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Passive acoustic monitoring of cetaceans in the northern Gulf of Mexico during 2010-2011

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Executive Summary

The goal of this report is to provide density estimates for cetaceans in the Gulf of Mexico during and following the time of the *Deepwater Horizon* Oil Spill. We document the instrumentation, data collection, and analysis of passive acoustic monitoring data collected between May 2010 and August 2011 with support from the Natural Resources Damage Assessment (NRDA) partners and the US Marine Mammal Commission. Data were collected from five locations in different habitats in the Gulf of Mexico, named based on the federal lease block in which they are located: Green Canyon, Mississippi Canyon, Main Pass, DeSoto Canyon, and Dry Tortugas. Specific cetacean species that are considered include: (1) sperm whales (*Physeter macrocephalus*), (2) pygmy and dwarf sperm whales (*Kogia breviceps* and *Kogia sima*), (3) beaked whales (*Mesoplodon europaeus*, *Ziphius cavirostris*, and an unknown species of *Mesoplodon sp.*), (4) delphinids and other small cetaceans (*Tursiops truncatus*, and a range of other species), and (5) Bryde's whale (*Balaenoptera edeni*).

We assume that the acoustic detections provide a measure of relative density. Ancillary data needed for an absolute density estimate include mean group size, maximum radius for detection, probability of detecting a group within the maximum radius, and probability of a group being vocally active. Sperm whales were found at their highest average density (12.1 animals / 1000 km²) near the Mississippi Canyon site; weekly sperm whale density estimates and their uncertainty are presented. Pygmy and dwarf sperm whales were found at high average density (28.0 animals / 1000 km²) near the Green Canyon site, and beaked whales were found at high average density (13.4 animals/ 1000 km²) near the Dry Tortugas site. The temporal patterns for dolphin presence are described. Calls ascribed to Bryde's whales are described. Further work is needed to refine density estimates and their uncertainty for pygmy/dwarf sperm whales and beaked whales, and to construct density estimates for dolphins and Bryde's whales.

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Introduction

On April 20, 2010, an explosion and subsequent fire onboard the semi-submersible drilling rig *Deepwater Horizon* resulted in a flow of hydrocarbons into the northern Gulf of Mexico (GOM) that continued for approximately 3 months. As an aid for monitoring marine mammals in the affected area, the Scripps Institution of Oceanography deployed one High-frequency Acoustic Recording Package (HARP) with support from the US Marine Mammal Commission and 4 additional HARPs with support from the Natural Resources Damage Assessment (NRDA) process. These HARPs were positioned both on the continental shelf and slope of the northern GOM, and near the Dry Tortugas off the western coast of Florida (Figure 1). This report documents the instrumentation, data collection, and analysis of data collected in the northern GOM between May 2010 and August 2011.

The objective of this report is to provide density estimates for cetaceans in the northern GOM that were present at the time of the *Deepwater Horizon* spill. Specific species that are considered include: (1) sperm whales (*Physeter macrocephalus*), (2) pygmy and dwarf sperm whales (*Kogia breviceps* and *Kogia sima*), (3) beaked whales (*Mesoplodon europaeus*, *Ziphius cavirostris*, and an unknown species of *Mesoplodon sp.*), (4) dolphins and other small cetaceans (*Tursiops truncatus*, and a range of other species), and (5) Bryde's whale (*Balaenoptera edeni*).

Data were collected from five locations in different habitats in the northeastern GOM. These sites have been named based on the federal lease block in which they are located: Green Canyon (GC), Mississippi Canyon (MC), Main Pass (MP), DeSoto Canyon (DC), and Dry Tortugas (DT). At each site a HARP was deployed and recorded continuously at 200kHz for 2-5 months per deployment. HARPs are bottom-mounted instruments containing a hydrophone, data logger, battery power supply, ballast weights, acoustic release system, and flotation (Wiggins and Hildebrand, 2007). The hydrophone is tethered to the instrument and buoyed approximately 10 m above the seafloor. All acoustic data were converted to sound pressure levels based on hydrophone calibrations performed at Scripps Institution of Oceanography and at the U.S. Navy's Transducer Evaluation Center facility in San Diego, California. Details of each HARP deployment are presented in Table 1.



Figure 1. Map of GOM HARP sites (orange squares) and Deep Water Horizon site (yellow star).

Table 1. HARP deployment time periods and locations.

Data_ID	Data Start Date	Data End Date	Recording Duration (Days)	Deployment Long. W	Deployment Lat. N	Deployment Depth (m)
GofMX_DC02	10/21/2010	2/6/2011	108	86-05.773	29-03.134	268
GofMX_DC03	3/21/2011	8/5/2011	135	86-05.800	29-03.210	260
GofMX_DT01	8/9/2010	10/26/2010	78	84-38.251	25-31.911	1320
GofMX_DT02	3/3/2011	7/12/2011	129	84-38.251	25-31.911	1320
GofMX_GC01	7/15/2010	10/11/2010	88	91-10.010	27-33.470	1115
GofMX_GC02	11/8/2010	2/2/2011	86	91-10.014	27-33.466	1160
GofMX_GC03	3/23/2011	8/8/2011	138	91-10.073	27-33.424	1100
GofMX_MC01	5/16/2010	8/28/2010	104	88-27.927	28-50.746	980
GofMX_MC02	9/7/2010	12/19/2010	103	88-27.907	28-50.771	980
GofMX_MC03	12/20/2010	3/21/2011	91	88-27.909	28-50.775	980
GofMX_MC04	3/22/2011	8/15/2011	146	88-27.946	28-50.775	980
GofMX_MP01	7/4/2010	9/25/2010	83	88-17.753	29-15.204	86
GofMX_MP02	11/7/2010	2/19/2011	104	88-17.808	29-15.318	93
GofMX_MP03	3/23/2011	9/6/2011	167	88-17.808	29-15.318	93

Density Estimation from Acoustic Data

The goal of our analysis is estimation of animal densities from the passive acoustic monitoring data. Our basic assumption is that the acoustic detections for each species at each site give a measure of the relative density over time. The analysis was conducted for each HARP site, and to provide sufficient data for each density estimate, the data were averaged over weekly time intervals. At the finest temporal scale, we determined the animals' presence within the detection range of the HARP during each 5 minute time period for which we have data. Absolute density at each site k and for each week t is estimated by:

$$\hat{D}_{kt} = \frac{n_{kt}}{\pi} \frac{(1 - \hat{c}_k) \hat{s}}{w^2 \hat{P}_k \hat{P}_v T_{kt}} \quad (1)$$

where n_{kt} represents the number of 5 minute windows that animal groups were detected at site k during week t , and T_{kt} represents the number of time intervals (5 minute windows) that were sampled at site k during week t . Likewise, c_k is the proportion of false detections, s is mean group size, P_k is the probability of detecting a group within a radius of size w (beyond which no detections are assumed to be possible) at site k , and P_v is the probability of a group being vocally active in a 5 minute period. This equation for the density estimator is based on well-established sampling methods called distance sampling (Buckland *et al.*, 2001). The components of the above equation are obtained either from direct measurement of the passive acoustic monitoring data, or from the published literature for each species considered. Additionally, we estimate acoustic detection ranges and associated errors using modeling methods. The exact method used varies by species, and details are described in each species section below. We assume that movement of the animals is small within the considered temporal sampling units (5 minutes).

For weekly estimates of density by site, the variance can be obtained using the delta method approximation (Marques *et al.*, 2009):

$$\hat{var}(\hat{D}_{kt}) = \hat{D}_{kt}^2 \{ CV^2(n_{kt}) + CV^2(\hat{c}_k) + CV^2(\hat{s}) + CV^2(\hat{P}_v) + CV^2(\hat{P}_k) \} \quad (2)$$

where $CV(x)$ denotes the coefficient of variation of the random quantity x , (i.e., the standard error of the estimate of x divided by the estimate). Confidence intervals can be obtained from the estimated variance by assuming that density follows a log-normal distribution (Marques *et al.* 2009).

Cetaceans of the Northern Gulf of Mexico

Sperm Whale

Of the endangered whales known to be present in the GOM, only sperm whales are thought to commonly occur. In the northern GOM sperm whales inhabit the continental slope and oceanic waters and are present in all seasons. The abundance estimate for northern GOM sperm whales is 1,665 ($CV=0.20$) individuals (Mullin, 2007). Sperm whales are among the species for which previous work regarding acoustic density estimation has been implemented. Their abundance previously has been estimated from acoustic data using towed line transects (Hastie *et al.*, 2003; Barlow and Taylor, 2005; Lewis *et al.*, 2007).

Sperm whales are deep diving foragers, and there is a direct relation between the presence of whales and their squid prey in the GOM (Davis *et al.*, 2007). Work in several places around the globe points to a remarkable consistency of dive times; their dive cycles consist of deep dives alternating with periods at the surface, with individual dive cycles lasting about 40 to 55 min (Papastavrou *et al.*, 1989; Zimmer *et al.*, 2003; Watwood *et al.*, 2006), and surface times of about 8 to 10 min. During the deeper part of their dives sperm whales produce a regular pattern of clicks, which are used for echolocation of prey (Miller *et al.*, 2004). Digital acoustic recording tags (DTAGs) have been used in previous studies to gather data from 37 individual sperm whales from the GOM, and these data have been used to describe their vocal behavior (Watwood *et al.*, 2006).

Studies using large-aperture acoustic arrays have measured sperm whale echolocation click source levels up to 236 dB rms re: $1\mu\text{Pa}$ @ 1 m, as well as showing a pronounced directionality and spectral emphasis above 10 kHz (Madsen and Mohl, 2000; Mohl *et al.*, 2000; Mohl *et al.*, 2003). Figure 2 illustrates the measured beam pattern for a sperm whale. The peak is diminished to half power at about 4° in either direction, giving a total beam width of about 8° (Mohl *et al.*, 2003). This suggests that the most intense clicks will result when an animal is oriented directly toward the hydrophone; these clicks we will designate as having been detected “on-axis” of the beam pattern. However, very few recorded clicks will be recorded on-axis, as the animals are presumed to have random horizontal orientations with respect to the hydrophone. The passage of a group of sperm whales near the Mississippi Canyon HARP is illustrated in Figure 3.

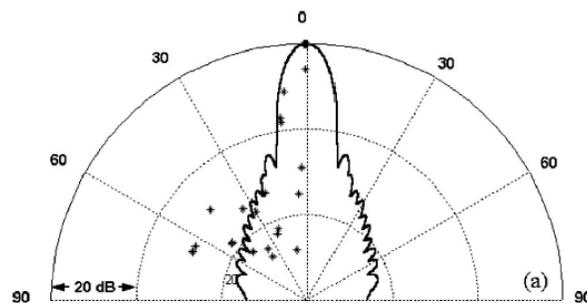


Figure 2. Directionality pattern for a sperm whale echolocation click. The thick line is the theoretical radiation pattern of a circular piston. (Mohl *et al.*, 2003).

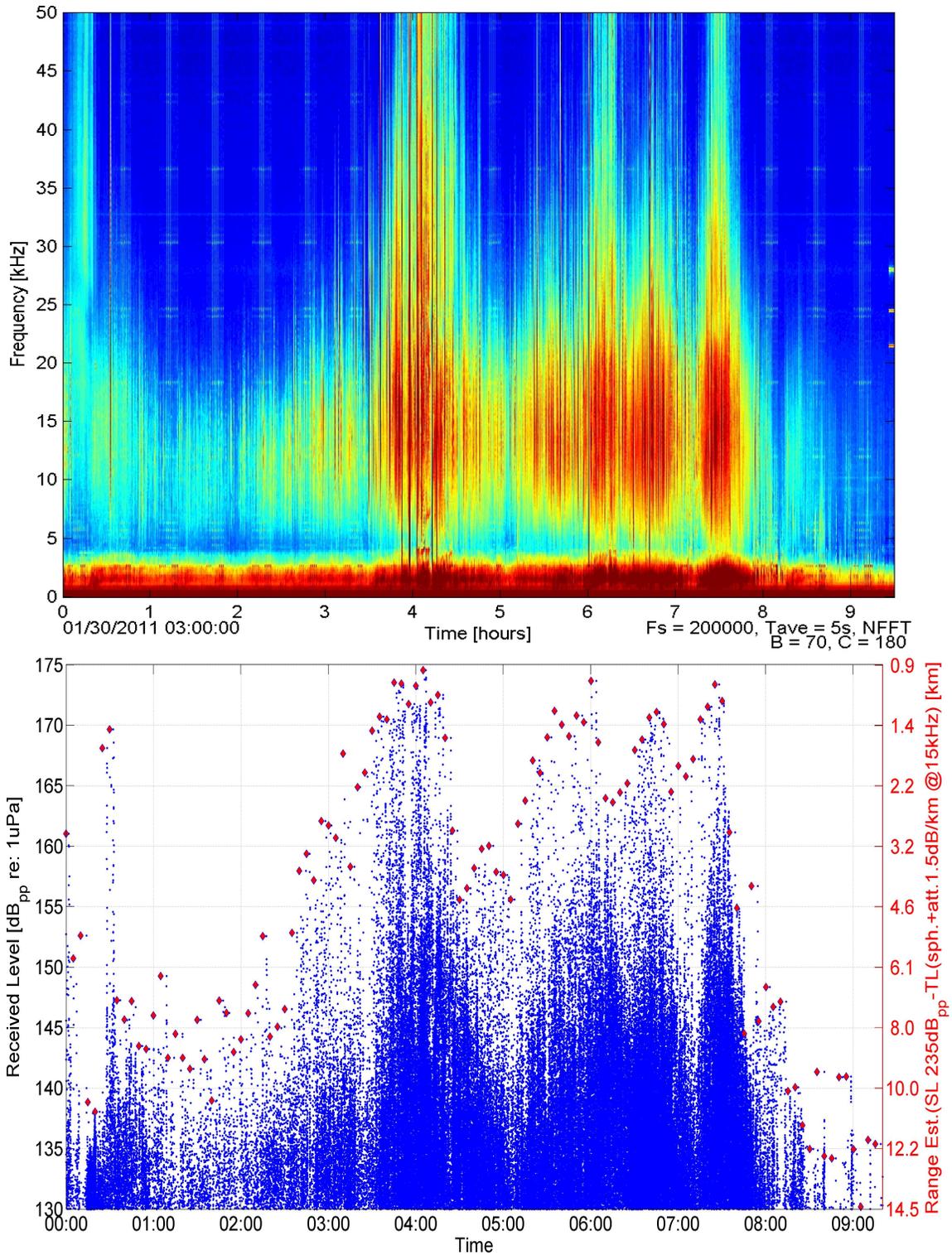


Figure 3. Encounter with sperm whales by the MC HARP as a spectrogram (top), in this image the received level of the signal is denoted by color with higher amplitudes as red and lower amplitudes as blue. Detected click amplitudes (bottom) are denoted on the left vertical scale. The red dots give the maximum received click amplitude during each 5 minute window. The right vertical scale converts maximum click level to range based on assumed source level and transmission loss.

