

# Patterned burst-pulse vocalizations of the northern right whale dolphin, *Lissodelphis borealis*

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Vocalizations from the northern right whale dolphin, *Lissodelphis borealis*, were recorded during a combined visual and acoustic shipboard survey of cetacean populations off the west coast of the United States. Seven of twenty single-species schools of *L. borealis* produced click and pulsed vocalizations. No whistles were detected during any of the encounters. Clicks associated with burst-pulse vocalizations were lower in frequency and shorter in duration than clicks associated with echolocation. All burst-pulse sounds were produced in a series containing 6–18 individual burst-pulses. These burst-pulse series were stereotyped and repeated. A total of eight unique burst-pulse series were detected. Variation in the temporal characteristics of like units compared across repeated series was less than variation among all burst-pulses. These stereotyped burst-pulse series may play a similar communicative role as do stereotyped whistles found in other delphinid species. © 2007 Acoustical Society of America. [DOI: 10.1121/1.2404919]

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## I. INTRODUCTION

The northern right whale dolphin, *Lissodelphis borealis*, is a slender, elongated delphinid species distinguished by the lack of a dorsal fin and is endemic to the North Pacific. It is one of the more abundant species in its range, which extends from Baja California to Alaska in the eastern Pacific and from Japan to the Aleutians in the western Pacific (Baird and Stacy, 1991). The population size off the west coast of the United States has been estimated as 20 632 (CV=0.26, Barlow, 2003). *Lissodelphis borealis* schools range from single animals to groups of greater than 2000 individuals, with average group sizes of approximately 100–200 animals (Rice, 1998; Jefferson *et al.*, 1994). They often associate with other species, particularly Pacific white-sided dolphins (*Lagenorhynchus obliquidens*).

Despite their relatively high abundance, little is known about the biology, behavior, or vocalizations of *L. borealis*. Vocalizations produced by other delphinids include whistles, burst-pulses, and echolocation clicks (Thomson and Richardson, 1995). The few acoustic recordings of *L. borealis* that have been reported in the literature include all three of these vocalization types (Fish and Turl, 1976; Leatherwood and Walker, 1979). The bulk of the reported vocalizations were echolocation clicks with energy that extended beyond the frequency sensitivity of the recording equipment (40 kHz).

In the fall of 2001, a combined visual and acoustic survey of cetaceans was conducted off the west coast of the United States (Appler *et al.*, 2004). During this survey, twenty single-species groups of *L. borealis* were encoun-

tered. Vocalizations were detected from seven of these groups, providing a unique opportunity to gain insight into the vocal behavior of this species. This paper describes the characteristics of individual vocalizations and series of vocalizations recorded during these seven encounters with *L. borealis*.

## II. METHODS

The ORCAWALE 2001 research survey combined visual line-transect and acoustic methods on the NOAA ship R/V *David Starr Jordan* to study cetacean populations within the exclusive economic zone off the west coast of Oregon, California, and Washington. Visual methods consisted of a team of three experienced visual observers searching with “big-eye” 25×150 power binoculars, 7× binoculars, and unaided eye (Appler *et al.*, 2004). All visual sightings were approached for accurate species identification and group size estimation.

A five-element hydrophone array (Sonatech, Inc., Santa Barbara) was towed at a depth of 2–4 m, 200 m behind the ship at 10 knots during daylight hours. The hydrophone array had a flat frequency response from 1.5 to 40 kHz ( $\pm 4$  dB at  $-132$  dB re  $1 \text{ v}/\mu\text{Pa}$  after internal amplification). Signals from the array were sent through a Mackie CR1604-VLZ mixer for equalization. Vocalizations detected on all hydrophones were recorded to a Tascam DA-38 eight-channel digital recorder (sample rate 48 kHz). Simultaneous (but not continuous) broadband recordings were made directly to a computer hard disk (sample rate 250 kHz) after being filtered

