be heard at sufficient distance to mask discreteness. Of 34 social sounds described by Dunlop *et al.* (2007) the closest to the sounds in question were "repetitive short grunt sounds in bouts" with a minimum frequency of 43 Hz. However, these are discrete units with peak frequency 74.8 Hz, near double that of the pulse trains. Bubble streams, described as 25–80 Hz pulse trains (Thompson *et al.*, 1986) offer another explanation, however, are typically far more broadband signals (45–1250 Hz, Thompson *et al.*, 1986; 45 Hz to >10 KHz, Dunlop *et al.*, 2007) than the pulses. More definitively, underwater video in the March 2013 example showed no bubble streams as sounds were produced.

It is possible that humpback whales produce low frequency pulse-trains, and other calls, well below that of most typical song and social sounds. Many questions arise, not least being, if it is a form of communication, who produces the signal and who is the intended receiver? Is it part of the extensive male repertoire of sounds; or is it female communication in an acoustic niche avoiding the high male-generated noise levels of the winter assembly?

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References and links

Au, W. W. L., Pack, A. A., Lammers, M. O., Herman, L. M., Deakos, M. H., and Andrews, K. (**2006**). "Acoustic properties of humpback whale songs," J. Acoust. Soc. Am. **120**, 1103–1110.

Cerchio, S., and Dahlheim, M. (**2001**). "Variation in feeding vocalizations of humpback whales, *Megaptera novaeangliae*, from Southeast Alaska," Bioacoustics **11**, 277–295.

Dunlop, R. A., Cato, D. H., and Noad, M. J. (**2010**). "Your attention please: Increasing ambient noise levels elicits a change in communication behavior in humpback whales (*Megaptera novaeangliae*)," Proc. R. Soc. London, Ser. B **227**, 2521–2529.

Dunlop, R. A., Noad, M. J., Cato, D. H., and Stokes, D. (**2007**). "The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*)," J. Acoust. Soc. Am. **122**, 2893–2905.

Payne, R., and McVay, S. (**1971**). "Songs of humpback whales," Science **173**, 585–597.

Payne, K., and Payne, R. (**1985**). "Large scale changes over 19 years in songs of humpback whales in Bermuda," Z. Tierpsychol. **6**, 89–114.

Silber, G. K. (**1986**). "The relationship of social vocalizations to surface behavior and aggression in the Hawaiian humpback whale, *Megaptera novaeangliae*," Can. J. Zool. **64**, 2075–2080.

Stimpert, A. K., Au, W. W. L., Parks, S. E., Hurst. T., and Wiley, D. N. (**2011**). "Common humpback whale (*Megaptera novaeangliae*) sound types for passive acoustic monitoring," J. Acoust. Soc. Am. **129**, 476–482.

Stimpert, A. K., Wiley, D. N., Au, W. W. L., Johnson, M. P., and Arsenault, R. (**2007**). "'Megapclicks': Acoustic click trains and buzzes produced during night-time foraging of humpback whales (*Megaptera novaeangliae*)," Biol. Lett. **3**, 467–470.

Thompson, P. O., Cummings, W. C., and Ha, S. J. (**1986**). "Sounds, source levels, and associated behavior of humpback whales, Southeast Alaska," J. Acoust. Soc. Am. **80**, 735–740.

Thompson, P. O., and Friedl, W. A. (**1982**). "A long term study of low frequency sounds from several species of whales off Oahu, Hawaii," Cetology **45**, 1–19.

Tyack, P. L., and Clark, C. W. (**2000**). "Communication and acoustic behavior of dolphins and whales," in *Hearing by Whales and Dolphins*, edited by W. W. L. Au, A. N. Popper, and R. R. Fay (Springer-Verlag, New York), pp. 156–224.