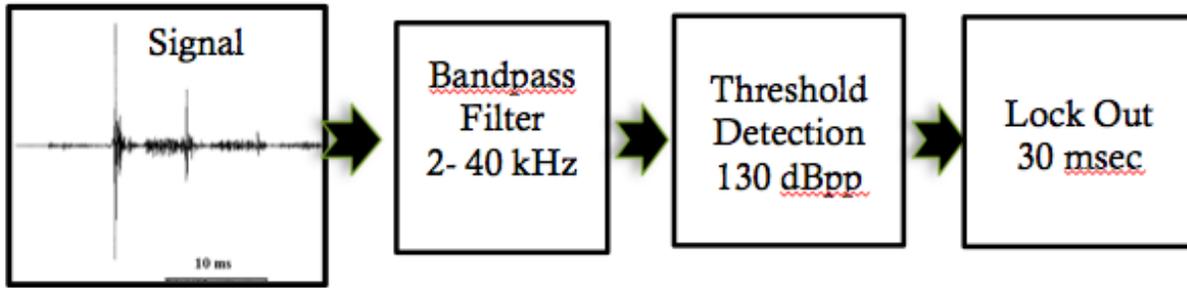


Figure 4. Detection algorithm for sperm whale echolocation clicks. Time series data are passed through a 2-40 kHz bandpass filter and a detection threshold of 130 dB peak-peak signal amplitude. After each detection a 30 msec lockout (no additional detections) is applied to prevent detection of multiple pulses within a single echolocation click.

The spectrogram of a sperm whale encounter (Figure 3) shows variation in the received amplitude that is related to the range between the animals and the hydrophone, as well as the orientation of the animals with respect to the hydrophone. To quantify the received sound levels of the individual echolocation clicks, a detection algorithm was run on the time series data, as illustrated in Figure 4. An example of the output of the click detector is presented in Figure 3, using the same data presented in the spectrogram.

To test for false positives, a trained analyst (KM) manually scanned a subset of data. It was found that for each site, a fraction of 5 minute windows contained detections none of which were due to sperm whales; typically a group of dolphins was mis-identified as sperm whales. We included this as the proportion of false detections in equation (1) by site ($c_k = 0.10, 0.02, 0.14$ with standard errors of 0.02, 0, 0.01 for MC, GC and DT respectively).

Range Estimation

We use the detected click amplitudes as an estimate for the range between the animals and the hydrophone. To minimize the amplitude variation owing to animal orientation, we select the highest amplitude click within each 5 minute window (Figure 3) and take this to be from on-axis orientation (Figure 5). The received signal level (RL) is related to the range, including both the attenuation and spherical spreading of the signal, as follows:

$$RL \text{ (dBpp)} = SL \text{ (235 dBpp)} - TL \left[20 \log(\text{range}) + 1.5 \frac{\text{dB}}{\text{km}} @ 15 \text{ kHz} \right] \quad (3)$$

Using a presumed source level (SL) of 235 dB pp re: $1\mu\text{Pa}$ @ 1 m for the on-axis clicks, yields an estimate of the range to the animals during each 5 minute window (red scale on right-hand vertical axis of Figure 3). Under these assumptions a received level of 174 dB pp re: $1\mu\text{Pa}$ suggests that the animals are at 1 km range from the hydrophone and a received level of 140 dB pp re: $1\mu\text{Pa}$ corresponds to a range of 10 km. By selecting an amplitude threshold of 130 dB pp re: $1\mu\text{Pa}$, we have equivalently set our maximum detection rang to be 14.5 km (Figure 3).

The assumptions inherent in these estimates are that at least one click in each 5 minute window is received on-axis, and that a nominal source level of 235 dB pp re: $1\mu\text{Pa}$ @ 1 m can be applied. If an on-axis click does not occur during a given period, assuming that it did will result in a measurement error, and the true distance to the group will be overestimated. The source level is assumed to have little variation, and if that is not the case, then measurement error will occur: distances to “loud” clicks will be underestimated, and to “faint” clicks overestimated. Further we assume that the distance is not estimated based on a click that corresponds to a false positive. Likewise, we will use these range estimates to

represent the center of a group of animals, whereas it more likely best represents those animals within the group that are closest to the hydrophone.

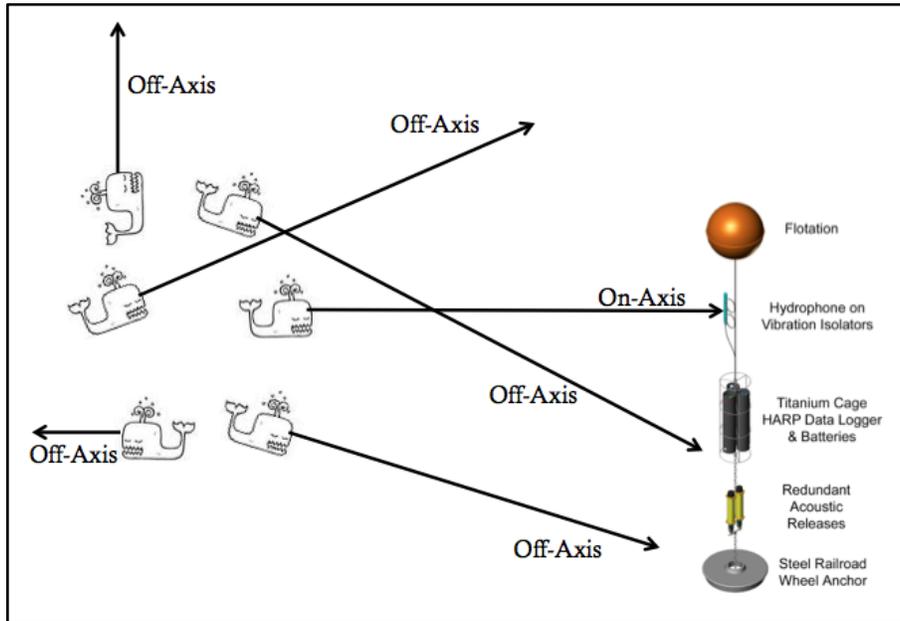


Figure 5. Illustration of sperm whale directional sound production, and how only a few clicks may be received at the hydrophone with the animals oriented on-axis. We presume that these on-axis clicks will provide the highest amplitude signals during each 5 minute measurement window.

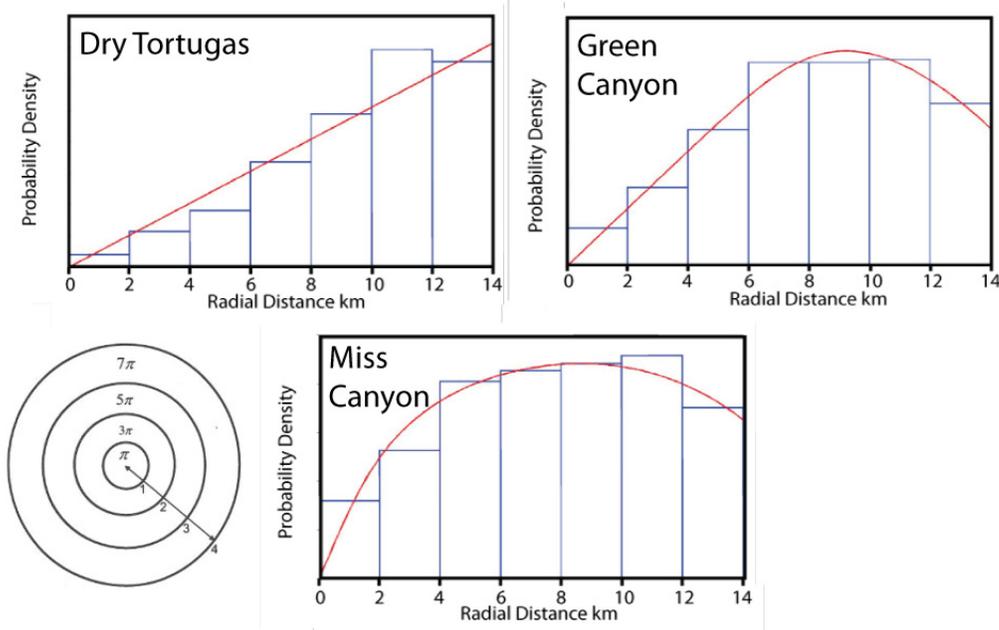


Figure 6. Probability of sperm whale click detection versus range for three HARP sites. For perfect detection the expected detection probability increases linearly with range. The area of each annulus (lower left corner) increases linearly with range.

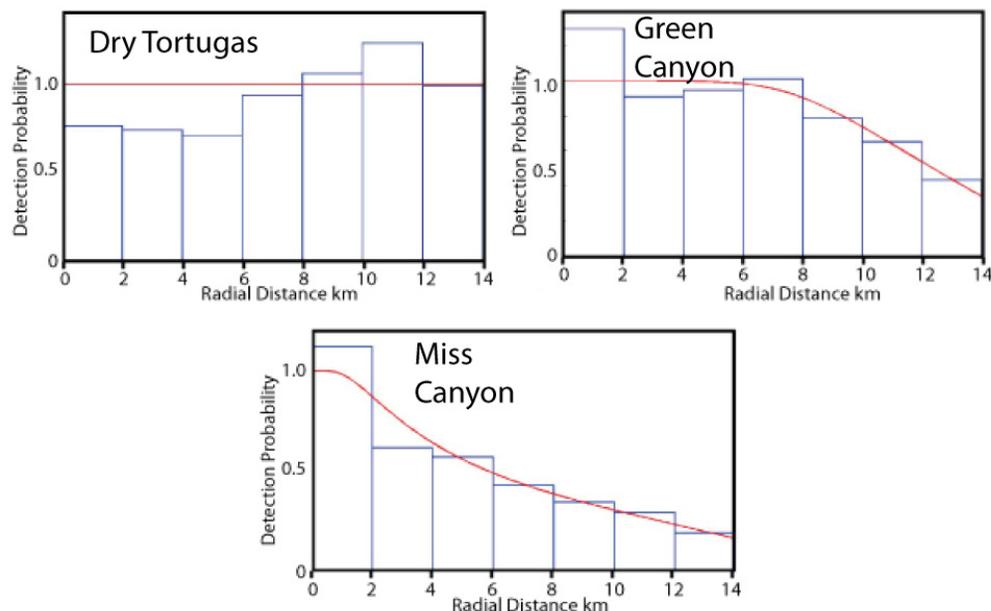


Figure 7. Detection probability for sperm whale clicks versus range for three HARP sites in the GOM. We have fitted detection functions (red line) per site, using either uniform (DT), half-normal (MC) or hazard rate (GC) models (see Buckland *et al.* 2001 for details of models).

Since sperm whales are deep divers and are not typically present on the shelf, we focus on the three HARP sites located in deep water, along the continental slope. Using range estimates for sperm whale clicks detected at these sites, the probability density for click detection versus range can be constructed (Figure 6). We have applied a 14 km maximum range cutoff, slightly less than the maximum range (14.5 km) allowed by the click detection threshold (i.e., using right truncation as per Buckland *et al.* 2001). For animals that are randomly distributed with respect to the hydrophone, and for perfect click detection, the expected probability density for click detection increases linearly with range, to reflect the increasing area of each incremental annulus for increasing range. The expected probability density, a linear increase with range, is observed for the Dry Tortugas site, whereas the Mississippi Canyon and Green Canyon sites show less than linear increases in probability density beyond 2 and 8 km range (respectively). Bathymetric blockage of acoustic propagation is a potential cause for the Mississippi Canyon and Green Canyon non-linear detection probability curves, but more detailed acoustic modeling is needed to test this idea. Dividing the probability density by the area of each annulus provides the detection probability versus range (Figure 7). The Dry Tortugas HARP detection probability is nearly uniform with range, whereas the Green Canyon and Mississippi Canyon HARPS show a distinct falloff in detection probability versus range. Parametric detection function models were fit to the distance data using maximum likelihood methods available in the software *Distance* (Thomas *et al.*, 2010); these provide empirical estimates for P_k , the probability of detecting a group of sperm whales within a radius of size 14 km at each site (0.36 ± 0.03 , 0.73 ± 0.01 , 1.0 ± 0 for MC, GC and DT respectively).

Group Size

Sperm whale group size for the northern GOM was estimated by the Sperm Whale Seismic Study (SWSS) group, during each of three field seasons, using a Peterson mark-recapture method (Jochens,

2008). Table 2 gives the group size estimate for each season as well as the combined value (6.1 ± 4.83 animals) using all three years. We will use the combined value for our estimate of group size (s) and the standard deviation from the three yearly estimates for purposes of density and variation in density estimation, respectively. Sperm whale group sizes in the GOM are known to be significantly smaller than what has been reported in the equatorial Pacific (Coakes and Whitehead, 2004).

Table 2. Sperm whale group size estimates from the SWSS project (Jochens, 2008)

Year	Group Size	(SD)
2003	6.9	4.54
2004	5.0	2.47
2005	7.6	7.85
Combined	6.1	4.83

Probability of Group Vocal Activity

Tag data are needed to estimate the percentage of time that a group of sperm whales will be vocally active. The Sperm Whale Seismic Study (SWSS) project collected a large body of sperm whale tag data in the northern GOM (Figure 8); these provide the best estimate of sperm whale vocal activity in the area.