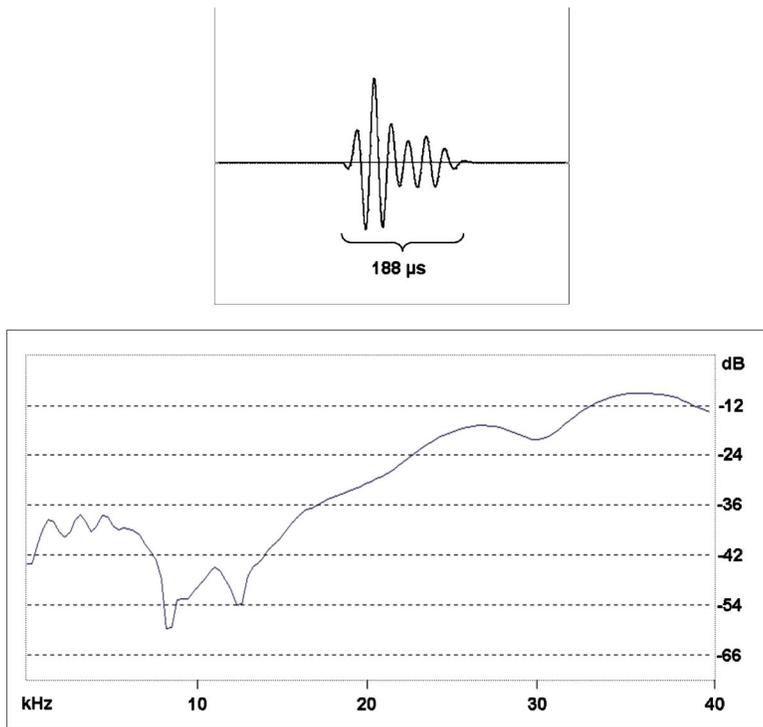


FIG. 1. Waveform and frequency spectrum of *Lissodelphis borealis* echolocation click. Orientation of the sound source relative to the hydrophone is unknown and is likely off-axis. Sample rate 250 kHz, 512 FFT size, 25% overlap.

at the Nyquist frequency (125 kHz) using an Avens Model 4128 band pass filter. Hard disk recordings were digitized using an analog-to-digital conversion card (National Instruments DAQCard-6062E) and automatic recording function within ISHMAEL, a real-time digital signal processing program (Mellinger, 2001).

Only recordings from confirmed single-species groups of *L. borealis* were included in the analysis. In addition, vocalizations were localized using ISHMAEL's beamforming function to ensure that the recorded vocalizations were produced by the observed animals. High quality echolocation click trains and burst-pulses were chosen from broadband digital recordings to examine characteristics of individual vocalizations. Vocalizations were considered to be high quality if they were greater than 9 dB above ambient noise. Given our sampling rate, the Nyquist frequency (125 kHz) greatly exceeded the upper bandwidth of our hydrophone (40 kHz), allowing us to better resolve the waveform of the clicks. However, the sensitivity of our hydrophones drops off dramatically above 40 kHz and it is probable that additional peaks in energy occur above 40 kHz. Individual clicks were measured using a MATLAB signal processing algorithm written by Lammers *et al.* (2004). Variables measured from individual clicks include: Peak frequency (Hz), 3 dB bandwidth (Hz), 10 dB bandwidth (Hz), and click duration (ms). In addition, inter-click interval (ms) and click train duration (ms) were measured from individual burst-pulses.

Individual burst-pulses always occurred in consistent, repeated patterns of six or more burst-pulse units. These repeated burst-pulse series were examined to compare the characteristics of a particular burst-pulse against the same unit in a successive burst-pulse series. Presence of the burst-pulse series was examined using the continuous Tascam recordings, which offered localization options using the phone-pair bearing algorithm in ISHMAEL (Mellinger, 2001).

Measurements of variation for a sample burst-pulse series were taken from the broadband recordings.

### III. RESULTS

Twenty single-species schools *L. borealis* were sighted during the ORCAWALE 2001 survey. Vocalizations were recorded from seven of these sightings, including 28 min of broadband digital recordings (250 kHz sample rate) from five sightings and 162 min of Tascam recordings (48 kHz sample rate) from seven sightings. Group sizes of nonvocal sightings of *L. borealis* ranged from 2 to 15 animals ( $n=13$ , mean=7.2); group sizes of vocal sightings of *L. borealis* ranged from 6 to 63 animals ( $n=7$ , mean=27.3).

