



## Notes

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### Bryde's whale calls recorded in the Gulf of Mexico

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Bryde's whales (*Balaenoptera edeni*) inhabit tropical and subtropical waters worldwide and, unlike most other mysticetes, they are not thought to make long seasonal migrations (Jefferson *et al.* 2008). They are the only balaenopterid regularly found in the U.S. waters of the Gulf of Mexico (GOM), with their range likely constrained to the shallow, northeastern part of the GOM around DeSoto Canyon (Maze-Foley and Mullin, 2006). Bryde's whales are likely the smallest population of cetaceans in the region (Maze-Foley and Mullin, 2006). While it is possible Bryde's whales are present in this area year-round as four reported strandings have been recorded across seasons (Mead 1977, Jefferson and Schiro 1997, Würsig *et al.* 2000), visual surveys have been conducted only during the spring (Waring *et al.* 2009).

National Oceanographic and Atmospheric Administration (NOAA) Fisheries has been conducting regular marine mammal surveys in the GOM since the 1990s. The number of Bryde's whales in the U.S. Exclusive Economic Zone (EEZ) was estimated at 35 (CV = 1.10) between 1991 and 1994 (Hansen *et al.* 1995), and 40 (CV = 0.61) between 1996 and 2001 (Mullin and Fulling 2004). Based on the most recent surveys conducted in 2003 and 2004, Bryde's whale population in the US EEZ in the GOM is estimated at 15 (CV = 1.98) individuals (Mullin 2007). It has been suggested that the GOM population is a distinct stock, but no evidence exists to confirm their separation from the nearby southern Caribbean or Atlantic stocks (Waring *et al.* 2009).

Bryde's whales produce a variety of call types in different geographic regions and it has been suggested calls may delineate different stocks (Oleson *et al.* 2003). Distinct low frequency (60–950 Hz) pulses, tonals, and moans have been described for free-ranging Bryde's whale adults and calves in the Eastern Tropical Pacific (ETP), the Gulf of California, southern Caribbean, and the North Pacific (Cummings *et al.* 1986, Edds *et al.* 1993, Oleson *et al.* 2003, Heimlich *et al.* 2005, Kerosky *et al.* 2012).

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No calls have been described previously for free-ranging Bryde's whales in the GOM. However, two call types have been recorded from a captive juvenile that stranded on the Gulf coast of Florida in 1988 (Edds *et al.* 1993). One type was a "growl-like" pulsed moan with amplitude and frequency modulation (200–900 Hz), and highly variable duration ranging between 0.3 and 51 s (Edds *et al.* 1993). The second was a sequence of discrete, 10 ms long pulses with the majority of energy between 400 and 610 Hz and interpulse interval of 50–130 ms (Edds *et al.* 1993). In addition, one call type has been described from free-ranging Bryde's whales in the southern Caribbean. This call has a slight frequency downswEEP with a fundamental frequency at approximately 44 Hz with two to four harmonics (the second harmonic is generally the strongest), and a mean duration of 1.6 s (Oleson *et al.* 2003).

Once Bryde's whale calls in the GOM are well described, passive acoustics can be used to learn more about their seasonal presence, range extent, and relative abundance in this region. In this paper, we describe (1) one call type recorded in the presence of Bryde's whales in the GOM, (2) a time series of the call's presence in long-term autonomous recordings from DeSoto Canyon in the northeastern GOM from October 2010 to July 2011, and (3) a possible Bryde's whale call that was only recorded on the long-term autonomous recordings. In this paper, we use the word "call" as a shorthand notation for sound recorded on our recording devices which was assumed to be produced by a Bryde's whale. To maintain the naming scheme first introduced for Bryde's whales by Oleson *et al.* (2003), we will refer to the call type recorded in the presence of Bryde's whales as Be9.

Initial data to identify calls produced by Bryde's whales in the GOM were collected during the 2011 NOAA Southeast Fisheries Science Center's Atlantic Marine Assessment Program for Protected Species (AMAPPS) survey. Between 28 July and 1 August 2011, visual and acoustic surveys for marine mammals were conducted aboard the NOAA ship *Gordon Gunter* from the southeastern edge of the GOM, just south of Florida, to Pascagoula, Mississippi, following the 200 m isobath (Fig. 1). Trained marine mammal observers conducted a line transect survey for cetaceans using 25× "Big Eye" binoculars concurrently with a passive acoustic survey. In addition, Directional Frequency Analysis and Recording (DIFAR) AN/SSQ-53E sonobuoys were deployed in arrays during baleen whale encounters.