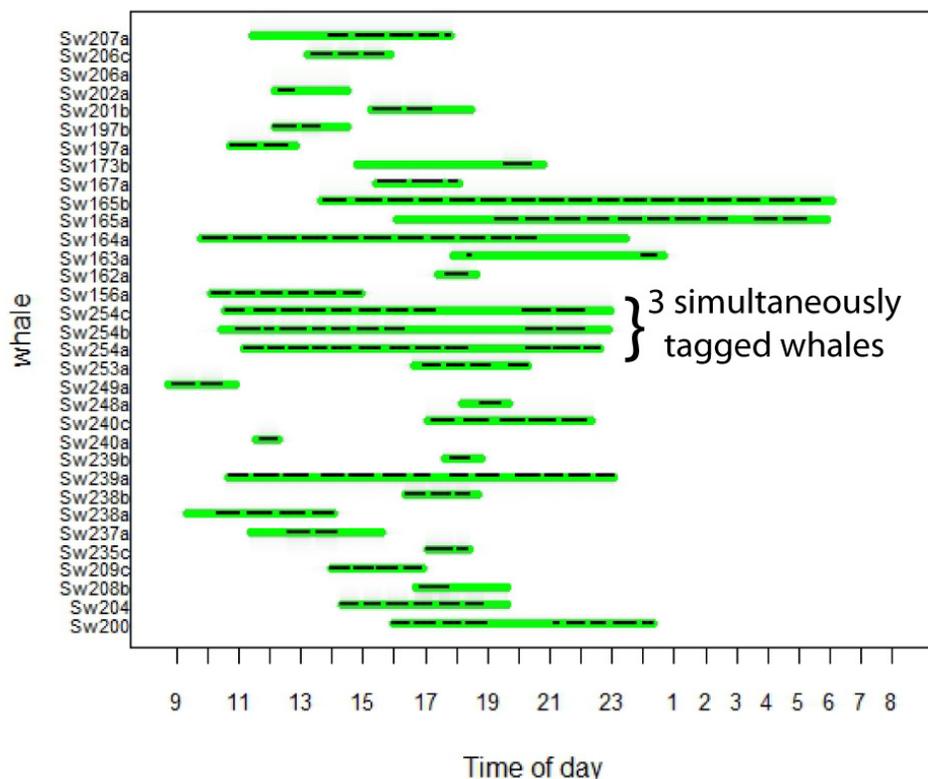


Figure 8. Sperm whales tagged by the SWSS Project. Green line denotes time of day with tag attachment, and black line denotes period with echolocation clicks. Animals Sw254a,b,c were three whales in the same group that were simultaneously instrumented with separate tags.

We estimate that individual sperm whales are vocally active about 60% of the time (ratio of black to green bars in Figure 8). There is a single instance where multiple animals in the same group were simultaneously tagged. These data provide insight into the synchronicity of echolocation for animals within a group. Although there is substantial overlap in the timing of echolocation, there is not complete overlap; approximately half of the quiet intervals for single animals are filled with echolocation from another animal in the group. This suggests that approximately $80 \pm 10\%$ of the time a group of sperm whales would be vocally active. We will use this as the value of P_v , the probability of a group being vocally active in a 5 minute period.

Detection Rate for Sperm Whales

The daily detection rate of sperm whales at the Mississippi Canyon, Green Canyon and Dry Tortugas HARP sites are presented in Figure 9. The weekly average of these data are used for density estimation with equation (1). Sperm whales were not detected at the shallow water sites, Main Pass and DeSoto Canyon.

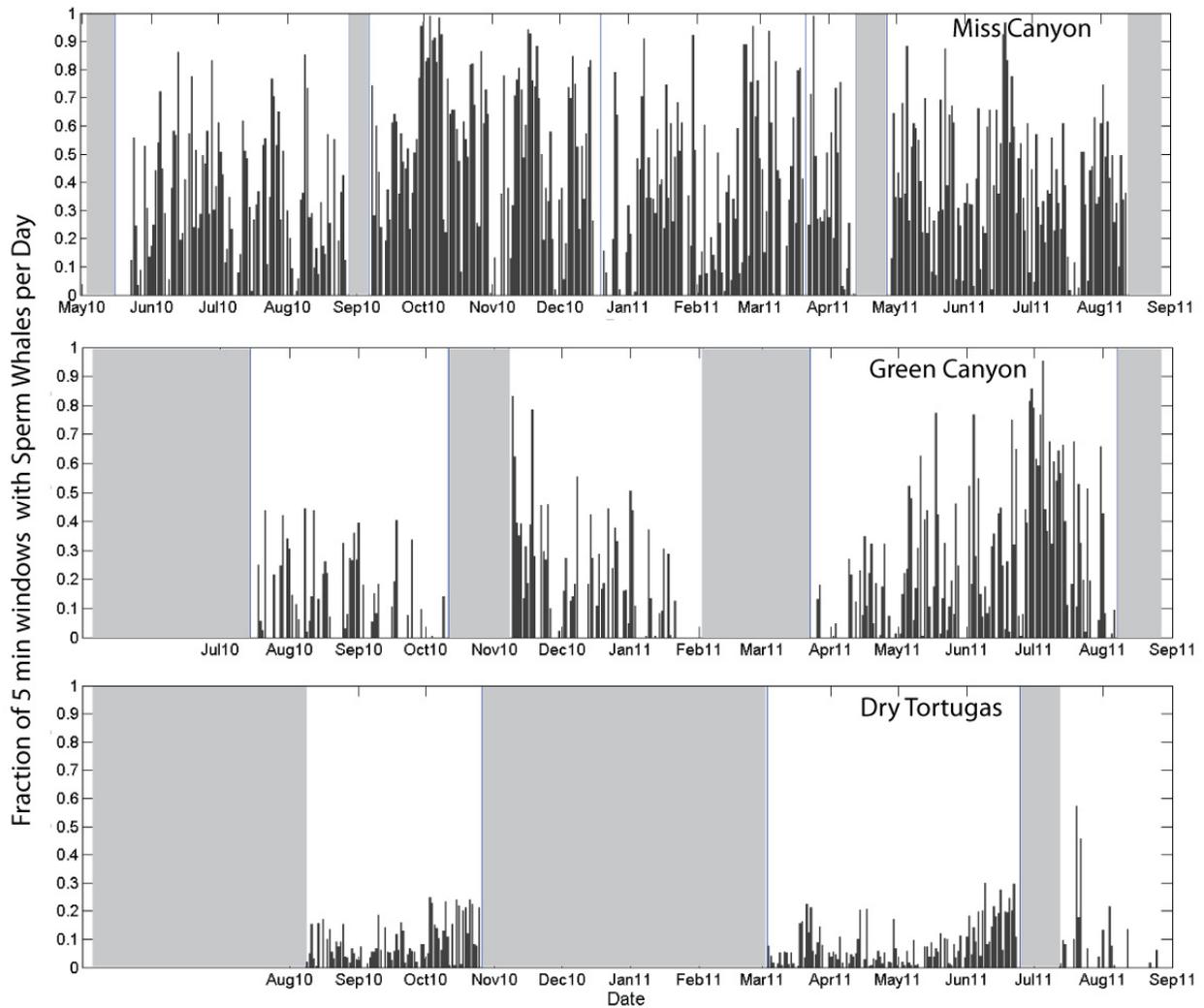


Figure 9. Sperm whale presence at Mississippi Canyon, Green Canyon and Dry Tortugas sites. Fraction of 5 minute windows with sperm whale detections are plotted daily between May 2010 and Aug 2011. Shaded areas lack data.

The data in Figure 9 reveal a significantly higher detection rate for sperm whales at the Mississippi Canyon HARP relative to the other sites, with the lowest detection rate at the Dry Tortugas HARP. None of the sites show strong seasonal variations in detections, although the Dry Tortugas site lacks complete seasonal coverage.

Density of Sperm Whales

A weekly density estimate for sperm whales at the three HARP sites in deep water is plotted in Figure 10. These were calculated using equation (1) with the parameters summarized in Table 3. The weekly average density of sperm whales at each site fluctuates. The Mississippi Canyon site has the highest average density (12.1 animals/1000 km²), whereas the Dry Tortugas site has a low average density (0.6 animals/1000 km²). This pattern would be enhanced if we have over-estimated the Dry Tortugas detection probability and under-estimated the Mississippi Canyon detection probability. However, since the sperm whale detection rate at Mississippi Canyon is about 7 times that at the Dry Tortugas (Table 3), these differences in density seem unlikely to result from errors in estimating the detection probability. The weekly estimates for all three sites, along with their error estimates are presented in Appendix 1.

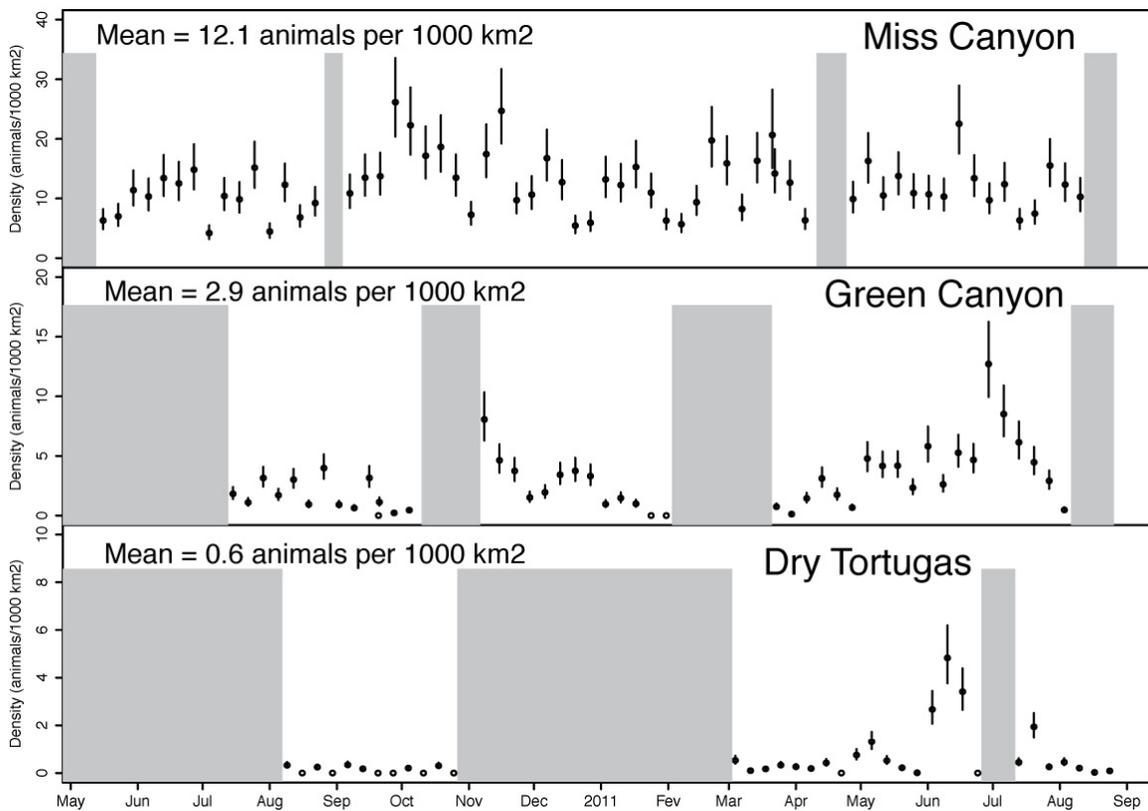


Figure 10. Weekly estimates of sperm whale density (animals/1000 km²) at Mississippi Canyon, Green Canyon and Dry Tortugas sites. Bars are 95% confidence intervals. Shaded areas lack data. Note different vertical scales on each plot.

Table 3. Density Estimates for Sperm Whales. MC = Mississippi Canyon, GC = Green Canyon, DT = Dry Tortugas.

Site	Density #/1000 km ²	N_{kt}/T_{kt} # groups/ #5 min windows	$I-C_k$ % True Detect	S Group Size	W Max Range (km)	P_k Prob Detect	P_v Prob Group Vocal
MC	12.1	0.373	0.9±0	6.1±4.83	14	0.36±.03	0.8±.09
GC	2.9	0.165	0.98±.01	6.1±4.83	14	0.73±.01	0.8±.09
DT	0.6	0.054	0.86±.02	6.1±4.83	14	1.0±0	0.8±.09

Kogia spp.

Dwarf and pygmy sperm whales, in the family *Kogiidae*, are small bodied cetaceans, compared to the sperm whale, but they are also deep diving foragers that eat mostly squid (West *et al.*, 2009). Dwarf sperm whales and pygmy sperm whales are difficult to differentiate at sea, and sightings of either species are usually categorized as *Kogia spp.* In the northern GOM, these animals occur primarily in oceanic waters and are documented to be present in all seasons. The abundance estimate for northern GOM dwarf and pygmy sperm whales is 453 (CV=0.35) individuals (Mullin, 2007).

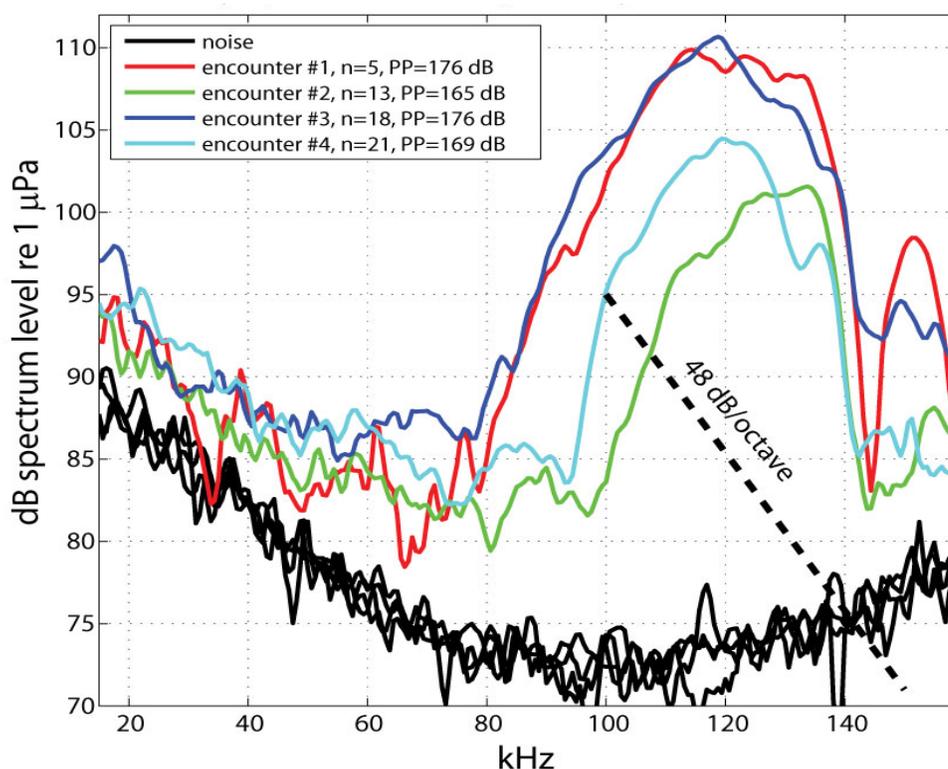


Figure 11. Average spectrum levels for echolocation pulses from *Kogia* encountered in the GOM. These data were collected at 320 kHz sample rate. The filtering typical for 200 kHz sample rate data is given as a dashed line. Although the peak spectral energy is well above 100 kHz, the low frequency tail of the energy distribution as well as some frequency aliasing, explain why these signals were detected by 200 kHz sample rate instruments. Black lines show noise floor.

