Whistle source levels of free-ranging bottlenose dolphins and Atlantic spotted dolphins in the Gulf of Mexico

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Whistles of bottlenose dolphins (Tursiops truncatus) and Atlantic spotted dolphins (Stenella frontalis) in the eastern Gulf of Mexico were recorded and measured with a calibrated towed hydrophone array. Surveys encountered groups of both bottlenose (N = 10) and spotted dolphins (N = 5). Analysis of those data produced 1695 bottlenose dolphin whistles and 1273 spotted dolphin whistles with a high signal-to-noise ratio. Whistle frequency metrics were lower in bottlenose than spotted dolphins, while whistle duration was longer in spotted dolphins, data that may help inform automatic classification algorithms. Source levels were estimated by determining the range and bearing of an individual dolphin from the array and then adding the predicted transmission loss to the calculated received level. The median bottlenose dolphin source level was 138 dB re 1 μPa at 1 m with a range of 114–163 dB re 1 μPa at 1 m. The median spotted dolphin source level was 138 dB re 1 μPa at 1 m with a range of 115–163 dB re 1 μPa at 1 m. These source level measurements, in conjunction with estimates of vocalization rates and transmission loss models, can be used to improve passive acoustically determined dolphin abundance estimates in the Gulf of Mexico.

I. INTRODUCTION

Dolphin whistle frequency contour and duration characteristics are well described in the scientific literature (reviewed in Au and Hastings, 2008). However, source levels for wild odontocetes whales rarely have been measured. Measured species include white-beaked dolphins (Lagenorhynchus albirostris, Rasmussen et al., 2006), spinner dolphins (Stenella longirostris, Watkins and Schevill, 1974) as well as two populations of bottlenose dolphins (Tursiops truncatus, Janik, 2000; Tursiops spp., Jensen et al., 2012).

Passive acoustic recorders make it feasible to monitor large areas of water for acoustically active marine species. Rates of acoustic occurrence and/or the temporal pattern of those signals can be used in resource monitoring and ecosystem management. However, it is not possible to determine the active space of the passive acoustic recorders without knowledge of the statistical distribution of whistle source levels. By incorporating source level characteristics of dolphin whistles with the propagation characteristics of the environment and vocalization rates, passive acoustic data can be used in population assessments. Specifically, the measurements can be refined from a metric of whistles per hour to a relative density metric of whistles/unit area/h.

Although the source level of whistles is typically less than those of echolocation clicks, whistles are produced at lower frequencies and therefore have less directionality and propagate farther than echolocation clicks (Miller, 2002; Lammers and Au, 2003). Because of these qualities, dolphin whistles may be more reliable for detecting dolphins. Source level values, along with transmission loss estimates, provide the data needed to predict the range-dependent probability of detection of dolphin whistles. These data can also be used for both the analysis of autonomous recorder data as well as general behavioral assessment.

Marine mammal source levels have also figured into recent studies of the effects of increasing anthropogenic noise levels (Hatch et al., 2008; Clark et al., 2009). These studies have begun to address ecosystem level changes in communication range given a known animal source level and changes in the ambient noise levels.

The goal of this study was to measure whistle characteristics and source levels from two species of dolphins commonly found on the West Florida Shelf: The bottlenose dolphin and the Atlantic spotted dolphin.

II. METHODS

A calibrated towed hydrophone array was used to record dolphins in the Gulf of Mexico off Florida; this made it possible to calculate accurate received levels. Acoustic source localization methods applied to the array data measured the range and bearing to whistling dolphins. The range was used to predict transmission loss, which was added to the received sound level to produce the source level estimates. Source level data presented in this study are broadband RMS measurements, reported as dB re 1 μPa at 1 m.

A. Field operations and hardware

Data were collected during cruises of the R/V Eugenie Clark (14 m with twin inboard engines) during April 2008.
and April–May 2009. The vessel left Mote Marine Laboratory (Sarasota, FL) in the morning and headed offshore while visually searching for dolphins. A typical search pattern included a high speed (~15 kn) run to the 30 m isobath whereupon the vessel would slow to ~10 kn and continue searching. These offshore waters were deep enough to safely deploy the hydrophone array. Furthermore, this offshore area typically had larger dolphin pods that were more likely to be vocalizing than the smaller inshore groups (Hawkins and Gartside, 2010). Figure 1 shows the study location, bathymetry, and vessel tracks for all surveys. The bottom surface sediment in these areas was predominantly sandy with grain sizes ranging from 1.0 to 2.5 phi (Hallock et al., 2010).

Once a dolphin group was located, the Innovative Transducers, Inc. (“squid”) hydrophone array was deployed. The active section of the array had sixteen elements irregularly spaced over its 120 m length. Approximately 50 m of the lead-in cable was deployed to keep the array “flying” shallow enough (estimated at <10 m below the surface) to prevent contact with the ocean floor. When towing the array, the vessel maintained a linear course while passing slowly by the dolphins at about 1–2 kn. This helped keep the towed array straight. Once past the dolphins, when the received signal level began to drop, the vessel then reversed course and returned to the dolphin group. Data collected during vessel turns, when the hydrophone array was curved, were eliminated from source level analysis.