DIFAR sonobuoys contain a directional hydrophone with a bandwidth from 10 to 2,400 Hz, which provides a magnetic bearing to the source of the received sound. The signals from the sonobuoy are transmitted via a single radio carrier frequency to a ship-mounted antenna. Sonobuoys are programmed to scuttle automatically after a maximum of 8 h after deployment. During the AMAPPS cruise, an omnidirectional X500 antenna (Diamond Antenna) with a P160VDG preamplifier (Advanced Receiver Research) was used to transmit the signal to ICOM radio receivers modified for low-frequency response (Greeneridge Sciences). The signal was digitized using a Sound Blaster Audigy USB sound card (Creative Technology). Incoming signals were monitored aurally *via* headphones and visually *via* a scrolling spectrogram in *Ishmael* software (David Mellinger, Oregon State University). In addition, digital recordings to wav files were made and annotated using *Logger2000* (Douglas Gillespie, International Fund for Animal Welfare). Times of all potential baleen whale sounds were noted.

During postanalysis, recordings made during Bryde's whale encounters were scanned to verify real-time detections and determine bearings to the sounds. Magnetic bearings to sound sources were extracted from the multiplexed DIFAR signal using an algorithm developed by Charles Greene (Greenridge Sciences), and modified

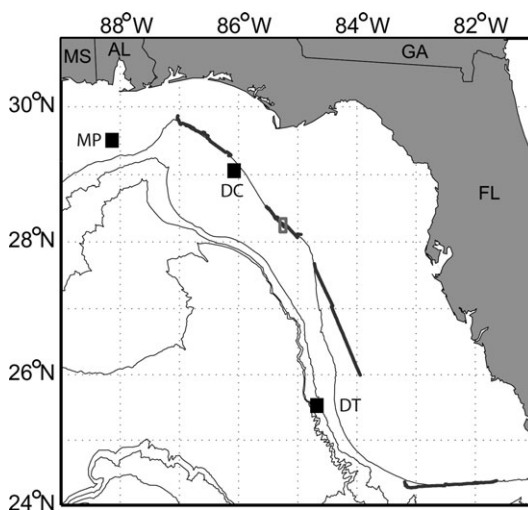


Figure 1. Area of the Gulf of Mexico surveyed from 28 July until 1 August 2011 during AMAPPS cruise (visual survey effort is shown in thick, solid lines). HARP deployment locations at Main Pass (MP), DeSoto Canyon (DC), and Dry Tortugas (DT) are marked with black squares. Bathymetry contours shown at 200 m, 1,000 m, 2,000 m, and 3,000 m. Rectangle is the approximate area of Bryde's whale sightings and recordings on 31 July 2011.

by David Mellinger (Oregon State University) and Mark McDonald (Whale Acoustics). When a bearing to the same call was extracted from more than one concurrent sonobuoy recording, the location of the source of that call was estimated from bearing crossings.

In addition to ship-based recordings, long-term passive acoustic recordings of Bryde's whales were collected using High-frequency Acoustic Recording Packages at three locations (HARPs; Wiggins and Hildebrand 2007). One HARP was deployed in DeSoto Canyon ( $29^{\circ}3.2'N$ ,  $86^{\circ}5.8'W$ , depth 260 m), northeastern GOM (Fig. 1), from 21 October 2010 until 17 January 2011 and again from 21 March until 6 July 2011, for a total recording effort of 4,665 hours. One HARP was deployed in southeastern GOM northwest of the Dry Tortugas ( $25^{\circ}31.9'N$ ,  $84^{\circ}38.3'W$ , depth 1,320 m) from 20 July until 26 October 2010 and again from 3 March to 15 May and 12 July to 14 November 2011. The final HARP was deployed in north-central GOM at Main Pass ( $29^{\circ}15.3'N$ ,  $88^{\circ}17.8'W$ , depth 90 m) from 29 June until 29 August 2010, from 2 November 2010 to 19 February 2011, 20 March to 14 April, and 2 May to 21 June 2011 (Fig. 1). All HARPs sampled at 200 kHz and data were decimated to a 2 kHz sample rate to enable quicker processing and analysis by applying the following steps. First, long-term spectral averages (LTSAs) were created with 5 s time and 1 Hz frequency resolution (Wiggins and Hildebrand 2007). Second, custom-made Matlab-based program *Triton* (Wiggins and Hildebrand 2007) was used to visually scan LTSAs for the presence of calls of interest. Calls matching recordings collected during the AMAPPS cruise or similar, balaenopterid-like sounds (Clark 1990) of low frequency ( $<500$  Hz), short duration (individual components no longer than 20 s), and high intensity (signal-to-noise ratio  $>10$  dB) were noted. The scrutinized LTSA windows were plotted with 0.5 h of data, over a frequency range of

