**Supplementary Information**

**Analysis Methods: Passive Acoustic Monitoring**

All acoustic data were analyzed after completion of the surveys. Analyses were manually accomplished through the use of Raven audio spectrogram software (K. Lisa Yang Center for Conservation Bioacoustics, Cornell Lab of Ornithology: https://ravensoundsoftware.com/). Because the data were recorded at a sample rate of 96 kHz, resulting in an analysis frequency range of 48 kHz, the data were initially viewed at a high resolution using a 32768-point window size and discrete Fourier transform, a Hann window, a 75% overlap, and a spectrogram page size of 60 seconds, resulting in a frequency resolution of 3 Hz and a time resolution of 0.085 seconds. Each station was analyzed separately two times; the full-scale data were viewed first followed by analysis of the 0-500 Hz range. Inspection of the full-scale data allowed for an initial general overview of the dataset and for observation of potential mid- and high-frequency activity by dolphin species, beaked whales, sperm whales (*Physeter macrocephalus*), and West African manatees (*Trichechus senegalensis*), all of which have been observed previously in the region. Inspection of the lower 0-500 Hz range facilitated close observation of the low frequency vocalization region occupied by large baleen whales known to have been observed in the area: southern right whales (*Eubaleana australis*), fin whales (*Balaenoptera physalus*), common minke whales (*B. acutorostrata*), Antarctic minke whales (*B. bonaerensis*), sei whales (*B. borealis*), Bryde’s whales (*B. edeni*/*brydei*), and humpback whales (*Megaptera novaeangliae*). To search for the infrasonic song notes of blue whales (*B. musculus*), the data were decimated to 200 Hz (SoX - Sound eXchange: [http://sox.sourceforge.net/](about:blank)) and investigated using Raven spectrogram software with a 2048‐point window size and DFT, a Hann window, and 75% overlap, resulting in a frequency resolution of 0.1 Hz and a time resolution of 2.6 seconds. An hour-long spectrogram page size was used.

In developing the analysis methodology, some exploration of data decimation/resampling was undertaken, and some investigations of filtering were made. The question of filtering arose in connection with the high degree of acoustic activity generated by the vessel during stationary benthic sampling periods. Noise up to approximately 25 kHz was consistently present throughout the dataset. It was most prominent in the 0-500 Hz frequency range and was found to mask potential low frequency vocalizations. Muted images, perhaps representing humpback song sequences and possibly right whale contact calls, were faintly visible in many of the acoustic recordings. However, these sounds were not found to be audible. Attempts to filter the data were undertaken with the goal of potentially increasing the signal to noise ratio within the 0-500 Hz range so that these sounds might be heard and/or observed more clearly in the spectrogram visualizations. However, after several attempts (which included explorations using Audacity audio software: [https://www.audacityteam.org/](about:blank)), it was found that it was not possible to effectively separate signal from noise within this dataset. For similar reasons, investigations involving down-sampling the data were made (again with Audacity audio software), but results from the observation of the resulting down-sampled data from several stations did not improve upon the initial wide frequency range and high analysis resolution approach.

The acoustic data were collected in connection with benthic sampling efforts at specific stations within the Study Area offshore of the shelf break (**Figure 1**). As a result, the acoustic detection of coastal-dwelling species (e.g., manatees) was not expected. Also, as mentioned previously, low frequency vessel noise tended to obscure and mask the low frequency calls of baleen whales. However, because a range of odontocete species have been observed in the region and visual sightings of odontocetes were documented (see sightings results below), a third analysis approach was undertaken to focus on high frequency and ultrasonic sounds. For this approach, data were viewed with a 2048-point window size and a DFT of 4096 points, with a Hann window, 90% overlap, and spectrogram page size of 5 seconds, resulting in a frequency resolution of 23.4 Hz and a time resolution of 2.14 milliseconds. Initial observation of the data revealed click sequences and buzzes characteristic of odontocete species known to have been observed in the region (e.g., beaked whales, delphinids, killer whales [*Orcinus orca*], pilot whales [*Globicephala* spp.], sperm whales, and pygmy/dwarf sperm whales [*Kogia* spp.]).