A total of 1142 echolocation clicks were measured from the broadband digital recordings (Table I). Peak frequency of echolocation clicks was 31.3 kHz (SD=3.7 kHz), and the maximum frequency ranged above the 40 kHz high-frequency response of the recording system. The waveform and spectrum of a typical echolocation click is shown in Fig. 1. Mean click duration for echolocation clicks was 0.31 ms (SD=0.08) (Table I).

TABLE I. Summary statistics (mean, standard deviation, minimum, and maximum) for individual echolocation clicks ( $n=1,142$ ) recorded from *Lissodelphis borealis*.

	Peak frequency (Hz)	Bandwidth (Hz)		Click duration (ms)
		3 dB	10 dB	
<b>Mean</b>	31 340	9411	18 891	0.31
<b>Standard Deviation</b>	3660	2895	5198	0.08
<b>Minimum</b>	23 193	4639	8301	0.09
<b>Maximum</b>	41 016	21 729	33 447	0.63

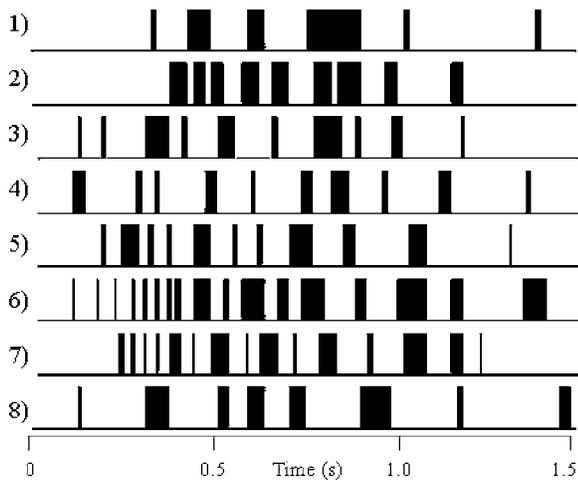


FIG. 2. Graphical representation of eight unique stereotyped burst pulse series encountered during this research. The width of the burst pulse units (black) and intervals (white) are proportional to the durations of each.

A total of 2974 clicks from 129 burst-pulses were measured from the broadband digital recordings (Table II). The mean peak frequency of burst-pulse clicks was 18.2 kHz (SD=5.5 kHz), with a 10 dB bandwidth greater than 22 kHz (mean=22.7 kHz, SD=7.0 kHz). The mean individual click duration was 0.18 ms (SD=0.06). The burst-pulse duration varied from 0.18 to 1.3 s, and burst-pulses were composed of between 2 and 159 individual clicks (Table II).

All burst pulses detected in these recordings occurred in a series, where each series was composed of 6–18 individual burst-pulse units. A total of eight unique stereotyped burst-pulse series were detected during the 162 min of Tascam recordings (Fig. 2), and most series were repeated in succession (Fig. 3). Based on our localizations, we determined that no more than one of the stereotyped burst pulse series was attributed to a single subgroup within a sighting. We could not determine whether the same individual was producing each stereotyped series. Some variation did exist among repetitions and included changes in one or more individual units within the series (Fig. 4).

One repeated burst-pulse series was chosen for closer examination of this variability. Ten units [Figs. 4(a)–4(j)], were present within this stereotyped burst pulse series. Ten variables (Table III) were measured to characterize each unit from up to eight of these repeated series (signal quality did not allow all measurements to be made on all units in each series). Analysis of variance (ANOVA) on each type of mea-

surement indicates that none of the frequency measures (peak frequency, center frequency, and three different measures of bandwidth) varied significantly among the units ( $p > 0.05$ ). Most temporal characteristics (click interval, burst-pulse duration, clicks per burst pulse, and burst-pulse interval) did vary significantly among units ( $p < 0.0001$ ), but click duration did not ( $p = 0.066$ ).