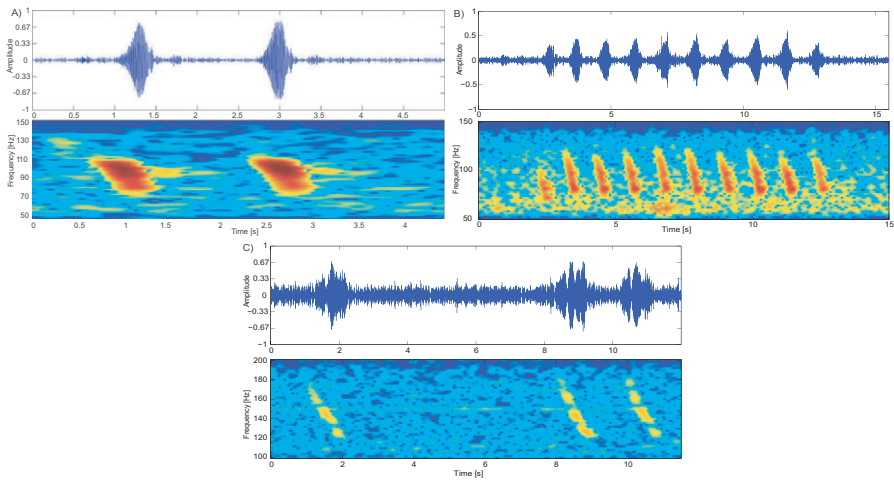
0–500 Hz. Sounds of interest identified in the LTSA were examined more closely by zooming in to 60 s of data and a frequency range of 10–400 Hz. The time of confirmed calls was logged.

The following characteristics of Bryde's whale calls were measured manually: minimum and maximum call frequencies (measured from spectrograms), and call start and end times (measured from time series plots that were band-pass filtered between 60 and 130 Hz). The duration of a call was calculated as the duration between the start of the first and the end of the last pulse. The number of pulses per call was noted and the interpulse interval (IPI) of each call was calculated by averaging the difference between the end of one call and the start of the subsequent call over the course of each calling bout. We define a calling bout as a series of calls separated by no more than 60 s. All calls recorded on sonobuoys were measured, while a subset of 30 calls of the most common call type recorded on the HARPs was measured from the HARP recordings. Only one call per 24 h period was used for the latter analysis to minimize the over-representation of calls from an individual whale. Mean and standard errors of all measurements are reported.

Call source level (SL, defined as the sum of transmission loss and received level) was determined by measuring peak-to-peak received level of calls from sonobuoy recordings and correcting them for sonobuoy and receiver sensitivities (Anonymous 1988), and estimating transmission loss (TL) from position information from crossed bearings. The TL was calculated empirically by using least squares to estimate the slope of the best-fit line through the scatter of measured received levels and the logarithm to base 10 of calculated range to the source. The range to the source was calculated as the distance between the sonobuoy deployment locations and the location of the bearing crossings from multiple sonobuoys. This empirical transmission loss was found to be  $15 \times \log_{10}[\text{range}(m)]$ . The source level of each call with measured bearing was calculated for each sonobuoy at which the call was recorded. We report the average call SL and its standard error based on these calculations, as well as the average difference in the SL calculated for individual calls from multiple sonobuoys.

To investigate for a diel pattern in Bryde's whale call production, we divided the call detections from HARPs into four light periods based on the timings of nautical and civilian sunrise and sunset: dawn, day, dusk, and night (Wiggins *et al.* 2005). The times were downloaded for 29°3'N, 86°6'W (DeSoto Canyon) for periods between October 2010 and July 2011 from the U.S. Naval Observatory's Astronomical Application Department (<http://aa.usno.navy.mil/>). Since the duration of daily light periods varies over the course of a year, we divided the number of calls in each daily light period by the duration of the light period to get the hourly call rate (calls/h). In addition, to remove bias due to the variation in daily call rates through the deployment period, each day's mean call rate was subtracted from the daily call rate for each light period. We used only days when at least one call was detected for this analysis. Since the mean adjusted data failed the Lilliefors' composite goodness-of-fit test for normal distribution, a nonparametric analysis of variance (ANOVA) Kruskal-Wallis test was used to test the null hypothesis that the call rate was constant during each light period. A multiple comparison test was used to evaluate which light periods had significantly different call rates. All statistical tests were conducted using Matlab's statistics toolbox.