Because of the short time scale required to observe the characteristic sounds produced by these species for which the analysis of time-series data provides information complementary to spectrographic analysis, high pass filtering was applied to the dataset. This procedure resulted in an analysis frequency range spanning about 25-48 kHz. As indicated previously, data below about 25 kHz contained almost continuous vessel noise which masked the potential detection of marine mammals whose sound-producing ranges intersected that frequency region. Low frequency vessel noise also generated energy above 25 kHz, so filtering out lower frequencies also removed noise from the region above 25 kHz. This procedure facilitated the detection of sounds with characteristics similar to those of odontocetes.

In general, with respect to the following analyses and results, it seems wise to keep in mind that “the study of rapidly pulsed acoustic sequences in cetaceans is in its infancy, and the functional role of repeated or patterned pulsed signals in most odontocetes is poorly understood” (Martin et al., 2019).

Because this study aimed to opportunistically collect acoustic detections of marine mammals that were present in the region and it was not designed to obtain aligned visual and acoustic data, our analyses focused on the goal of investigating potential sources of observed sounds attributed to marine mammals known to inhabit the study region. Our approach takes into consideration: 1) this study’s visual sightings data, 2) general information regarding species that have previously been observed in the deep waters off Angola, and 3) specific characteristics of our acoustic data and their potential alignment with sounds that have been previously associated with specific marine mammal species.

It is important to note that this study is not intended to be exhaustive but rather to describe a general investigation of a subset of sounds observed within the dataset that appeared to be of particular interest with regard to the possibility that they may have been produced by odontocetes. Our focus is primarily on sounds within the 25-kHz to 48-kHz range due to the presence of mechanical noise in the lower frequencies of our dataset as previously described.

**Results: Passive Acoustic Monitoring**

As one means of developing potential conjectures regarding which species might be considered as possible sources of these sounds, we first reviewed sightings that occurred roughly within the surrounding spatial area and within relatively contiguous time periods. We began by looking at sightings which occurred closest to the acoustic data collection time period, followed by others that occurred at more distant times (see **Table 1**).

**Table 1. Subset of marine mammal sightings and associated acoustic recordings.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Date** | **Initial Sighting Time (hr:min:s)** | **Sighting Location or Recording Station** | **Common Name** | **Scientific Name** | **Group Size** | **Behavior** | **Acoustic Recording Begin Time (hr:min)** | **Acoustic Recording End Time (hr:min)** |
| 7 Sept 2018 | 15:23:09 | Transit | Unidentified delphinid | N/A | 24 | Traveling | --- | --- |
| 7 Sept 2018 | 17:38:23 | Transit | Atlantic spotted dolphin | *Stenella frontalis* | 75 | Traveling, bowriding | --- | --- |
| 7-8 Sept 2018 | --- | Station 25 | --- | --- | --- | --- | 23:05 | 2:12 |
| 8 Sept 2018 | 16:51:04 | Station 21 | Probable southern right whale | *Eubalaena australis* | 2 | Traveling | --- | --- |
| 8 Sept 2018 | 17:13:40 | Station 21 | Common dolphin | *Delphinus* spp. | 50 | Social, traveling | --- | --- |
| 8 Sept 2018 | --- | Station 18 | --- | --- | --- | --- | 17:48 | 20:11 |
| 12 Sept 2018 | 15:48:37 | Station 30 | Unidentified delphinid | N/A | 40 | Unknown | --- | --- |
| 12 Sept 2018 | 16:35:05 | Station 30 | Unidentified delphinid | N/A | 5 | Traveling | --- | --- |
| 12 Sept 2018 | 17:11:17 | Station 30 | Unidentified delphinid | N/A | 75 | Traveling | --- | --- |
| 14 Sept 2018 | --- | Station 17 | --- | --- | --- | --- | 21:09 | 23:45 |
| 16 Sept 2018 | 13:34:59 | Transit | Striped dolphin | *Stenella coeruleoalba* | 65 | Milling | --- | --- |

We focused our exploration on click sequences because the low frequency noise constrained our usable frequency range to 25-48 kHz, and the whistle sounds attributed to odontocete species are generally found below 25 kHz. Also, click sequences were the most frequently observed delphinid sounds found in our data.