The analog output from the array was filtered and amplified with Alligator Technologies SCS-820 filter boards housed in an SCS-800 chassis. The eight-pole Bessel low-pass filters were set to a corner frequency of 30 kHz. A National Instruments PCI-6071E card installed in a Dell Precision 380 workstation digitized the filtered data at a sampling rate of 64 kHz. Data were collected using ISHMAEL (Mellinger, 2001) in 2008 and RAVEN (Charif et al.; 2007) in 2009.

B. Hydrophone calibration

To calibrate the hydrophone array, a Tektronix AFG321B signal generator produced a 10 s frequency sweep (1 Hz to 30 kHz). A Hafler P1000 amplifier projected the signal through a Lubell Labs UW30 underwater speaker. Each element of the array was, in turn, placed about 2 m in front of the Lubell projector along with a reference hydrophone of known sensitivity; a Reson TC4013 (−212 dB re 1 V/μPa; 1 Hz to 170 kHz) connected to a VP1000 amplifier. The reference hydrophone was placed as close to the array element as possible, and several frequency sweeps were simultaneously digitized from both the array element and the reference hydrophone. Later, a fast Fourier transform (1024 points) was performed on the digitized signals to obtain the response amplitude as a function of frequency. The frequency response of the array elements decreased in sensitivity above 4 kHz by 1.2 dB/kHz. Between 1 Hz and 4 kHz, the array elements were 17.3 ± 2.9 dB (n = 12) more sensitive than the Reson hydrophone. Therefore the array sensitivity was determined to be −194 dB re 1 V/μPa with a roll off in sensitivity of 1.2 dB/kHz above 4 kHz.

C. Whistle data analysis

Only single species groups were observed. An operator manually reviewed the recordings to identify high signal-to-noise (SNR) whistles using the XBAT program (Figueroa, 2007) that presented the data as multichannel spectrograms. Spectrogram settings included a 50% overlap and 1024 point FFT and used a Hanning window. Whistles were manually identified and recorded as “events,” which are time and frequency limits that encompass the entire fundamental frequency contour of each whistle. Each whistle event was exported as a multichannel file with 0.5 s of additional data before and after the event.

The data from each whistle file was analyzed with a custom MATLAB program (Mathworks Inc., Natick, MA). The program read the data samples and converted them to pressure values using the calibration value for the hydrophone array and the amplifier gain. The data were high-pass filtered at 2 kHz to remove vessel noise. An ambient noise selection for each whistle was hand-selected for each whistle file. The ambient noise intensity value was subtracted from the whistle recording to calculate the received sound level. The frequency of peak energy was determined, and the high-frequency roll-off function for the array was used to correct the received level value.

The minimum and maximum frequencies and the duration of each whistle were also measured by hand. The frequency of peak energy was measured with a MATLAB program. These acoustic characteristics were compared between species. Because we recorded groups of dolphins, it is possible that individuals were unequally represented in our samples. Therefore traditional frequentist statistics were inappropriate. Instead, the minimum and maximum frequencies as well as whistle duration were evaluated using a resampling permutation test (Kaplan, 1999). In this procedure, a random sample representing 10% of each measure for each species (127 for Stenella, 170 for Tursiops) was
selected from the entire sample for both species. The mean difference in this sample was calculated. The procedure was repeated 1000 times. The resulting distribution represents the resampled difference between populations under the null hypothesis. The observed difference in means between whistle metrics of the two species was then compared to the resampled null hypothesis distribution. The probability that the observed difference would be found in the resampled null hypothesis distribution was determined.

1. Range estimation

The process of acoustic localization using sparse hydrophone array data is well established (Watkins and Schevill, 1974). Given a known geometry of passive receivers, the only additional data required for localization are the speed of sound in water and the relative time of arrival delays between all pairs of receivers. The most basic technique to measure time of arrival differences is to cross correlate pairs of incoming waveforms (or spectrograms) and select the time value with the largest cross-correlation value as the time of arrival difference (Clark and Ellison, 2000). This simple procedure, referred to as “peak-picking” works well in simple acoustic environments (e.g., shallow Arctic isothermal waters). However, in areas with more complex propagation, the peak of the cross-correlation function may not represent the actual time delay value. Rather it may be found in one of the local maxima (or “subpeaks”) that typically occur within the cross-correlation function. There are multiple computational methods to address this issue (e.g., Spiesberger, 2005). The correlation sum estimation (CSE) locator function (Cortopassi, personal communication) was used to produce dolphin location estimates for these data.