The echolocation sounds produced by dwarf and pygmy sperm whales have peak energy at frequencies near 130 kHz (Au, 1993), above the upper frequency band recorded by the GOM HARPs. However, the lower portion of the *Kogia* energy spectrum is within the 100 kHz HARP bandwidth (Figure 11). To better understand how *Kogia* echolocation clicks may be represented in the GOM HARP data, a short-term HARP deployment was undertaken at the Mississippi Canyon site, using a recording bandwidth of 160 kHz. Four encounters with *Kogia* were found in 41 hours of recording. Figure 11 shows the average spectra for *Kogia* clicks during each of these four encounters. The data reveal that although most of the click energy is above 100 kHz, a signal-to-noise ratio of at least 20 dB is possible for the portion of energy below 100 kHz. Likewise, the HARP anti-alias filter (dashed line in Figure 11) will allow some spectral leakage from the energy above 100 kHz. All *Kogia* detections were found by manual scanning of the HARP data. There are few other sources of energy in the band near 100 kHz; and there is little or no chance that we have confused *Kogia* with dolphins given the differences in the bandwidth of their clicks. For purposes of density estimation we take the *Kogia* detection false alarm rate to be zero.

Source Level and Detection Range

Little is known about the source level or directionality of *Kogia* echolocation pulses in the wild. A captive pygmy sperm whale was measured to have a 175 dB rms re: 1 μ Pa @ 1m source level, but this is thought to be lower than what the animal would produce in the wild (Madsen *et al.*, 2005a). To better characterize the *Kogia* echolocation click source level and detection range, a series of plots were produced to explore the trade-off between source level and detection range (Figure 12). The maximum received level (*RL*) for *Kogia* clicks from each 5 minute window with detections was converted to a “pseudorange” using the attenuation and spherical spreading of the signal, and assuming a 127 m height difference between the sensor and the animals:

$$RL \text{ (dBpp)} = SL \text{ (dBpp)} - TL \left[20 \log(\text{range}) + 26.6 \frac{\text{dB}}{\text{km}} @ 115 \text{ kHz} \right] \quad (4)$$

The resulting plots (Figure 12) suggest that a source level of about 200 dB rms re: 1 μ Pa @ 1m provides the most plausible probability density for detection of *Kogia* clicks, with a linearly increasing number of detections for small distances. Likewise the model suggests an 800 m maximum detection range (*w*) with $P_k = 0.43$, the probability of detecting a group within an 800 m radius. To obtain these estimates we have lumped data from all sites, and we assume that the detection probability will be the same at all sites. This is a reasonable assumption given the extremely small maximum range for detection (800 m).

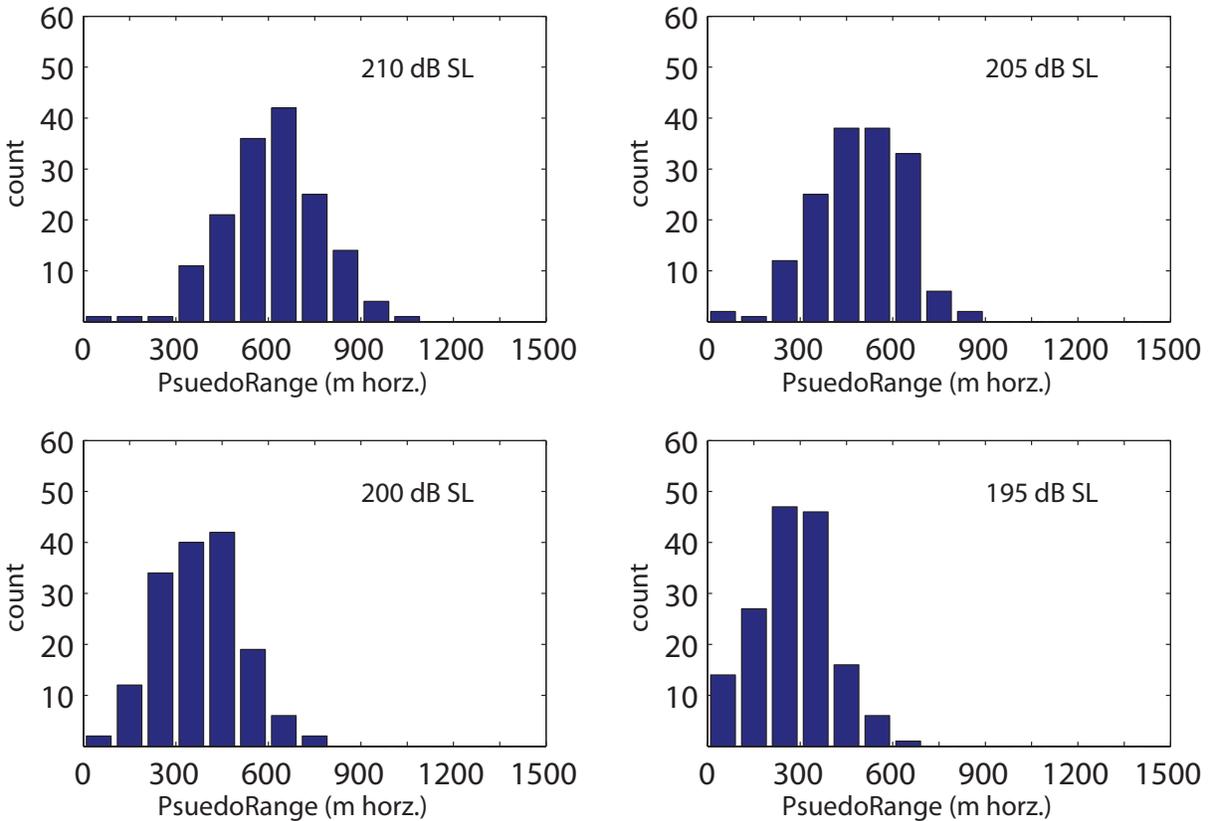


Figure 12. *Kogia* click detection versus range for all HARP sites in deep water. Each plot assumes a click source level, and then translates click received levels into a horizontal “pseudorange”. By selecting the plot that best increases linearly with range, an estimate for *Kogia* source level of about 200 dB rms re: $1 \mu\text{Pa}$ @ 1m is obtained.

Group Size

To estimate *Kogia* group size we examined acoustic encounters with high received signal amplitudes from the GOM, and compared them to visual group size estimates (Baird, 2005). For the acoustic encounters ($n=38$) we derived a minimum number of animals based on overlapping click sequences with consistent inter-click intervals. Most acoustic encounters revealed only 1 or 2 animals, and in only a few instances were 3 or 4 animals detected, yielding an average group size of 1.63 animals. We compared the acoustic group size estimate to the sighting data of Baird (2005) from Hawaii (Figure 13). The visual data, although more limited in total numbers of encounters ($n=18$) revealed overall larger groups of animals and had a higher mean (2.33 ± 1.50 animals). Study of dwarf sperm whales in the Bahamas found a similar median group size of 3, with an $n=54$ (Dunphy-Daly *et al.*, 2008).

Under the assumption that the acoustic encounters may be missing animals, especially for large groups (>4) we will adopt the Baird *et al.* (2005) visual group size estimate for *Kogia* density estimation. Future acoustic data collection with higher bandwidth (e.g., 160 kHz) may allow longer-range detections and provide more confidence in the acoustic group size estimate.

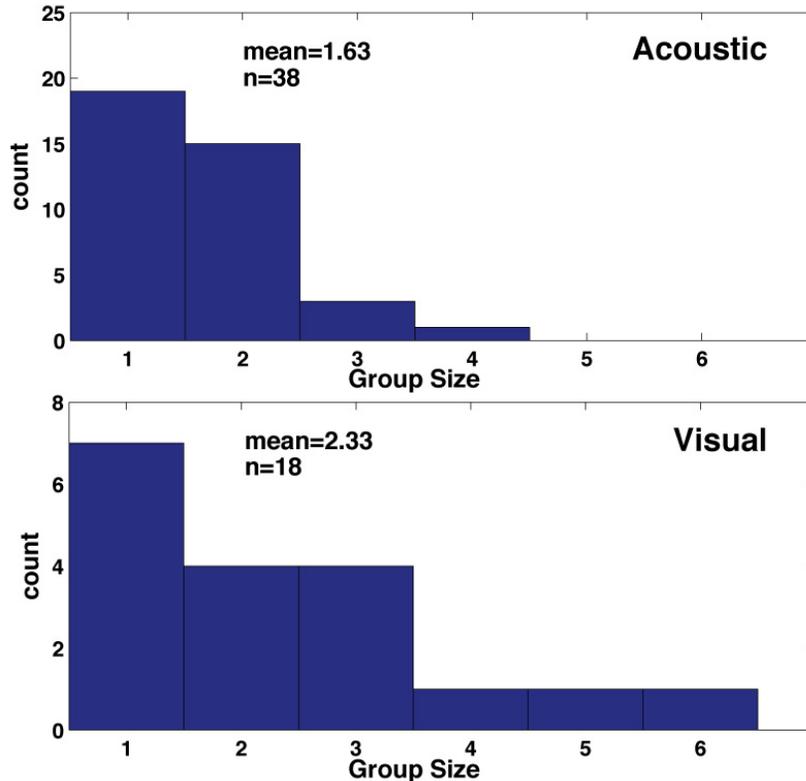


Figure 13. *Kogia* group size distribution for acoustic (upper) and visual (lower – from Baird *et al.* 2005). Limited acoustic detection range (800 m max) may miss some group members, especially for larger groups, making the acoustic estimate a lower bound on group size.

Probability of Group Vocal Activity

There are no data available on *Kogia* vocal rates in the wild. The only published data on *Kogia* diving rates, which may be related to vocal rates, is from a rehabilitated and released pygmy sperm whale (Scott *et al.*, 2001). About $14 \pm 7\%$ of the time the animal was found to be near the sea surface, but this varied with time of day. The dive durations, presumed to be feeding, had a maximum of just over 8 minutes suggesting the animal was feeding at shallow depths. Given the lack of data for *Kogia* we draw on beaked whale data as an analogy. For beaked whales a large body of tag data has been collected (Zimmer *et al.*, 2005; Baird *et al.*, 2006; Johnson *et al.*, 2006; Tyack *et al.*, 2006). These data suggest that beaked whales may be vocally active about 40% of the time. Likewise, simultaneous tracking of two echolocating Cuvier's beaked whales (Wiggins *et al.*, 2012) suggests a group vocal activity rate of about 50%. We use this as a proxy for *Kogia* group calling, in the absence of appropriate field data.

Detection Rate for *Kogia*

The daily detection rate of *Kogia* at the Mississippi Canyon, Green Canyon and Dry Tortugas HARP sites are presented in Figure 14. The fraction of 5 minute windows with detections are plotted in daily bins over the period May 2010 to August 2011; we use a weekly average of these data for density estimation. The data in Figure 14 reveal a significantly higher detection rate for pygmy and dwarf sperm whales at the Mississippi Canyon and Green Canyon HARPs, with low detection rates at the Dry Tortugas HARP. None of the sites show strong seasonal variations in detections, although the Dry Tortugas data set lacks complete seasonal coverage.