We describe potential sources for these groups of sounds found in three subsets of the entire dataset beginning chronologically with sounds recorded near the time of the right whale sighting. We next refer to recorded sounds preceding that sighting, and finally we describe sounds recorded about a week afterwards. The three groups of sounds are: 1) a subset of data collected on 8 September in the early evening between 17:48 and 20:11 near the time that right whales were sighted; 2) a second subset collected previous to that sighting between 23:05 (just before midnight) on 7 September and 2:12 in the early morning of 8 September; and 3) a third subset collected in the late evening between 21:09 and 23:45 on 14 September, almost a week after the right whale sighting (**Table 1**).

In connection with the first data subset, a group of animals identified as either short-beaked or long-beaked common dolphins (*Delphinus capensis* or *D. delphis*—the sighting vessel was too far away to determine species level) with a maximum estimated group size of 50 was sighted in the vicinity of Station 21 (**Figure 2**) in the late afternoon (17:13) on 8 September. These animals were observed to be interacting with the two right whales that were initially sighted just about a quarter of an hour beforehand at 16:51. Observers noted a large amount of leaping and splashing by the dolphins near the whales.

About half an hour after this common dolphin sighting, acoustic data for this first data subset began to be collected at Station 18 (starting at 17:48) located about 12 km from Station 21. If the right whale and common dolphin behavior continued to be ongoing at this time, it is possible that we may have captured at least some sounds produced by these common dolphins during their behavioral interactions with the two right whales.

As mentioned previously, the low frequency vocalizations of right whales ranging up only to about 500 Hz were not observed, potentially due to masking by the continuous presence of vessel noise in the data throughout this frequency range. However, as noted, this low frequency noise did not extend above about 25 kHz. The 25-kHz to 48-kHz range encompasses a segment of the lower range of frequencies in which sounds made by common dolphins have been observed (Dziedzic, 1978; Au, 1993; Richardson et al., 1995; Soldevilla et al., 2008; Henderson et al., 2012).

#### Common Dolphin (*Delphinus* spp.)

It is not unlikely that enough sound energy may have remained over the 12-km propagation distance for sounds within the 25-48 kHz range, produced in the vicinity of Station 21, to be acoustically detected at Station 18. In frequencies spanning the 10-40 kHz range, the sound energy lost over a 12-km distance (due to sound absorption by the ocean, which takes place through the conversion of sound energy into heat) ranges from approximately 12-120 dB re 1μPa (Tyack & Clark, 2000). Although the measurement of source levels of click sequences made by delphinid species in the wild has generally been found to be extremely difficult to accomplish, Rasmussen, Miller, and Au were able to determine a reliable source level range for clicks made by free-ranging white-beaked dolphins, *Lagenorhynchus albirostris* Gray 1846 (Goold, 1996; Rasmussen et al., 2002). This source level measurement is centered at about 200 dB re 1μPa. Using it as a rough guide for common dolphin sound production suggests that even with a reduction in energy of 120 dB, some energy would remain that might possibly allow common dolphin sounds produced near Station 21 to be detected in data collected by the hydrophone 12 km away at Station 18.

We found low amplitude instances of click sequences in these data, and although these click sequences lie within the 23-67 kHz range linked to common dolphins (Dziedzic, 1978; Au, 1993; Richardson et al., 1995), because common dolphins have not yet been found to produce distinctive, species-specific clicks (Soldevilla et al., 2008; Henderson et al., 2012), we can only suggest that these animals may perhaps be one of the sources of these click sequences.