Three groups of Bryde's whales were observed visually during the AMAPPS survey in the GOM, all on 31 July 2011. No calves were observed in these groups. Balaenopterid-like calls (Fig. 2a) were recorded only during the encounter with the first group, sighted at 1430 GMT. Three DIFAR sonobuoys were deployed in an array



*Figure 2.* Time series and spectrograms of Bryde's whale calls. (A) Be9 pulses recorded with a sonobuoy on 31 July 2011 (600 point FFT, 98% overlap, Hanning window, band-pass filter 60–130 Hz), (B) Be9 call sequence recorded on the HARP at DeSoto Canyon on 8 June 2011 (1,000 point FFT, 95% overlap, Hanning window, band-pass filter 60–130 Hz), and (C) possible Bryde's whale calls recorded on the HARP at DeSoto Canyon on 24 June 2011 (1,000-point FFT, 95% overlap, Hanning window, band-pass filter 110–180 Hz).

during the sighting at 0, 11, and 42 min after the initial sighting. A small boat was deployed between the second and third sonobuoy deployment. During this encounter, four Bryde's whales were observed. At 1610 GMT, visual observers noted a decrease in time between dives from 10 min to 4–5 min. The NOAA ship *Gordon Gunter* and the small boat stayed with the group until 1800 GMT for a total of 3.5 h. Visual observers noted 22 whale position updates during that time period, but there were no updates on sonobuoy locations. No other anthropogenic activity was evident in the area during this time.

During the above encounter, one call type, consisting of pulse pairs, was identified as a likely Bryde's whale call based on the location of bearing crossings of the sound sources to the area of whale sightings and the lack of other cetacean sightings during this period. A total of 14 individual pulses were recorded and 12 were localized successfully using recordings from two sonobuoys. The first 6 pulses (recorded between 1443 and 1447 GMT) were localized between 620 and 1,050 m from the visual sightings that were noted 13–15 min earlier. Subsequent visual reposition was noted approximately 2 km and 9–12 min from that acoustic localization. Pulses recorded between 1510 and 1514 GMT, 15–17 min after the last visual position, placed the source of the pulse 480–970 m from the visual sighting. Visual resightings within 1–2 min yielded locations that were up to 700 m apart. No other whale species were sighted on 31 July, although a group of four bottlenose dolphins (*Tursiops truncatus*) was sighted 27 min before the first Bryde's whale sighting. No other dolphins were sighted until five hours after the last Bryde's whale recording.

These recorded Be9 calls were frequency downswept pulse pairs, less than one second long (Fig. 2a, Table 1). The estimated mean call SL was  $155 \pm 14$  dB re: 1  $\mu$ Pa at 1 m. There was an average 15 dB difference in the individual SL values calculated

*Table 1.* Characteristics of Bryde's whale Be9 calls recorded on sonobuoy and HARP, as well as Be6 calls reported by Oleson *et al.* (2003). We report mean and standard error of all values measured for this study, but only means were available from the Oleson *et al.* (2003) study.

	Sonobuoy	HARP	Be6
Start frequency (Hz)	110 $\pm$ 4	143 $\pm$ 3	208
End frequency (Hz)	78 $\pm$ 7	85 $\pm$ 6	76
Pulse duration (s)	0.4 $\pm$ 0.1	0.7 $\pm$ 0.1	N/A
Interpulse interval (s)	1.3 $\pm$ 0.1	0.6 $\pm$ 0.2	0.5
Source level (dB re: 1 $\mu$ Pa at 1 m)	155 $\pm$ 14	N/A	N/A

from each sonobuoy for each call. No other balaenopterid-like calls were recorded during this time. In addition, no potential baleen whale sounds were recorded during the second and third Bryde's whale sighting on 31 July. At 1841 GMT the antenna preamplification was lost, resulting in a significantly decreased radio signal reception range that may explain the lack of recordings during those sightings.