#### IV. DISCUSSION

The study of broadband clicks produced by free ranging delphinids in offshore habitats is challenging due to the highly directional nature of these sounds as well as bandwidth limitations of recording equipment. Temporal, frequency, and amplitude characteristics of clicks vary depending on the orientation of the animal relative to the hydrophone (Au, 1993). In experiments with captive animals on bite plates it is possible to ensure that signals are recorded on-axis. This is difficult, if not impossible, in free ranging situations due to rapid changes in the orientation of the animals and difficulty in identifying which animal in a group is vocalizing. However, while controlled experiments with trained animals provide important data about signal characteristics and sonar capabilities, they do not allow a full understanding of the function and use of these signals in natural habitats. In addition, passive acoustic techniques are increasingly being utilized as a method to monitor cetacean populations (Goold, 1998; Rankin and Barlow, 2005; Stafford *et al.*, 2001). The ability to identify species based on their vocalizations is imperative in these situations, and this is especially important for species such as *L. borealis* for which very few descriptions of vocalizations exist and the likelihood of a controlled study in captivity is small. Despite the limitations of *in situ* recordings from wild dolphins, these data are essential in learning to distinguish dolphin species using their vocalizations.

A previous description of free-ranging *L. borealis* vocalizations included two types of whistles recorded in the presence of a small group of *L. borealis* (Leatherwood and Walker, 1979). A high frequency whistle at 16 kHz that appears to “blend in” to a burst-pulse vocalization was noted and several lower frequency whistles were also described. The lower frequency whistles are similar to those produced by *Globicephala* spp. (Rendell *et al.*, 1999), a species that *L. borealis* have been known to associate with (Jefferson *et al.*, 1994). In contrast to the findings of Leatherwood and Walker (1979), acoustic monitoring in the presence of twenty sight-

TABLE II. Summary statistics (mean, standard deviation, minimum, and maximum) for individual clicks ( $n = 2,974$ ) in burst-pulses recorded from *Lissodelphis borealis*.

	Peak frequency (Hz)	Click interval (ms)	Bandwidth (Hz)		Click duration (ms)	Burst pulse Duration (ms)	Clicks per burst pulse
			3 dB	10 dB			
<b>Mean</b>	18 196	1.15	10 275	22 702	0.18	26.98	24.6
<b>Standard Deviation</b>	5543	0.4	3157	7025	0.06	25.68	24.6
<b>Minimum</b>	6348	0.28	5127	9277	0.08	1.34	2
<b>Maximum</b>	37 109	6.46	28 564	48 340	0.51	178.62	159

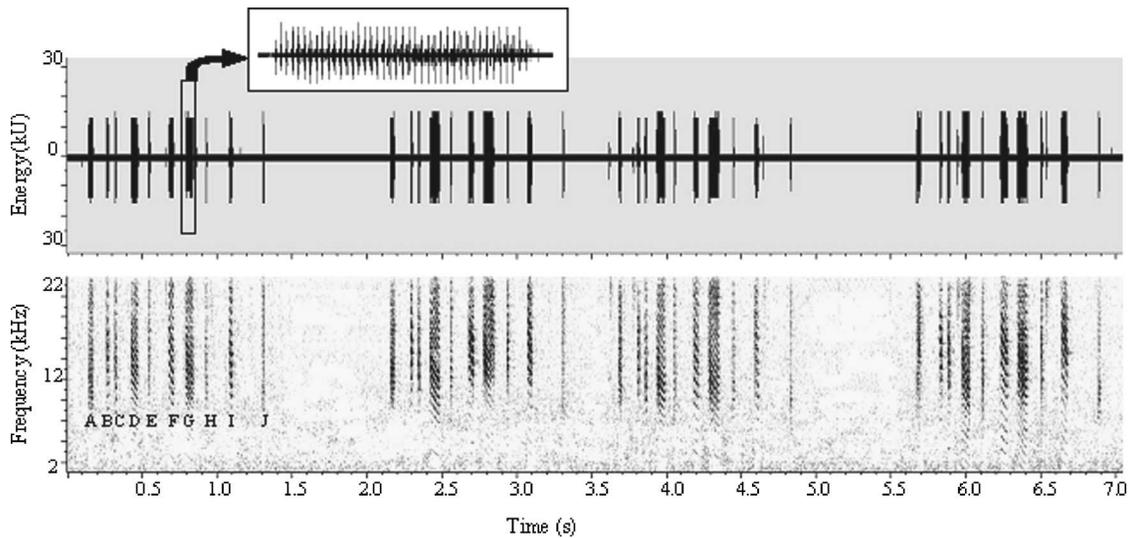


FIG. 3. Waveform and spectrogram of a burst-pulse series repeated four times in succession (Fig. 2, series 4). Inset waveform shows rapid pulsing within individual burst pulses; pulse repetition rate is represented in the frequency banding appearance of the burst pulses in the spectrogram. Individual burst pulse units A–J (Table III) are labeled for the first series. Sampling rate 48 kHz, 512 FFT size, Hann window function.