#### Atlantic Spotted Dolphin (*Stenella frontalis*)

The second acoustic data subset was collected much earlier in the morning of 8 September at Station 25 (southeast of both Station 18 and Station 21). Data collection began on 7 Septemberjust before midnight (23:05) and ended after about 3 hours (at 2:12 in the morning of 8 September). A group of sounds, clear representatives of those generally associated with delphinids, were chosen from the 2 hours of data collected between midnight and 2:00 on 8 September.

Within a somewhat contiguous time period earlier in the afternoon of 7 September at 17:38 (about 6 hours before the acoustic data collection session), as the vessel was initially transiting to Station 25 from the southeast, a group of Atlantic spotted dolphins (maximum estimated group size of 75 individuals), including calves, was sighted traveling and bow riding near the vessel.

Additionally, about two hours previous to this sighting of Atlantic spotted dolphins, a group of traveling unidentified delphinids (with a maximum estimated size of 24 individuals) was observed at 15:23 during the vessel’s transit from the southeast.

Atlantic spotted dolphin clicks are bimodal. They are characterized by a high peak frequency within 110-130 kHz and a low peak frequency within 40-50 kHz (Au & Herzing, 2003). These peaks appear to occur alternately at different intensities depending on the signal level. Although the high peak frequency lies beyond the 48 kHz upper frequency limit of our data, the click sequences in this data subset all span most of the 40-50 kHz range within which low click peak frequencies have been observed. Because of the 48 kHz upper frequency limit of our data and potential masking by noise below 25 kHz, we cannot determine the full bandwidth of these broadband clicks. Therefore, although we cannot state that click peak frequencies are definitively present in these data, we suggest that these animals may plausibly be a source of these sounds.

#### Multiple Delphinid Species

The third acoustic data subset containing sounds potentially attributable to odontocete species was made on the evening of 14 September between 21:09 and 23:45 at Station 17. We again note sightings that occurred within roughly contiguous time periods and spatial locations as a step toward potentially identifying species that may be conjectured as potential sources of these sounds.

On the afternoon of 12 September (roughly two days preceding this third acoustic data collection session), three groups of unidentified delphinids were sighted in the vicinity of Station 30 which was about 40 km from Station 17. Station 30 is located within a group of nine stations, all approximately 1 km distant from one another (**Figure 2**). The first group of delphinids (with an estimated maximum group size of 40 individuals) was sighted in the middle of the afternoon at 15:48. The second group (with an estimated maximum group size of only 5 animals) was sighted at about an hour later at 16:35; these animals appeared to be traveling. The third and largest group (with an estimated maximum group size of 75 individuals) was sighted at 17:11; these animals also appeared to be traveling. A typical traveling speed for dolphins is about 11 km per hour (Au & Weihs, 1980; Williams et al., 1993; Rohr et al., 2002), so it is plausible that these groups of dolphins may have travelled over the 40 km from Station 30 to Station 17 in the course of two days.

Another sighting potentially useful in suggesting specific species as sound sources for these data occurred early in the afternoon (13:34) on 16 September, roughly a day and a half following the acoustic recording session. A pod of milling striped dolphins (with an estimated maximum group size of 65 individuals) was sighted as the vessel transited between Stations 24 and 25 (approximately 30 km from Station 17). Using 11 km per hour as a typical traveling speed, it is reasonable to suggest that these striped dolphins could have moved from the vicinity of Station 17 to this location over the intervening day and a half.

In addition, over the 5 or 6 days between this third acoustic data collection session and the two described previously, it may also be the case that the common dolphins sighted near the right whales may also have traveled from Station 21 to Station 17 and could also be considered as a potential source of the click sequences found in this third data subset. Likewise, the Atlantic spotted dolphins sighted during transit from the southeast into this area of the study region also could have traveled farther northwest into this area.

Clearly, all sighted delphinid species, as well as other delphinids that have been observed previously in the region, may be potential sources for any of the sounds comprising these three acoustic data subsets. However, the frequency range constraints of our data bias our ability to detect some species over others. Previous observations of specific frequency ranges spanned by click sequences and approximate lengths of inter-click intervals (ICIs) attributed to individual species have suggested a set of possible species classifications.