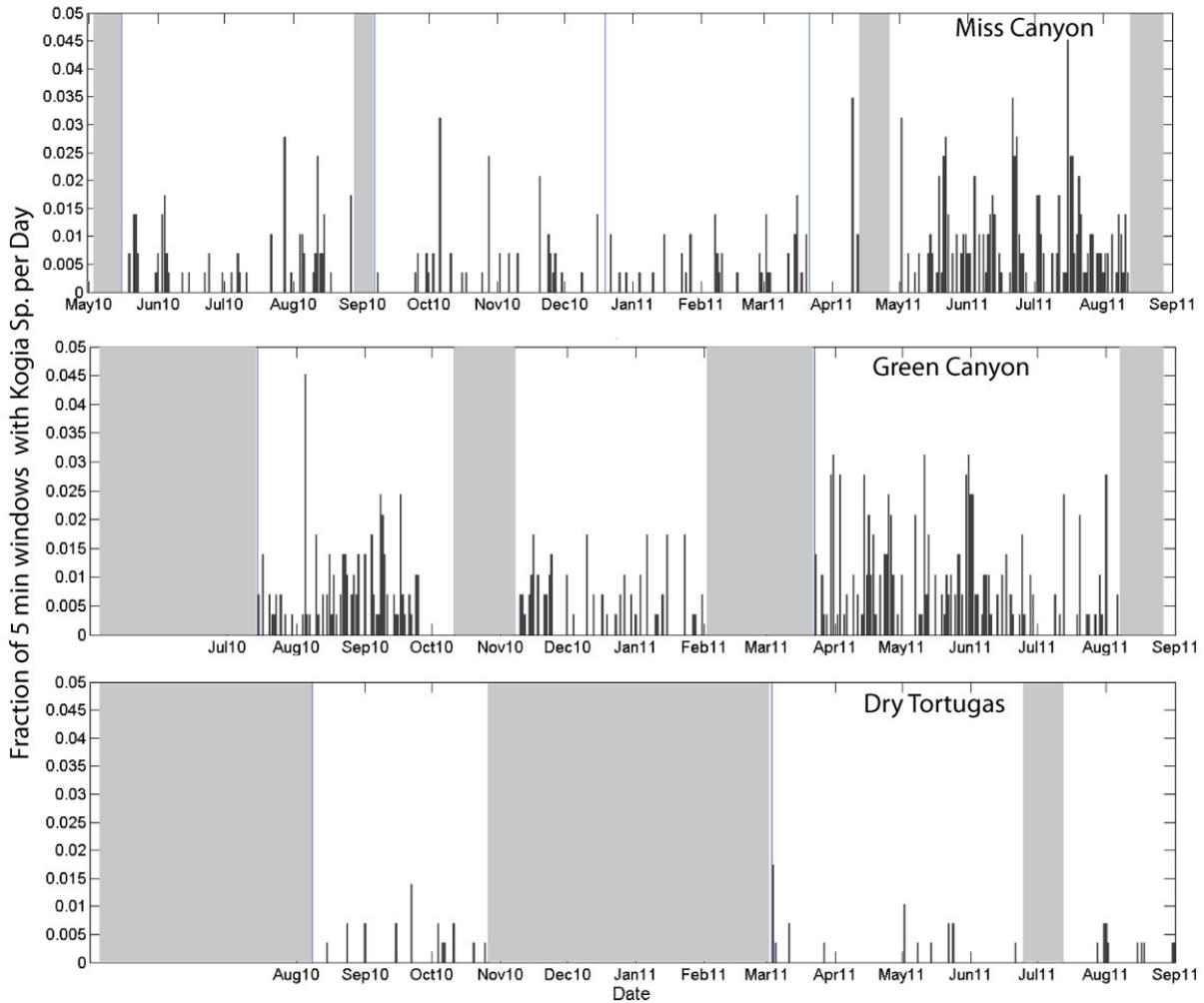


Figure 14. *Kogia* presence at Mississippi Canyon, Green Canyon and Dry Tortugas sites. Fraction of 5 minute windows with detections plotted daily between May 2010 and Aug 2011. Shaded areas lack data.

Density of *Kogia*

A density estimate for *Kogia* at each of the three deepwater HARP sites was calculated using equation (1) with the parameters summarized in Table 4. The density of *Kogia* varies between sites, and the Green Canyon site has the highest average density (28.0 animals/1000 km²).

Table 4. Density Estimates for *Kogia*.

Site	Density #/1000 km ²	N_{kt}/T_{kt} # groups/ #5 min windows	$I-C_k$ % True Detect	S Group Size	W Max Range (m)	P_k Prob Detect	P_v Prob Group Vocal
MC	18.9	0.0035	1.0	2.33±1.50	800	0.43	0.5
GC	28.0	0.0052	1.0	2.33±1.50	800	0.43	0.5
DT	5.9	0.0011	1.0	2.33±1.50	800	0.43	0.5

Beaked whales

Several species of beaked whales (Cuvier's, Gervais', Blainville's and Sowerby's) are known to strand in the northern GOM. The numbers of stranded animals are: Cuvier's (18), Gervais' (16), Blainville's (4), and Sowerby's (1). The abundance estimate for northern GOM Cuvier's beaked whales is 65 (CV=0.67) and the combined estimate for Gervais' and Blainville's beaked whale is 57 (CV=1.40) individuals (Mullin, 2007). Sowerby's beaked whale is thought to only rarely occur in the GOM. The acoustic signatures of these beaked whales are well known. They produce echolocation clicks with peak energy in the band 25 – 50 kHz, and can be classified by species on broadband acoustic recordings.

Much is known about the relation between diving and vocal behavior of beaked whales, in particular Blainville's and Cuvier's (Madsen *et al.*, 2005b; Zimmer *et al.*, 2005; Baird *et al.*, 2006; Johnson *et al.*, 2006; Tyack *et al.*, 2006). They produce echolocation clicks during the deeper part of their dives, and the probability of detecting beaked whales clicks as a function of distance from the sensor and other covariates has been studied (Marques *et al.*, 2009; Ward *et al.*, 2011). Based on a cue-based approach, their density was estimated from a single acoustic sensor in the Bahamas (Küsel *et al.*, 2011).

GOM HARP data were examined for beaked whales with the result that three distinctive acoustic echolocation signatures were found: Cuvier' beaked whale, Gervais' beaked whale, and an unknown species that we designate as the "53 kHz" beaked whale (Figure 15). Each of these beaked whales has a distinctive acoustic signature with respect to their frequency content, inter-pulse interval and frequency sweep rate. The Gervais' acoustic signatures can further be subdivided into two sub-groups, though the significance of this is unclear at present. We classify both signature subgroups as Gervais' based on prior recordings of signature spectra concurrent with visual identification. Blainville's and Sowerby's beaked whales, which could have been present based on their stranding records, were not found in the acoustic data. The "53 kHz" beaked whale has previously been reported from Cross Seamount near Hawaii (McDonald *et al.*, 2009), and is presumably a species with tropical distribution, but without simultaneous visual and acoustic detection. For the purposes of this report we will combine the three kinds of beaked whales detected in the GOM into a single density estimate. Beaked whale acoustic detections were obtained by manual scanning, and they contain no false alarms to the best of our knowledge.

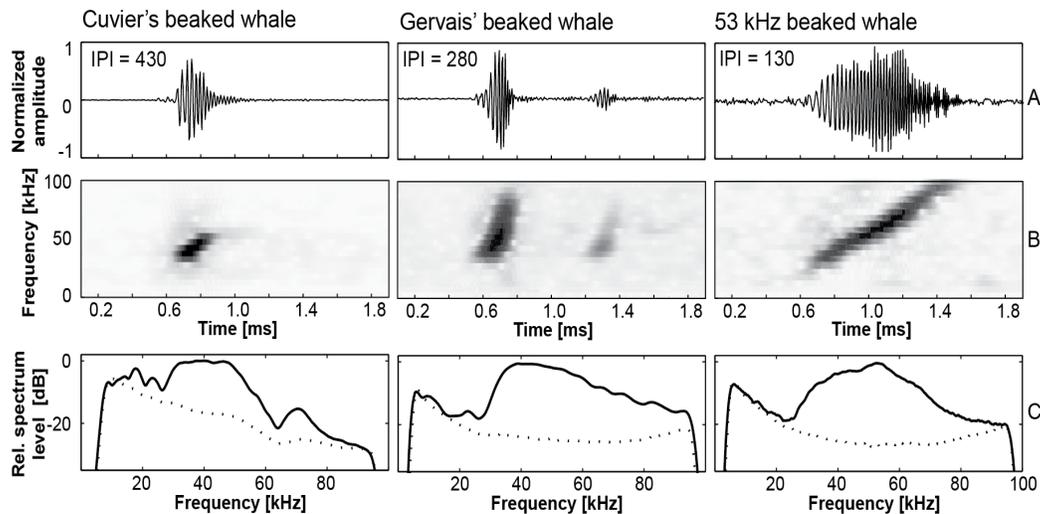
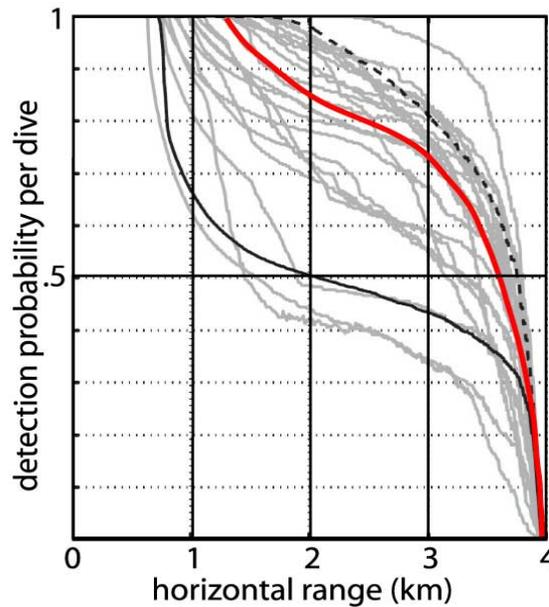


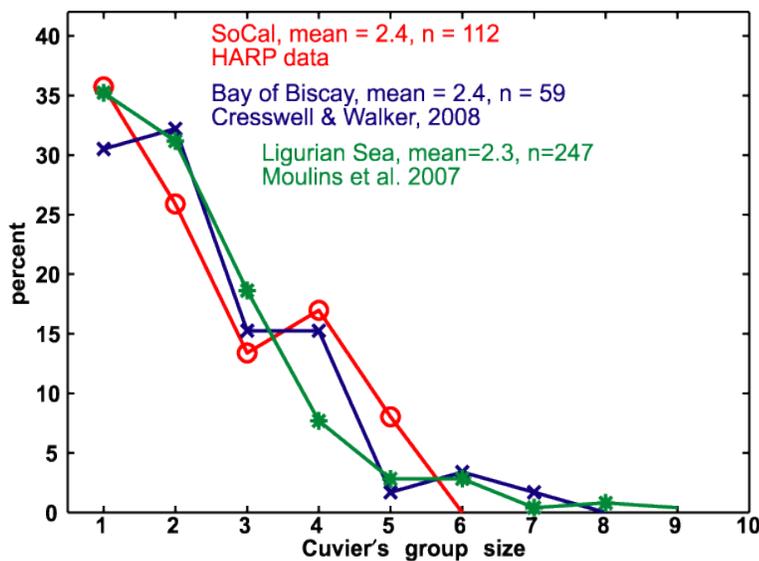
Figure 15. Acoustic signatures of beaked whales. Time series and inter-pulse interval (IPI in ms) (upper), spectrogram (middle) and spectral shape (lower) for Cuvier's (left), Gervais' (center) and an unknown species designated as "53 kHz" beaked whale (right). Dotted line shows noise floor.

Detection Range

The detection range of Cuvier’s beaked whale has previously been studied using tag data (Zimmer *et al.*, 2008). *Figure 16* shows detection functions derived from dives made by six individual Cuvier’s beaked whales. These data suggest that all dives within 700 m of the hydrophone will be detected, and that no dives beyond 4 km will be detected. For density estimation we will use a maximum detection radius of 4 km and detection probability (P_k) of 0.64, as obtained from *Figure 16*, and assume the same function for all sites.



*Figure 16. Detection functions for echolocating Cuvier’s beaked whales. The gray lines show the probability of detection for clicks generated during 23 dives made by six Cuvier’s beaked whales (Zimmer *et al.*, 2008). Red line is fitted average used for density estimation.*



*Figure 17. Group size distribution for Cuvier’s beaked whales derived from (red) acoustic data and (blue and green) visual data (Moulins *et al.*, 2007).*

Group Size

To estimate beaked whale group size we compared acoustic with visual group size estimates (Figure 17). The acoustic encounters were derived based on overlapping click sequences with consistent inter-click intervals. The visual estimates were based on surveys conducted in the Bay of Biscay and the Ligurian Sea (Moulins *et al.*, 2007). There is good agreement between the acoustic and visual group size estimates, with a mean of 2.4 animals.

Probability of Group Vocal Activity

As presented earlier beaked whales are known to be vocally active about 40% of the time, and simultaneous tracking of Cuvier's beaked whales (Wiggins *et al.*, 2012) suggests group vocal activity of about 50%.

Detection Rate for Beaked Whales

The daily detection rate of beaked whales at the Mississippi Canyon, Green Canyon and Dry Tortugas HARP sites are presented in Figure 18. The fraction of 5 minute windows with detections are plotted in daily bins over the period May 2010 to August 2011; we use a weekly average of these data for density estimation. The data reveal a significantly higher detection rate for beaked whales at the Dry Tortugas site. None of the sites show strong seasonal variations in detections, although the Dry Tortugas data set lacks complete seasonal coverage.

Density of Beaked Whales

A density estimate for beaked whales at each of the three HARP sites in deep water was calculated with the parameters summarized in Table 5. The density of beaked whales varies between sites. The Dry Tortugas site has a significantly higher average density (13.4 animals/1000 km²) for beaked whales than the two northern sites (2.6 animals/1000 km² at MC and 1.8 animals/1000 km² at GC). Although we have assumed the same detection probability (0.64) and maximum detection range (4 km) for all sites, variation in these parameters by site is one possible factor in the density estimate differences. Better understanding of site variations may result from acoustic propagation modeling. However, differences in detection probability are unlikely to be the sole explanation for the estimated differences in density between sites, given the large (>7) observed differences in detection rate (Table 5).

Table 5. Density Estimates for Beaked Whales.