ings of single-species *L. borealis* schools in this study failed to detect a single whistle. We suggest that the whistles presented in Leatherwood and Walker (1979) may have been produced by another species in the area that was not detected by the research team.

The phylogeny of *Lissodelphis* spp. is not well understood, but they appear to be most closely linked with dolphins of the genus *Lagenorhynchus* and *Cephalorhynchus* under the group Lissodelphinidae (May-Collado and Agnarsson, 2006). *Cephalorhynchus* spp. are not known to produce whistles (Dawson, 1991; Herman and Tavolga, 1980), and a large proportion of the vocalizations recorded in the presence of *Lagenorhynchus* spp. have been click or pulsed sounds. Our research suggests that *Lissodelphis borealis* follows the same trend as other Lissodelphinidae in producing only or predominantly click and pulsed vocalizations.

While bandwidth and logistical constraints in this study prevent detailed descriptions of the click sounds of *L. borealis*,

general trends, and characteristics can be noted. For example, clicks associated with burst-pulses were shorter in duration and had lower peak and center frequencies than those associated with echolocation click trains. This is similar to what has been found in other delphinids and it has been suggested that these burst-pulse sounds may function in communication (Lammers *et al.*, 2004; Dawson, 1991).

The recordings presented in this study allow a general characterization of the vocalizations themselves, but also provide insight into the signaling behavior of *L. borealis*. Previous studies of odontocete vocalizations have found differences in the function of stereotyped calls across taxonomic groups. In dolphins, repeated stereotyped whistles are unique at an individual level (Caldwell *et al.*, 1990; Janik and Slater, 1998; McCowan and Reiss, 2001), while stereotyped discrete calls in *O. orca* are shared between matrilineal groups (Ford, 1991; Miller and Bain, 2000). *P. macrocephalus* codas, on the other hand, appear to function at larger

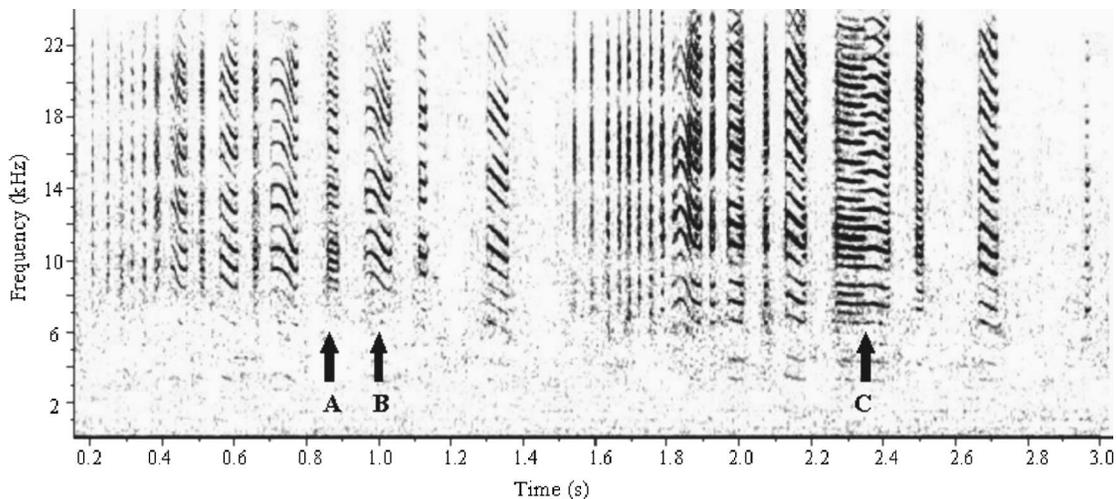


FIG. 4. Variation in burst-pulse series (Fig. 2, series 6). The individual burst-pulse units highlighted by (a) and (b) are replaced by (c) during one of six repeated burst pulse series. Sampling rate 48 kHz, 512 FFT size, Hann window.