Calls similar to the Be9 pulse pair calls that were recorded during the first Bryde's whale sighting were frequently recorded in the long-term HARP recordings from DeSoto Canyon. These downswep pulses recorded on the HARP had a slightly higher frequency than the calls recorded on sonobuoys (Fig. 2b, Table 1). The pulses usually came in sequences of varying lengths between 2 and 25 pulses averaging eight pulses per sequence, but occasionally only a single pulse was recorded. The average duration of these pulse sequences was  $9.1 \pm 8.1$  s.

A total of 680 Bryde's whale Be9 calls were detected on 53 days of HARP recordings from DeSoto Canyon. The calls were detected consistently between March and July, as well as in October and January, with a distinct absence of calls in November and December (Fig. 3). A peak in calls occurred in late June, but there were also relatively high numbers of calls during late March, early April, and early January. No data were available from mid-July to mid-October or late January to mid-March. The Be9 call rate was significantly higher during dusk and night than during dawn and day (Kruskal-Wallis ANOVA = 35.3,  $df = 3$ ,  $P = 0.000$ ) at DeSoto Canyon (Fig. 4). No Bryde's whale calls were recorded at the Dry Tortugas or the Main Pass HARP locations during our monitoring effort.

An additional, possible Bryde's whale call was detected in the long-term recordings from DeSoto Canyon 93 times, all during five days in late June, concurrent with the peak in Be9 call detections. This call type also consisted of downsweps, although they occurred at a higher frequency (approximately 170–110 Hz) and typically consisted of three segments (Fig. 2c). They most frequently occurred in doublets, but single downsweps and triplets were also present, always in a repeated sequence.

This is the first description of free-ranging Bryde's whale calls in the GOM and we are confident these calls were produced by Bryde's whales for the following reasons. (1) The localized sources of the calls during the AMAPPS survey were within a few hundred meters and 15 min of the visual observations of Bryde's whales. A fine-scale temporal and spatial offset between visual observations and acoustic detections is frequently observed (Širović *et al.* 2006, Oleson *et al.* 2007a, Gedamke and Robinson 2010). Baleen whales generally call at depth and can stay submerged as long as 15 min (Croll *et al.* 2001, Oleson *et al.* 2007b, Parks *et al.* 2011), so the calling whale is not likely to surface at the same location where its calls were produced. (2) No

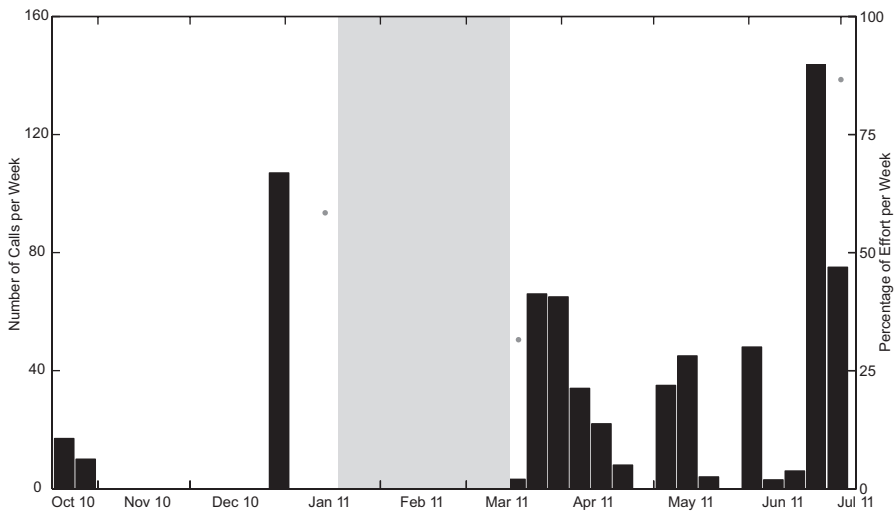


Figure 3. Number of Bryde's whale Be9 calls (black bars) recorded per week at the DeSoto Canyon HARP between 21 October 2010 and 6 July 2011. Gray shaded area is a period during which there was no recording effort and gray dots represent times when there was less than 100% recording effort during the week (right vertical axis).