Site	Density #/1000 km ²	N_{kt}/T_{kt} # groups/ #5 min windows	$I-C_k$ % True Detect	S Group Size	W Max Range (km)	P_k Prob Detect	P_v Prob Group Vocal
MC	2.6	0.0175	1.0	2.4	4.0	0.64	0.5
GC	1.8	0.0120	1.0	2.4	4.0	0.64	0.5
DT	13.4	0.0895	1.0	2.4	4.0	0.64	0.5

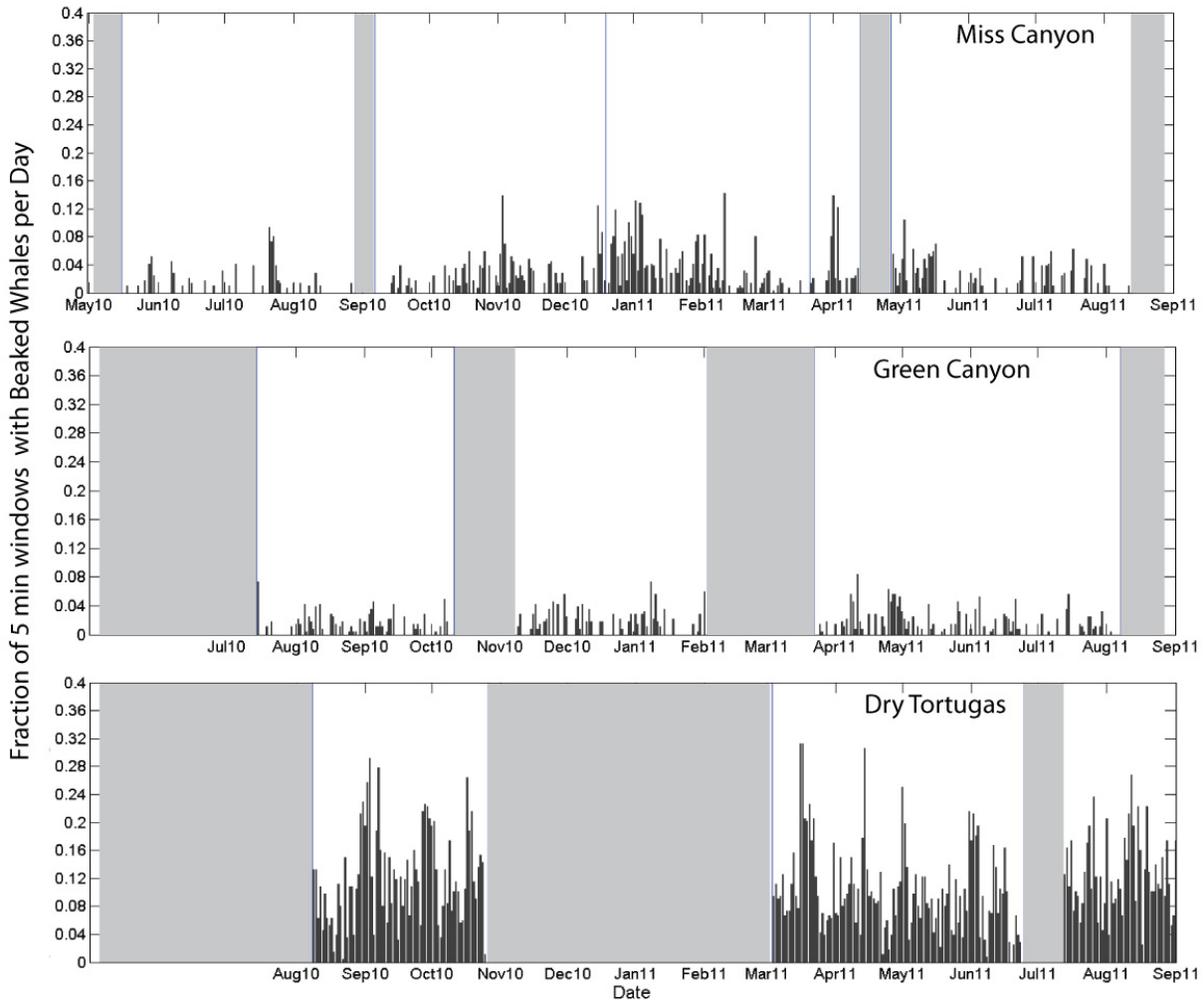


Figure 18. Beaked whale presence at Mississippi Canyon, Green Canyon and Dry Tortugas sites. Fraction of 5 minute windows with detections are plotted daily between May 2010 and Aug 2011. Shaded areas lack data.

Delphinids

A broad range of delphinid species are known to inhabit the offshore northern GOM including: bottlenose dolphin (Shelf and Oceanic), Risso’s dolphin, Atlantic spotted dolphin, pantropical spotted dolphin, Clymene dolphin, striped dolphin, rough toothed dolphin, melon-headed whale, spinner dolphin, false killer whale, short-finned pilot whale, pygmy killer whale, killer whale, and Fraser’s dolphin. The detailed acoustic repertoire for these species is not well known. More work is needed to allow their sounds to be distinguished by either acoustic analysts or with automatic classification methods.

For the purposes of this report we consider delphinids together as a group and not as individual species. Figure 19 shows dolphin presence at the 5 HARP sites, as the daily fraction of 5 minute windows with acoustic detections. The data reveal a significantly higher detection rate and a more steady presence (lower CV) for delphinids at the DeSoto Canyon HARP (Table 6) when compared to the other sites. The Main Pass site, in particular, has a highly variable delphinid presence (higher CV). These sites do not exhibit strong seasonal variations in detections (with the possible exception of Green Canyon),

although the DeSoto Canyon and Dry Tortugas sites lack a complete seasonal cycle of data, needed to test for seasonal variations.

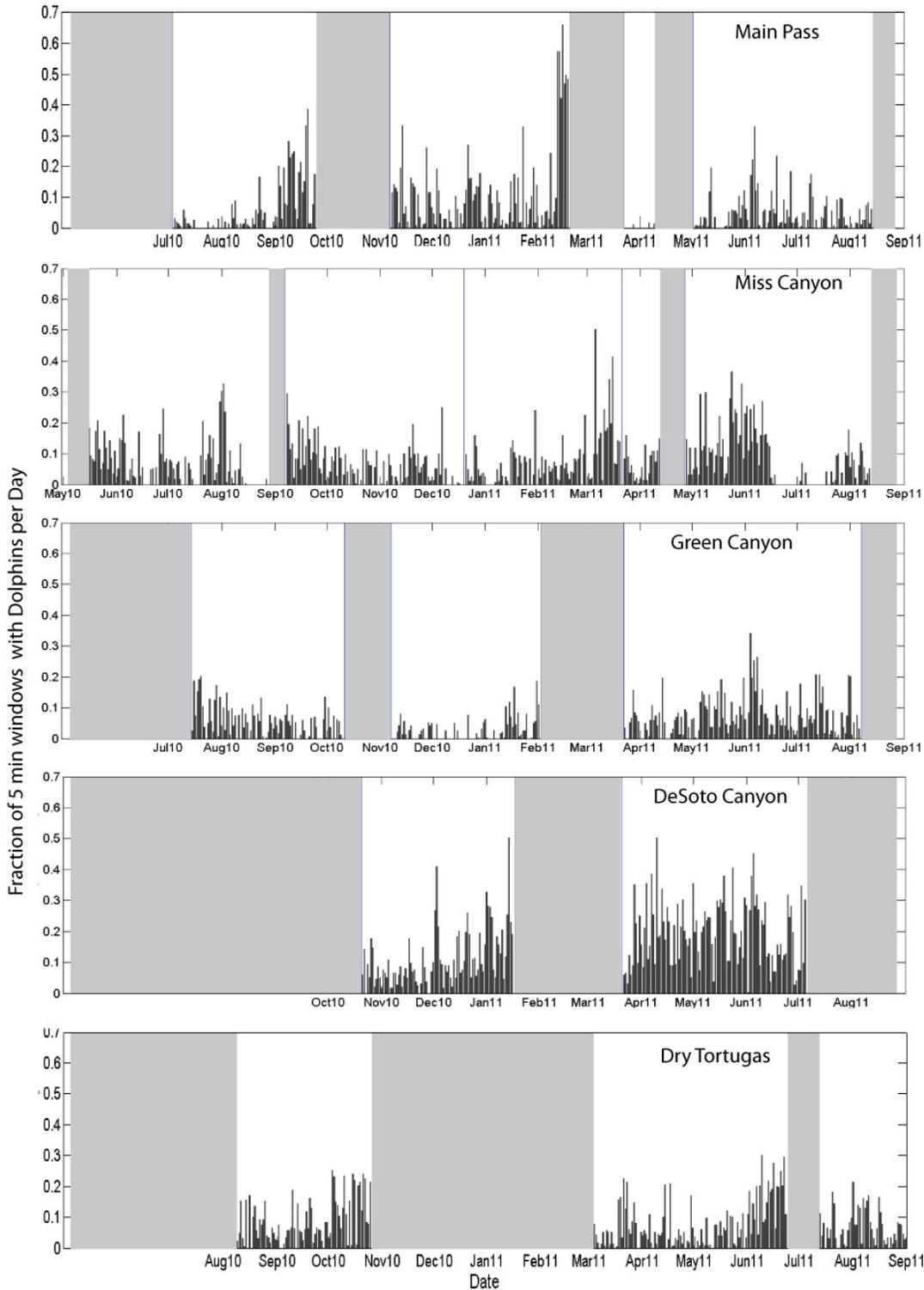


Figure 19. Delphinid presence at GOM HARP sites. Fraction of 5 minute windows with detections are plotted daily between May 2010 and Aug 2011. Shaded areas lack data.

Table 6. Presence of Delphinids at GOM HARP sites. Fraction of 5-minute windows with detections and associated CV.

Site	N_{kt}/T_{kt} # groups detected/ #5 min windows	CV
MP	0.068	1.214
MC	0.072	0.726
GC	0.054	0.649
DC	0.166	0.498
DT	0.081	0.589

Data are currently lacking on delphinid average group size, maximum detection range, and other parameters needed to estimate absolute density. Seasonal variations in acoustic propagation may occur between summer and winter (Figure 20). In the summer, an acoustic waveguide may be present near the sea surface, keeping much of the energy confined to the surface layer and limiting direct paths to the seafloor, where the HARP sensors are located. In the winter, a broader set of acoustic rays arrive at the seafloor. These differences in propagation are important for sounds that are generated near the sea surface, such as those made by delphinids. We plan to model these seasonal variations in acoustic propagation to better understand potential seasonal variations of the acoustic detection range for delphinids.

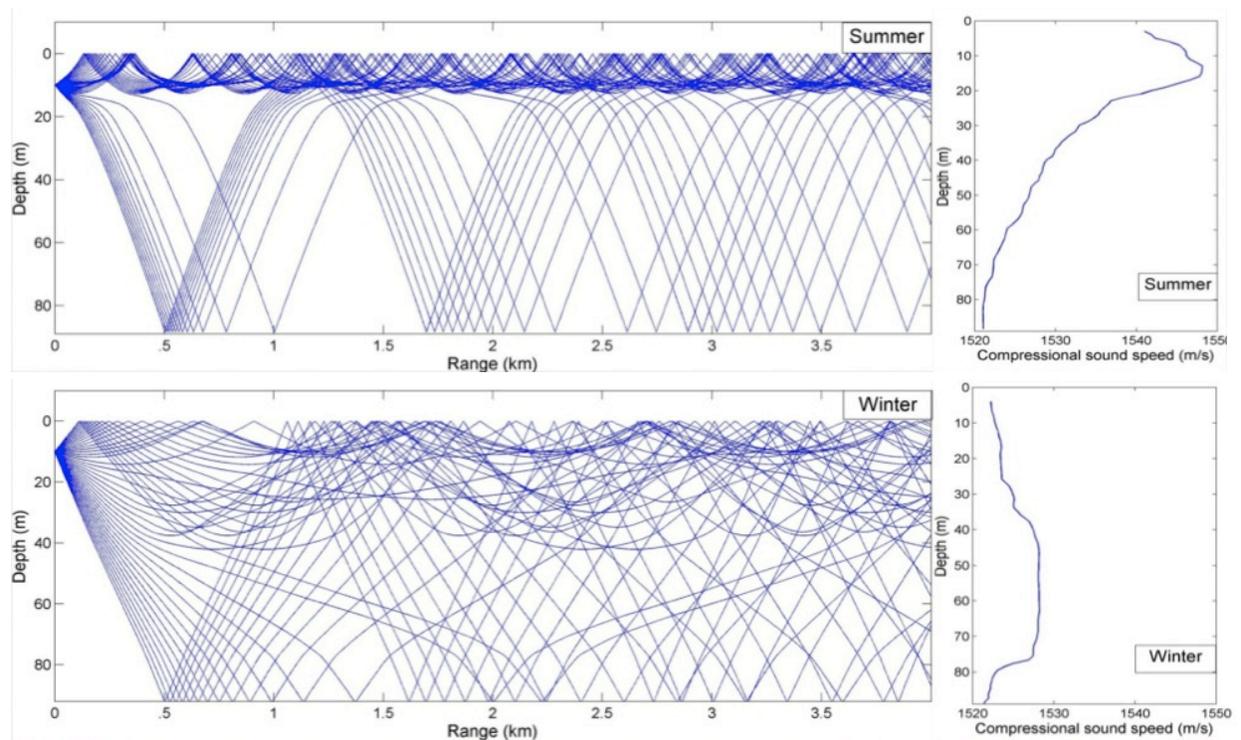


Figure 20. Ray-trace model (left) and sound speed profile (right) for Main Pass HARP site in summer (upper) and winter (lower). A warm surface layer in summer creates an acoustic waveguide.

Bryde's whale

Bryde's whales inhabit tropical and sub-tropical waters worldwide and, unlike most other baleen whale species, 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 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 cetacean population in the region (Maze-Foley and Mullin, 2006). Since the early twentieth century, there have been only four reported Bryde's whale strandings along the coast of the GOM (Mead, 1977). The number of individuals found in the U.S. Exclusive Economic Zone (EEZ) was estimated at 35 (CV=1.10) between 1991-1994 (Hansen *et al.*, 1995), and 40 (CV=0.61) between 1996-2001 (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). While it has been suggested that the GOM population is a distinct stock, no evidence exists to confirm their separation from the nearby southern Caribbean or Atlantic stocks (Waring *et al.*, 2009).

No calls have been described previously for free-ranging Bryde's whales in the GOM, but two call types have been recorded from a captive juvenile that stranded on the Gulf coast of Florida in 1988 (Edds *et al.*, 1993). In addition, one call type has been described in the southern Caribbean, a slight frequency downsweep of short duration (Oleson *et al.*, 2003).

Initial data to identify calls produced by Bryde's whales in the GOM were collected during the 2011 NOAA Fisheries' 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, MI, following the 200 m isobath (Figure 21). Trained marine mammal observers conducted a line transect survey for cetaceans using 25x "Big Eye" binoculars concurrently with a passive acoustic survey using a towed hydrophone array sampling between 1-250 kHz. In addition, Directional Frequency Analysis and Recording (DIFAR) AN/SSQ-53E sonobuoys were deployed in triangular arrays after 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 sound of interest. The signals from the sonobuoy are transmitted via a radio carrier frequency to a ship-mounted antenna. During AMAPPS cruise, an omnidirectional antenna with a pre-amplifier was used, which transmitted the signal to ICOM radio receivers modified for low-frequency response (Greeneridge Sciences Inc.). Incoming signals were monitored aurally via headphones and visually via a scrolling spectrogram in the software program *Ishmael* (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 post-analysis, recordings made during the encounters with Bryde's whales 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 (Greeneridge Sciences Inc.), and modified by David Mellinger (Oregon State University) and Mark McDonald (Whale Acoustics). When a bearing to the same call was extracted from more than one sonobuoy recording, the position of the source of that call was estimated from bearing crossings.