However, the potential for definitive linking of specific dolphin species to these (and other) parameters is just now beginning to be investigated, and in many cases only a small number of measured observations have so far been made (Henderson et al., 2012). Keeping in mind that our data’s limited frequency range constrains the marine mammal acoustic activity we can observe within the study region, our purpose here is to attempt, with reference to previous studies, only to provide conjectures regarding specific species as sources for observed sounds.

Our classification criteria centered primarily around frequency ranges: 1) that intersected the available frequency range of our data (25-48 kHz) and 2) were within click sequences from species known to inhabit the region had been previously observed. These criteria included, in some cases, assessments of frequency ranges containing peak frequencies or center frequencies. In a few cases, characteristic ICI measurements were available. The most stringent criteria included the presence of “click packets” as an identifying feature of click sequences made by the rough-toothed dolphin (*Steno bredanensis*) (Au ,1993; Miyazaki & Perrin, 1994; Richardson et al., 1995; Flores & Ximinez 1997; Soldevilla et al., 2008; Baumann-Pickering et al., 2010; Roch et al., 2011; West et al., 2011; Baumann-Pickering et al., 2015; Rankin et al., 2015; Rankin et al., 2017; Jefferson, 2018). However, no click sequences containing these click packets were found, perhaps due in part to the comparatively high specificity of this feature.

As a result of this approach to classification, the available acoustic criteria tend towards the general rather than the specific, which broadens the outline of our study so that in itself it tends towards being more inclusive than exclusive. However, it is certainly the case that sounds attributed to a number of odontocete species known to inhabit the region were clearly not found in these data.

Within the combined three click sequence data subsets, all of the sequences were attributable to any one of three species based on their previously observed click frequency ranges: common dolphins (Dziedzic, 1978; Au, 1993; Richardson et al., 1995; Soldevilla et al., 2008; Henderson et al., 2012), striped dolphins (Zanardelli et al., 1990; Gannier, 1999; Kastelein et al., 2003; Archer, 2018) and spinner dolphins (*Stenella longirostris*) (Lammers et al., 2003; Schotten et al., 2004; Benoit-Bird & Au, 2009; Baumann-Pickering et al., 2010; Perrin, 2018). A total of 83% of the click sequences aligned with the frequency range observed for Fraser’s dolphins (*Lagenodelphis hosei*) (Watkins et al., 1994; Dolar, 2018; Voices in the Sea [Scripps], accessed 19 June 2020), and 79% aligned with the frequency range attributed to Risso’s dolphins (*Grampus griseus*) (Au, 1993; Richardson et al., 1995; Corkeron and van Parijs, 2001; Neves, 2013; Hartman, 2018).

The 83% of the click sequences coincided with both the frequency range and a set of observed characteristic ICI measurements for bottlenose dolphins (*Tursiops truncatus*) (Diercks et al., 1971; Au et al., 1974; Au, 1993; Richardson et al., 1995; Baumann-Pickering et al., 2010; Luís et al., 2016; Wells & Scott, 2018; Accomando et al., 2020), and 88% potentially contained center frequencies at 40 kHz, a characteristic feature of click sequences produced by false killer whales (*Pseudorca crassidens*) (Kamming & van Velden, 1987; Thomas & Turl, 1990; Richardson et al., 1995; Baird, 2018).

For those species known to inhabit the region and whose peak frequency ranges significantly overlapped our data’s available frequency range, 79% of the click sequences were classified as potentially having been made by either Atlantic spotted dolphins (Au & Herzing, 2003; Lammers et al., 2003; Herzing & Perrin, 2018) or pantropical spotted dolphins (*Stenella attenuata*) (Jefferson, 2015; Schotten et al., 2004; Gong et al., 2019).

We also included two sets of criteria consisting of characteristic peak frequencies that only partially overlapped the 25-48 kHz available frequency range of our data. With this approach, 71% of the click sequences were classifiable as potentially having been made by killer whales (Diercks et al., 1971; Richardson et al., 1995; Au, 2004; Ford, 2018; Holt et al., 2019) and 58% as potentially having been made by pygmy killer whales (*Feresa attenuata*) (Madsen et al., 2004; Baird, 2018).