TABLE III. Summary statistics for burst-pulse units (identified as A–J) within the repeated burst-pulse series shown in Fig. 1 ( $n=8$ ). The burst-pulse interval is measured from the end of the lettered unit to the beginning of the next lettered unit.

Unit		Sample size	Peak frequency (Hz)	Click interval (ms)	Bandwidth (Hz)		Click duration (ms)	Burst pulse duration (ms)	Clicks per burst-pulse	Burst-pulse interval (s)
					3 dB	10 dB				
A	Mean	6	19 595	1.96	9705	18757	0.16	19.54	9.8	0.115
	Standard Deviation		4867	0.46	1841	5112	0.02	8.23	3.7	0.008
B	Mean	5	17 177	1.10	7707	14 304	0.22	13.18	13.0	0.039
	Standard Deviation		5353	0.75	946	2400	0.08	5.22	2.5	0.004
C	Mean	5	18 804	0.79	8457	16 428	0.18	9.79	12.2	0.085
	Standard Deviation		4958	0.03	1110	2451	0.02	2.17	2.8	0.009
D	Mean	7	17 519	1.13	9449	18 536	0.18	34.84	29.6	0.073
	Standard Deviation		4799	0.18	1131	4119	0.02	14.61	10.8	0.006
E	Mean	8	16 086	0.98	8643	18 811	0.17	9.71	9.1	0.114
	Standard Deviation		5711	0.07	1026	4205	0.02	12.93	11.3	0.007
F	Mean	5	18 165	0.89	8016	15 399	0.20	27.14	31.0	0.071
	Standard Deviation		5559	0.05	1198	2518	0.02	14.57	17.1	0.003
G	Mean	7	17 705	1.11	9161	18 569	0.17	45.74	40.7	0.088
	Standard Deviation		4369	0.10	1061	4178	0.01	12.31	9.3	0.005
H	Mean	7	18 883	1.02	8831	18 248	0.17	11.68	10.7	0.134
	Standard Deviation		6848	0.06	1302	4129	0.02	16.00	13.8	0.013
I	Mean	6	19 152	0.93	7887	16 181	0.19	19.03	20.5	0.209
	Standard Deviation		6873	0.07	883	2961	0.01	10.82	12.0	0.011
J	Mean	6	19 706	1.07	8287	15 675	0.19	13.07	14.0	...
	Standard Deviation		5911	0.18	1157	2330	0.02	13.34	16.3	...

population levels (Watkins and Schevill, 1977; André and Kamminga, 2000). Caldwell and Caldwell (1966) described individual variation in a stereotyped burst-pulse recorded from a captive *Lagenorhynchus obliquidens*, and suggested the existence of a “signature” burst-pulse vocalization. Simple stereotyped burst-pulse vocalizations have also been examined for Risso’s dolphins, *Grampus griseus* (Corkeron and Van Parijs, 2001). However, the repeated series of burst-pulses presented here appear to be complex stereotyped patterning of burst-pulses that has not been previously described in cetaceans.

Each unique burst pulse series detected during this survey were localized to the same subgroup of animals within a sighting. Therefore, a particular burst pulse series was produced by either a single individual or by the different individuals within a given subgroup. Specific burst pulse series were not detected in more than one sighting or more than one subgroup within a sighting. Our research suggests that *L. borealis* do not whistle, and that the stereotyped burst-pulse series that they do produce may serve the same communicative function as the stereotyped whistles produced by other delphinids or the stereotyped discrete calls found in *O. orca*.

While our research presents the existence of repeated patterns of stereotyped burst pulses in *L. borealis*, we can only speculate as to the behavioral function of these vocalizations. Future research should examine these burst pulse series to determine if they are unique to individuals, suggesting the possibility of a behavioral context similar to the repeated stereotyped whistle produced by other small dolphins, or if burst pulse series are shared by other related individuals, suggesting a behavioral context similar to the discrete calls of killer whales.

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