Time and frequency characteristics of all detected Bryde's whale calls were measured to define their features. Analyst measured features included: frequency minimum and frequency maximum picked

from spectrograms, and call start and end times picked from time series plots (band-pass filter 60-130 Hz). The duration of a call was calculated as the time 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 call bout.

To determine the call source level (SL), which is the sum of transmission loss and received level, we measured peak-to-peak received level of calls from sonobuoy recordings and estimated transmission loss from position information from crossed bearings. Transmission loss was calculated empirically, using the slope of the best-fit line through the calculated range to the source and measured received levels. The range was calculated as the distance between the sonobuoy deployment locations and the location of the crossing of bearings from multiple sonobuoys. This empirical transmission loss was found to be $15 * \log_{10}(\text{range})$. The source level of each call with measured bearing was calculated for each sonobuoy at which the call was recorded. The average source level and its standard deviation were calculated from the averages for each call based on the two individual calculations, but we also report the average difference in the calculated source level for individual calls.

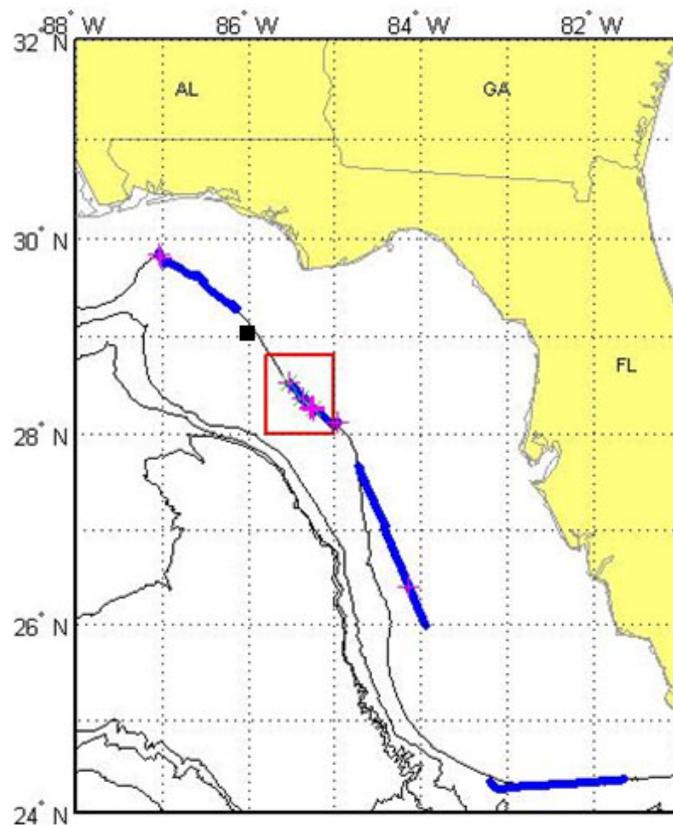


Figure 21. Locations surveyed from 28 July - 1 August 2011 during AMAPPS cruise. Tracks of visual survey effort are shown in blue solid lines, sonobuoy deployment locations are denoted with pink +, the initial Bryde's sighting locations are green x, and black square denotes DeSoto HARP location. Bathymetry lines shown at 200m, 1000m, 2000m, and 3000m. Red square is the approximate area of Bryde's whale sightings and recordings on 31 July 2011 expanded in Figure 22.

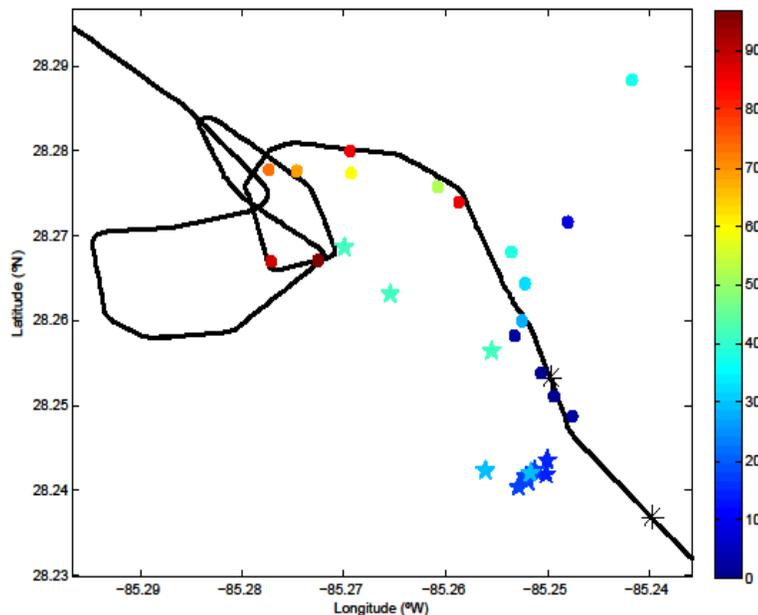


Figure 22. Acoustic localizations (stars) of the Bryde's whale calls and visual whale positions (dots) from the first 97 minutes of the 31 July 2011 sighting, with minutes elapsed since the initial sighting at 1430 denoted by color. Ship track shown as black line and sonobuoy deployment locations are black asterisks.

Three groups of Bryde's whales were encountered during the survey in the GOM, but calls of interest were recorded only during the encounter with the first group, the 31 July 2011 sighting at 1430 GMT (Figure 22). During this encounter, four Bryde's whales were observed diving, with no other identifiable behavior. Three DIFAR sonobuoys were deployed in an array (the first one immediately after the sighting, the second 11 min, and the third 42 min later). A small boat was deployed between the second and the third sonobuoy deployment. The NOAA ship *Gordon Gunter* and the small boat stayed with the group until 1800 GMT for a total of 3.5 hours and visual observers had 22 whale position updates during that time period.

One call type, consisting of pulse pairs, was identified as a likely Bryde's whale call based on the localization of the sound sources to the area of whale sightings (Figure 22) and its similarity to recordings of Bryde's whales in other regions. The recorded calls were frequency downswept pulse pairs (110 ± 4 to 78 ± 7 Hz), less than a second long (0.35 ± 0.06 s) with an IPI = 1.34 ± 0.13 s (Figure 23). No other baleen whale-like calls were recorded during this time. Seven pulse pairs (14 pulses total) were recorded simultaneously on two sonobuoys. No calls were recorded after the deployment of the small boat, thus no calls were recorded on all three sonobuoys. Of the 14 individual pulses, 11 were localized successfully. The first 8 pulses (recorded between 1443 GMT and 1458 GMT) were localized to an area 1 km west-northwest of the first sonobuoy deployment locations (Figure 22). The last three pulses (recorded between 1510 and 1514) were localized to an area northwest of both sonobuoys (Figure 22). The mean call SL was 155 ± 14 dB re: $1 \mu\text{Pa}$, @ 1 m but there was an average 23 dB difference in the individual SL values calculated from each sonobuoy. No other whales were sighted on 31 July, although a group of 4 bottlenose dolphins was sighted 27 minutes before the first Bryde's whale sightings. No other dolphins were sighted for five hours after the last Bryde's whale recording.

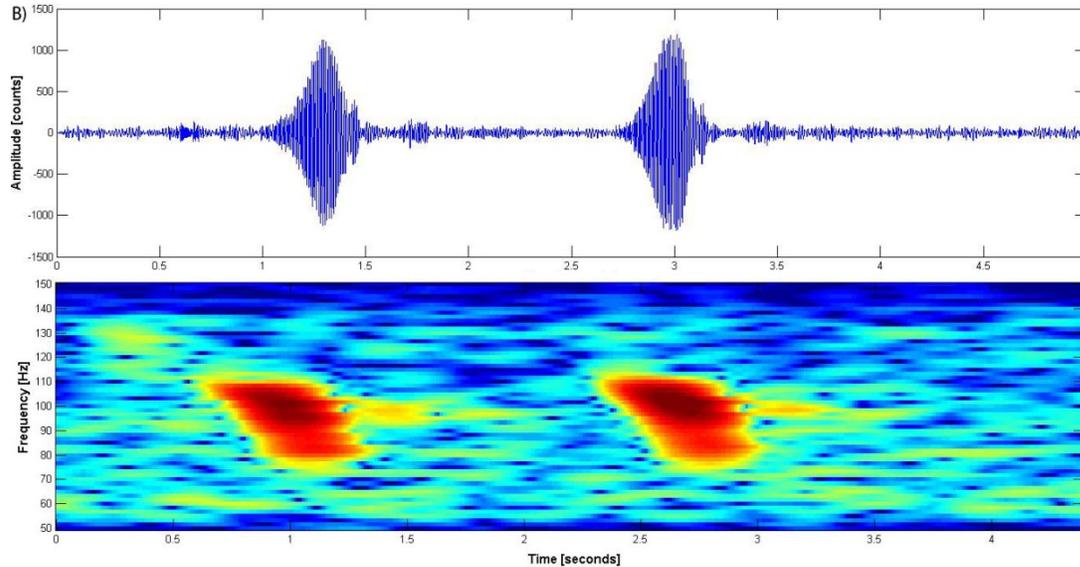


Figure 23. Two Bryde's whale pulses recorded with a sonobouy on 31 July 2011 (600-point FFT, 98% overlap, Hanning window, band-pass filter 60-130 Hz).

No possible baleen whale sounds were recorded during the second and third Bryde's whale sighting on 31 July. At 1841 GMT the antenna pre-amplification was lost, resulting in a significantly decreased radio signal reception range and may explain the lack of recordings during those sightings.

We provide the first description of free-ranging Bryde's whale calls in the GOM. The localized sources of the calls are within a few hundred meters of the visual observations of Bryde's whales around the times of calling bouts. Considering no other whales were sighted around the same time and these pulses are not similar to sounds from the only other species sighted in the vicinity, bottlenose dolphins (Lilly and Miller, 1961; Caldwell *et al.*, 1990; Baron *et al.*, 2008), we are confident these calls were produced by Bryde's whales. There are additional lines of evidence that support Bryde's whales as the source of these calls. First, a mismatch between visual observations and acoustic detections is frequently observed (Širovic *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 it made its calls. Second, calls reported here exhibit characteristics similar to those of Bryde's whales from other regions (Oleson *et al.*, 2003). While they are not an exact match with the calls recorded from a captive juvenile from this area, both types exhibit pulsed characteristics albeit in different frequency ranges (Edds *et al.*, 1993). Their difference, however, may be explained by the fact that one was produced by a juvenile while the life stage of whales producing the other calls is unknown, or it could be due to the vastly different context under which the calls were recorded (captive versus free-ranging). However, 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 that the calls reported here were produced by Bryde's whales. Subsequent efforts will be directed at identifying these calls in the HARP data and obtaining the parameters needed for density estimation from passive acoustic monitoring data.

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Appendix 1

Weekly sperm whale density estimates along with their CV and lower/upper bounds are presented for the Mississippi Canyon (MC), Green Canyon (GC) and Dry Tortugas (DT) HARPs. Also tabulated are the number of clicks detected and the number of 5-minute windows with clicks for each interval.

Site	Start Time	End Time	Time (Days)	# clicks	# 5min windows	Density Estimate	CV	Lower Bound	Upper Bound
MC	5/16/10 0:00	5/23/10 0:00	7.000	90089	411	6.31	0.135	4.85	7.98
MC	5/23/10 0:00	5/30/10 0:00	7.000	52935	456	7.00	0.134	5.39	8.84
MC	5/30/10 0:00	6/6/10 0:00	7.000	100455	742	11.39	0.131	8.83	14.32
MC	6/6/10 0:00	6/13/10 0:00	7.000	257425	673	10.33	0.131	8.00	13.00
MC	6/13/10 0:00	6/20/10 0:00	7.000	180438	874	13.42	0.130	10.41	16.84
MC	6/20/10 0:00	6/27/10 0:00	7.000	168909	816	12.53	0.130	9.71	15.73
MC	6/27/10 0:00	7/4/10 0:00	7.000	327963	966	14.83	0.130	11.52	18.60
MC	7/4/10 0:00	7/11/10 0:00	7.000	73989	273	4.19	0.139	3.19	5.34
MC	7/11/10 0:00	7/18/10 0:00	7.000	118928	678	10.41	0.131	8.06	13.09
MC	7/18/10 0:00	7/25/10 0:00	7.000	108231	642	9.86	0.132	7.62	12.40
MC	7/25/10 0:00	8/1/10 0:00	7.000	308377	988	15.17	0.130	11.78	19.03
MC	8/1/10 0:00	8/8/10 0:00	7.000	106425	290	4.45	0.139	3.40	5.66
MC	8/8/10 0:00	8/15/10 0:00	7.000	251228	801	12.30	0.130	9.53	15.45
MC	8/15/10 0:00	8/22/10 0:00	7.000	81278	445	6.83	0.134	5.26	8.63
MC	8/22/10 0:00	8/28/10 19:15	6.802	136837	584	9.23	0.132	7.13	11.62
MC	9/7/10 0:36	9/14/10 0:36	7.000	243581	707	10.86	0.131	8.41	13.65
MC	9/14/10 0:36	9/21/10 0:36	7.000	109405	878	13.48	0.130	10.46	16.92
MC	9/21/10 0:36	9/28/10 0:36	7.000	180268	894	13.73	0.130	10.65	17.23
MC	9/28/10 0:36	10/5/10 0:36	7.000	537320	1703	26.15	0.128	20.37	32.71
MC	10/5/10 0:36	10/12/10 0:36	7.000	462175	1451	22.28	0.128	17.34	27.89
MC	10/12/10 0:36	10/19/10 0:36	7.000	162174	1118	17.17	0.129	13.34	21.51
MC	10/19/10 0:36	10/26/10 0:36	7.000	155742	1214	18.64	0.129	14.50	23.35
MC	10/26/10 0:36	11/1/10 23:36	7.000	139728	878	13.48	0.130	10.46	16.92
MC	11/1/10 23:36	11/8/10 23:36	7.000	104519	473	7.26	0.134	5.59	9.17
MC	11/8/10 23:36	11/15/10 23:36	7.000	262952	1136	17.44	0.129	13.56	21.86
MC	11/15/10 23:36	11/22/10 23:36	7.000	397262	1608	24.69	0.128	19.23	30.89
MC	11/22/10 23:36	11/29/10 23:36	7.000	98916	633	9.72	0.132	7.52	12.23
MC	11/29/10 23:36	12/6/10 23:36	7.000	120328	693	10.64	0.131	8.24	13.38
MC	12/6/10 23:36	12/13/10 23:36	7.000	219364	1091	16.75	0.129	13.02	21.00
MC	12/13/10 23:36	12/19/10 19:11	5.816	85030	689	12.73	0.131	9.86	16.01
MC	12/20/10 2:05	12/27/10 2:05	7.000	63865	355	5.45	0.136	4.18	6.91
MC	12/27/10 2:05	1/3/11 2:05	7.000	49763	386	5.93	0.136	4.55	7.50
MC	1/3/11 2:05	1/10/11 2:05	7.000	316448	859	13.19	0.130	10.23	16.56
MC	1/10/11 2:05	1/17/11 2:05	7.000	87680	798	12.25	0.131	9.50	15.39