Two studies were used as references to determine the extent to which melon-headed whales (*Peponocephala electra*) may have been sound sources. In the first study, for a group size of 50 animals, median peak frequencies of averaged clicks were found to span 24.4-29.7 kHz (Baumann-Pickering et al., 2010). The second study’s data had an upper frequency limit of 24 kHz, and strong click energy was found within 13-24 kHz. In addition, the authors suggested that it appeared likely that the frequency content of the clicks extended well beyond the 24-kHz limit. Because our data’s usable lower frequency limit is 25 kHz, we could only conjecture that click energy might possibly extend down to a 13 kHz lower limit. Also, neither study clearly specified an upper frequency limit. As a result, although 50% of the click sequences contained energy that *potentially* extended below 25 kHz and was also present to some extent within the 25-48 kHz range, we could only speculate that melon-headed whales might be a source of these click sequences (Mullin et al., 1994; Richardson et al., 1995; Baumann-Pickering et al., 2010; Frankel & Yin 2010; Kaplan et al., 2014; Perryman & Danil, 2018).

Two of the click sequences were also speculatively (and hesitatingly) based on a very small number of ICI measurements potentially attributable to either Blainville’s beaked whales (*Mesoplodon densirostris*) (Richardson et al., 1995; Johnson et al., 2004; Madsen et al., 2005; Madsen et al., 2013; MacLeod, 2018) or Gervais’s beaked whales (*Mesoplodon europaeus*)(Gillespie et al., 2009; MacLeod, 2018).

**Recommendations**

**Acoustics Studies**

Future environmental baseline studies in this region would benefit from the following acoustics methods and equipment:

* Record acoustic data covering the broadest possible frequency range given the wide range of marine mammal species occurring in this region;
* Utilize autonomous units to record away from the vessel in order to minimize vessel noise interference within the range of complex vocalizations made by baleen whales and sperm whales and to capture, in addition to characteristic ultrasonic click sequences, odontocete whistles which would assist in providing important additional information regarding species identification; and
* Utilize long-term autonomous units deployed year-round to minimize vessel noise interference and to determine seasonal presence of specific species and animal groups.

**Visual Surveys**

We recommend the following protocols for future visual surveys in this region:

* Utilize 25x150 power binoculars (one mounted on the port side and one mounted on the starboard side) to enable 360-degree scans around the survey vessel and to maximize the distance at which MFOs can detect and identify marine fauna, which is particularly important during benthic surveys because the vessel’s position is relatively fixed, and MFOs are able to visually scan only a small portion of the overall study area and are prevented from approaching marine fauna to confirm species identifications and group size estimates;
* Utilize a minimum of four MFOs to minimize observer fatigue and promote greater alertness during observations (e.g., four MFOs rotate through the following stations: port side observer, starboard side observer, data recorder, and rest);
* Conduct year-round systematic line transect surveys to determine spatial and temporal distribution patterns and baseline abundance/density estimates of marine species in this region (for methods see CODA, 2009; Hammond et al., 2013; Whitt et al., 2013, 2015), which will enable industry representatives to calculate changes in abundance over time, particularly before, during, and after any seismic and/or drilling operations; and
* Invest in large-scale regional line transect surveys covering lease blocks of different oil and gas companies in order to obtain useful and statistically sound data about marine fauna across international boundaries and to ensure that all stakeholders have quantitative data available to use for determining potential impacts and benefits of anthropogenic activities on marine fauna and to effectively monitor biodiversity in their areas of interest.
* Photographs of the individual humpback whales sighted during our study can be used to develop a humpback whale photo-identification database or catalog which is currently lacking for this region. Suitable photographs of humpback whales from future studies can be added to the catalog and used to compare matches to gain a better understanding of humpback whale occurrence in this part of the eastern tropical Atlantic.

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# Figure and table legend

Table 1. Subset of marine mammal sightings and associated acoustic recordings.