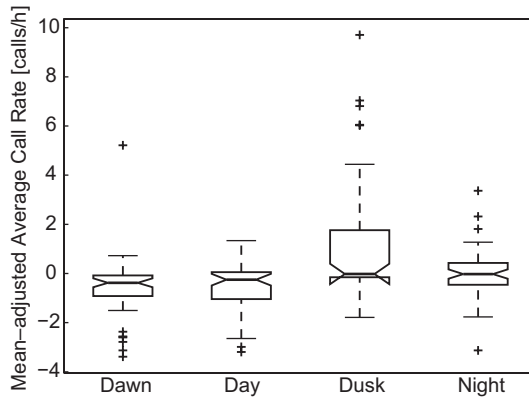


Figure 4. Box-and-whisker plot of mean-adjusted average call rate for Bryde's whale Be9 calls recorded at the DeSoto Canyon HARP during four light periods. Whiskers represent the lowest and the highest datum still within 1.5 interquartile range of the lower and the upper quartile, respectively, and plus symbols are outliers.

other whales were sighted for hours and these pulses are not similar to sounds from the only other species sighted in the vicinity, bottlenose dolphin (Lilly and Miller 1961, Caldwell *et al.* 1990, Baron *et al.* 2008). (3) Calls reported here exhibit frequency and temporal characteristics similar to those of Bryde's whales from other regions (Oleson *et al.* 2003), including a relatively low source level (Cummings *et al.* 1986). (4) The combination of the call source levels, depths of the hydrophones at

which the recordings were made, and their frequency characteristics, makes them unlikely to be attributable to a fish (Wysocki 2006).

Our recordings are not a good match to the calls recorded from a captive juvenile Bryde's whale from this area. Calls reported here are much lower frequency (80–150 Hz *vs.* 300–900 Hz) and slower pulse rate (1–2 pulses/s *vs.* 20–70 pulses/s) than captive juvenile calls (Edds *et al.* 1993). Differences in these recordings could be due to the vastly different context under which the calls were recorded (free-ranging *vs.* captive) or difference in age class (likely adult *vs.* juvenile). In summary, based on the concurrent visual observations, temporal and frequency characteristics of these calls, and the lack of other potential sources for this call, we are confident the Be9 calls reported here were produced by Bryde's whales.

The second call reported here as a possible Bryde's whale also has features that are common to balenopterid calls (low-frequency, short duration). In addition, its relative similarity in duration, bandwidth, and pulse patterns to Be9 and the confirmed Bryde's whale call Be6 recorded in the ETP (Oleson *et al.* 2003), lead us to believe it may also be from a Bryde's whale. Even though it is somewhat higher frequency than the Be9 call, it is within the frequency and temporal range reported from other Bryde's whale populations (Oleson *et al.* 2003, Heimlich *et al.* 2005). Finally, its occurrence during the days when the Be9 call was abundant in the data is also an indication that these calls may be an alternative call type produced by Bryde's whales in the GOM.

Relatively consistent presence of Be9 calls in our data from DeSoto Canyon during winter and spring is consistent with the hypothesis that this population is resident in the GOM (Waring *et al.* 2009) and possibly does not range over a large area. Lack of detections in October and November may be explained by its small population size (Mullin 2007). Also, we would not expect to detect the whales frequently given that the area we were monitoring was relatively small (assuming 10 km detection range, that area is approximately 315 km<sup>2</sup>). However, passive acoustic data only allow us to detect presence of calling animals, so when no calls are detected it could mean the animals are simply not calling due to a change in behavioral state. We do not have long-term passive acoustic data at DeSoto Canyon between late July and mid-October, and the sighting from the AMAPPS cruise only extends Bryde's whale presence in this area to the end of July. Historical visual surveys were conducted only during spring (Waring *et al.* 2009), and we are not familiar with any other published information on Bryde's whales presence in this area between August and mid-October.

The relatively small number of calls detected in our recordings is consistent with the small population size in this area. The size of this population estimated from visual surveys is between 15 and 40 animals (Hansen *et al.* 1995, Mullin and Fulling 2004, Mullin 2007). We recorded a few tens to just over a hundred calls a week, which is a reasonable number for a small population size and relatively small area of monitoring. However, more targeted recordings to obtain the call production rate, and additional measurements of the call source levels, would allow us to estimate population size using passive acoustic recordings (Marques *et al.* 2009).

In summary, with this first record of confirmed calls from free-ranging Bryde's whales in the GOM, we have been able to learn about the persistence of Bryde's whales in this region of the Gulf. Our recordings covered a relatively small portion of the Gulf of Mexico, but this description of Bryde's whale calls can be used to analyze other previously collected recordings from the Gulf that could shed more light on their distribution, occurrence, or preferred habitat. In addition, more directed studies of the calling behavior of this Bryde's whale population, along with additional long-

term recordings, would provide an even better understanding of their presence in the area and may present opportunities for population abundance estimation in the future.

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