MC	1/17/11 2:05	1/24/11 2:05	7.000	197530	995	15.28	0.130	11.87	19.16
MC	1/24/11 2:05	1/31/11 2:05	7.000	390374	715	10.98	0.131	8.50	13.80
MC	1/31/11 2:05	2/7/11 2:05	7.000	157550	410	6.30	0.135	4.84	7.96
MC	2/7/11 2:05	2/14/11 2:05	7.000	64530	370	5.68	0.136	4.36	7.20
MC	2/14/11 2:05	2/21/11 2:05	7.000	98473	610	9.37	0.132	7.24	11.79
MC	2/21/11 2:05	2/28/11 2:05	7.000	340440	1285	19.73	0.129	15.35	24.71
MC	2/28/11 2:05	3/7/11 2:05	7.000	311671	1035	15.89	0.129	12.35	19.92
MC	3/7/11 2:05	3/14/11 2:05	7.000	178951	536	8.23	0.133	6.35	10.37
MC	3/14/11 2:05	3/21/11 2:05	7.000	242179	1063	16.32	0.129	12.68	20.46
MC	3/21/11 2:05	3/21/11 14:27	0.515	26468	99	20.65	0.161	15.10	27.16
MC	3/22/11 6:00	3/29/11 7:00	7.000	174789	924	14.19	0.130	11.01	17.80
MC	3/29/11 7:00	4/5/11 7:00	7.000	203935	824	12.65	0.130	9.81	15.89
MC	4/5/11 7:00	4/12/11 7:00	7.000	90616	413	6.34	0.135	4.87	8.02
MC	4/12/11 7:00	4/13/11 12:03	1.210	1	1	0.09	1.008	0.02	0.26
MC	4/27/11 9:58	5/4/11 9:58	7.000	91072	645	9.90	0.132	7.66	12.46
MC	5/4/11 9:58	5/11/11 9:58	7.000	266603	1061	16.29	0.129	12.66	20.42
MC	5/11/11 9:58	5/18/11 9:58	7.000	267152	684	10.50	0.131	8.13	13.21
MC	5/18/11 9:58	5/25/11 9:58	7.000	301139	897	13.77	0.130	10.69	17.28
MC	5/25/11 9:58	6/1/11 9:58	7.000	185644	710	10.90	0.131	8.44	13.70
MC	6/1/11 9:58	6/8/11 9:58	7.000	133276	697	10.70	0.131	8.29	13.46
MC	6/8/11 9:58	6/15/11 9:58	7.000	116505	672	10.32	0.131	7.99	12.98
MC	6/15/11 9:58	6/22/11 9:58	7.000	315843	1467	22.53	0.128	17.54	28.19
MC	6/22/11 9:58	6/29/11 9:58	7.000	124085	872	13.39	0.130	10.39	16.81
MC	6/29/11 9:58	7/6/11 9:58	7.000	111615	632	9.71	0.132	7.50	12.21
MC	7/6/11 9:58	7/13/11 9:58	7.000	114700	807	12.39	0.130	9.61	15.56
MC	7/13/11 9:58	7/20/11 9:58	7.000	25959	413	6.34	0.135	4.87	8.02
MC	7/20/11 9:58	7/27/11 9:58	7.000	85276	486	7.46	0.134	5.75	9.42
MC	7/27/11 9:58	8/3/11 9:58	7.000	136259	1011	15.53	0.129	12.06	19.47
MC	8/3/11 9:58	8/10/11 9:58	7.000	142239	803	12.33	0.130	9.56	15.48
MC	8/10/11 9:58	8/13/11 20:18	3.431	36194	328	10.28	0.137	7.86	13.04
GC	7/15/10 0:00	7/22/10 0:00	7.000	20671	221	1.82	0.140	1.39	2.32
GC	7/22/10 0:00	7/29/10 0:00	7.000	16640	133	1.10	0.151	0.82	1.42
GC	7/29/10 0:00	8/5/10 0:00	7.000	84449	382	3.15	0.133	2.43	3.97
GC	8/5/10 0:00	8/12/10 0:00	7.000	43353	207	1.71	0.141	1.30	2.18
GC	8/12/10 0:00	8/19/10 0:00	7.000	33990	366	3.02	0.134	2.32	3.81
GC	8/19/10 0:00	8/26/10 0:00	7.000	37440	114	0.94	0.155	0.70	1.22
GC	8/26/10 0:00	9/2/10 0:00	7.000	150587	483	3.98	0.131	3.08	5.01
GC	9/2/10 0:00	9/9/10 0:00	7.000	5602	111	0.92	0.155	0.68	1.19
GC	9/9/10 0:00	9/16/10 0:00	7.000	46803	77	0.63	0.168	0.46	0.84
GC	9/16/10 0:00	9/19/10 19:16	3.803	100565	208	3.16	0.141	2.40	4.03
GC	9/20/10 5:25	9/20/10 11:41	0.261	0	0	0.00	0.000	0.00	0.00
GC	9/20/10 14:40	9/26/10 16:42	6.085	8173	119	1.13	0.153	0.84	1.47

GC	9/27/10 10:13	10/4/10 10:13	7.000	4572	27	0.22	0.228	0.14	0.32
GC	10/4/10 10:13	10/11/10 10:13	7.000	1523	55	0.45	0.183	0.32	0.62
GC	10/11/10 10:13	10/11/10 19:52	0.402	410	34	4.88	0.211	3.24	6.90
GC	11/8/10 2:00	11/15/10 2:00	7.000	262176	978	8.06	0.127	6.29	10.07
GC	11/15/10 2:00	11/22/10 2:00	7.000	130146	562	4.63	0.130	3.60	5.82
GC	11/22/10 2:00	11/29/10 2:00	7.000	67542	454	3.74	0.132	2.90	4.71
GC	11/29/10 2:00	12/6/10 2:00	7.000	7194	184	1.52	0.143	1.15	1.94
GC	12/6/10 2:00	12/13/10 2:00	7.000	74414	236	1.95	0.139	1.48	2.48
GC	12/13/10 2:00	12/20/10 2:00	7.000	84466	415	3.42	0.132	2.64	4.31
GC	12/20/10 2:00	12/27/10 2:00	7.000	110597	455	3.75	0.132	2.90	4.72
GC	12/27/10 2:00	1/3/11 2:00	7.000	45310	401	3.31	0.133	2.55	4.17
GC	1/3/11 2:00	1/10/11 2:00	7.000	55822	116	0.96	0.154	0.71	1.25
GC	1/10/11 2:00	1/17/11 2:00	7.000	30767	178	1.47	0.144	1.11	1.88
GC	1/17/11 2:00	1/24/11 2:00	7.000	2729	120	0.99	0.153	0.73	1.29
GC	1/24/11 2:00	1/31/11 2:00	7.000	0	0	0.00	0.000	0.00	0.00
GC	1/31/11 2:00	2/2/11 16:23	2.599	0	0	0.00	0.000	0.00	0.00
GC	3/23/11 0:00	3/30/11 1:00	7.000	7964	90	0.74	0.162	0.54	0.98
GC	3/30/11 1:00	4/6/11 1:00	7.000	213	15	0.12	0.286	0.07	0.19
GC	4/6/11 1:00	4/13/11 1:00	7.000	6345	175	1.44	0.144	1.09	1.85
GC	4/13/11 1:00	4/20/11 1:00	7.000	15167	378	3.12	0.133	2.40	3.93
GC	4/20/11 1:00	4/27/11 1:00	7.000	41008	211	1.74	0.141	1.32	2.22
GC	4/27/11 1:00	5/4/11 1:00	7.000	8014	81	0.67	0.166	0.48	0.88
GC	5/4/11 1:00	5/11/11 1:00	7.000	55169	580	4.78	0.130	3.71	6.00
GC	5/11/11 1:00	5/18/11 1:00	7.000	166176	505	4.16	0.131	3.23	5.23
GC	5/18/11 1:00	5/25/11 1:00	7.000	152817	507	4.18	0.131	3.24	5.25
GC	5/25/11 1:00	6/1/11 1:00	7.000	21198	283	2.33	0.137	1.79	2.96
GC	6/1/11 1:00	6/8/11 1:00	7.000	179914	705	5.81	0.129	4.52	7.28
GC	6/8/11 1:00	6/15/11 1:00	7.000	31718	317	2.61	0.135	2.01	3.31
GC	6/15/11 1:00	6/22/11 1:00	7.000	70952	639	5.27	0.129	4.09	6.60
GC	6/22/11 1:00	6/29/11 1:00	7.000	100077	566	4.67	0.130	3.62	5.86
GC	6/29/11 1:00	7/6/11 1:00	7.000	227295	1542	12.72	0.126	9.95	15.85
GC	7/6/11 1:00	7/13/11 1:00	7.000	106959	1033	8.52	0.127	6.65	10.64
GC	7/13/11 1:00	7/20/11 1:00	7.000	183253	745	6.14	0.128	4.78	7.69
GC	7/20/11 1:00	7/27/11 1:00	7.000	69875	542	4.47	0.130	3.47	5.61
GC	7/27/11 1:00	8/3/11 1:00	7.000	60471	353	2.91	0.134	2.24	3.68
GC	8/3/11 1:00	8/7/11 22:46	4.907	270	40	0.47	0.200	0.32	0.66
DT	8/9/10 0:00	8/16/10 0:00	7.000	3001	62	0.33	0.177	0.23	0.44
DT	8/16/10 0:00	8/23/10 0:00	7.000	0	0	0.00	0.000	0.00	0.00
DT	8/23/10 0:00	8/30/10 0:00	7.000	2862	47	0.25	0.191	0.17	0.34
DT	8/30/10 0:00	9/6/10 0:00	7.000	0	0	0.00	0.000	0.00	0.00
DT	9/6/10 0:00	9/13/10 0:00	7.000	2459	65	0.34	0.175	0.24	0.46
DT	9/13/10 0:00	9/20/10 0:00	7.000	539	34	0.18	0.211	0.12	0.25

DT	9/20/10 0:00	9/27/10 0:00	7.000	0	0	0.00	0.000	NA	0.00
DT	9/27/10 0:00	10/4/10 0:00	7.000	0	0	0.00	0.000	NA	0.00
DT	10/4/10 0:00	10/11/10 0:00	7.000	4451	39	0.21	0.202	0.14	0.29
DT	10/11/10 0:00	10/18/10 0:00	7.000	0	0	0.00	0.000	NA	0.00
DT	10/18/10 0:00	10/25/10 0:00	7.000	7436	58	0.31	0.180	0.22	0.41
DT	10/25/10 0:00	10/26/10 10:06	1.421	0	0	0.00	0.000	0.00	0.00
DT	3/4/11 0:00	3/11/11 0:00	7.000	3767	101	0.53	0.158	0.39	0.70
DT	3/11/11 0:00	3/18/11 0:00	7.000	301	19	0.10	0.260	0.06	0.15
DT	3/18/11 0:00	3/25/11 0:00	7.000	2020	33	0.17	0.213	0.12	0.25
DT	3/25/11 0:00	4/1/11 1:00	7.000	1805	63	0.33	0.176	0.24	0.45
DT	4/1/11 1:00	4/8/11 1:00	7.000	1554	50	0.26	0.187	0.18	0.36
DT	4/8/11 1:00	4/15/11 1:00	7.000	900	36	0.19	0.207	0.13	0.27
DT	4/15/11 1:00	4/22/11 1:00	7.000	3483	81	0.43	0.166	0.31	0.57
DT	4/22/11 1:00	4/29/11 1:00	7.000	0	0	0.00	0.000	0.00	0.00
DT	4/29/11 1:00	5/6/11 1:00	7.000	4012	143	0.76	0.149	0.57	0.98
DT	5/6/11 1:00	5/13/11 1:00	7.000	7048	250	1.32	0.138	1.01	1.68
DT	5/13/11 1:00	5/20/11 1:00	7.000	9084	99	0.52	0.159	0.38	0.69
DT	5/20/11 1:00	5/27/11 1:00	7.000	952	42	0.22	0.197	0.15	0.31
DT	5/27/11 1:00	6/3/11 1:00	7.000	9	2	0.01	0.718	0.00	0.03
DT	6/3/11 1:00	6/10/11 1:00	7.000	31765	505	2.67	0.131	2.07	3.35
DT	6/10/11 1:00	6/17/11 1:00	7.000	79051	914	4.83	0.127	3.76	6.03
DT	6/17/11 1:00	6/24/11 1:00	7.000	41132	646	3.41	0.129	2.65	4.28
DT	6/24/11 1:00	6/24/11 8:27	0.311	0	0	0.00	0.000	0.00	0.00
DT	7/13/11 0:00	7/20/11 0:00	7.000	2272	85	0.45	0.164	0.33	0.59
DT	7/20/11 0:00	7/27/11 0:00	7.000	18861	367	1.94	0.134	1.49	2.45
DT	7/27/11 0:00	8/3/11 0:00	7.000	4557	49	0.26	0.189	0.18	0.35
DT	8/3/11 0:00	8/10/11 0:00	7.000	3665	86	0.45	0.164	0.33	0.60
DT	8/10/11 0:00	8/17/11 0:00	7.000	4925	39	0.21	0.202	0.14	0.29
DT	8/17/11 0:00	8/24/11 0:00	7.000	60	5	0.03	0.464	0.01	0.05
DT	8/24/11 0:00	8/31/11 0:00	7.000	490	17	0.09	0.272	0.05	0.14