The CSE locator software is an implementation of a band-pass filtered near field beamforming source location algorithm. The inputs to the beamformers are the waveforms at each sensor. A search space is defined around the array. For each candidate location within the search space, the waveforms are delayed and summed as if they originated from that candidate location. The energy sum is then calculated for the candidate location. Next the program searches for an energy maximum within a given radius of the array centroid using a stochastic search algorithm. The candidate location with the maximum energy output of the beamformer is selected as the estimated location of the signal source. The search grid used here was a $4 \times 4$ km grid with a 10 m spacing centered on the array.

2. Transmission loss calculation

To predict transmission loss, acoustic integration model (Frankel et al., 2002) simulations were created for five dolphin recording locations (see Table I) that were chosen to span the maximum possible range of water depths (15–38 m) for all recording sessions. In each simulation, the Bellhop propagation model (Porter and Bucker, 1987) predicted the transmission loss as a function of range. Twelve propagation simulations were run for each location. These consisted of a source dolphin at depths of 1, 2, 5, and 10 m and a receiver at depths of 2, 5, and 10 m. The median and median absolute deviation at each range step were calculated, and a logarithmic curve was fit to each median result.

The source modeling frequency was 7.5 kHz. April sound velocity profiles were extracted from the Generalized Digital Environmental Model Variable Resolution (V 2.5) database (Oceanographic and Atmospheric Material Library, 2000) and are shown in Fig. 2(A). Bathymetry was obtained from the NGDC Coastal Relief Model at a three arc-second resolution (NOAA National Geophysical Data Center, 2009). A surface wind speed of 10 kn was specified to inform the surface loss model. A bottom loss function was calculated for a sandy bottom (Jackson and Richardson, 2007) and is shown in Fig. 2(B). Bellhop model parameters included the following: 1600 rays, a ray fan span of $-90^\circ$ to $90^\circ$.

![Graph A](image)

**TABLE I. Transmission loss calculation sites.**

<table>
<thead>
<tr>
<th>Modeling site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Water depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26.8°N</td>
<td>82.9°W</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>27.2°N</td>
<td>83.3°W</td>
<td>38</td>
</tr>
<tr>
<td>3</td>
<td>27.5°N</td>
<td>83.0°W</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>27.6°N</td>
<td>83.0°W</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>27.1°N</td>
<td>82.8°W</td>
<td>21</td>
</tr>
</tbody>
</table>

![Graph B](image)

**FIG. 2.** The sound velocity profiles extracted from GDEMENV are shown in panel (A). The bottom loss function calculated for a sandy bottom is shown in (B).
þ90°, coherent calculation mode and the inclusion of Thorp attenuation. The results were ranged averaged using a 1/3 octave setting (Harrison and Harrison, 1995). These simulations predicted transmission loss as a function of range.

III. RESULTS

The vessel surveyed 8 days during 2008 and 11 days during 2009. Surveys encountered groups of both bottlenose dolphins (N = 10) and spotted dolphins (N = 5). Spotted dolphins, on average, were found in significantly deeper water than bottlenose dolphins (30.8 m vs 21.8 m; T = 3.3, p < 0.01). Recordings were made on 11 days with a total of 32.5 h of data recorded. Analysis of the recordings produced 1695 bottlenose dolphin whistles and 1273 spotted dolphin whistles with a high signal-to-noise ratio (±10 dB). The CSE locator estimated the location of the source of each whistle. A total of 1030 whistles were acoustically located within 500 m of the array. The received level of each of these whistles was calculated.

A. Transmission loss calculation

Water depth can affect acoustic propagation. The transmission loss model was therefore run for depths that covered the range of recording sites. The transmission loss curves for the locations with depths of 20, 21, 27, and 38 m were very similar. Spreading coefficients for logarithmic curves [TL = C × log10(range)] fit to these data had values of C = 18.01, 18.10, 18.7 and 18.18 with a median of 18.13 (Fig. 3). The shallower modeling location (15 m) had a spreading coefficient of C = 18.92. Therefore the shallow water curve was used for all recordings in water less than 20 m. The largest median absolute deviation for the five sites was 3.9 dB, and this value was used as a measure of uncertainty in the transmission loss prediction for all locations.

B. Whistle characteristics

The sampling rate limited the frequency response of the system to 32 kHz, and the frequency roll-off of the array also somewhat limited the ability to record higher frequencies. Nevertheless the data appeared to include the majority of the fundamental frequencies with few instances (21 of 2975) of the fundamental frequency exceeding the frequency range of the recording system. It is therefore possible to present data on whistle characteristics (Table II).

The distributions of duration values were highly skewed toward shorter whistles in both species. The median duration of spotted dolphins whistles (median = 0.35 s) was significantly longer than those of bottlenose dolphins (median = 0.27 s). The minimum frequencies of the bottlenose dolphin whistles were also significantly lower than those from spotted dolphins. The median values were 4050 and 5263 Hz, respectively. Likewise, the highest frequency of the whistles was significantly higher for spotted dolphins (median = 12.561 Hz) than for bottlenose dolphins (median = 9250 Hz). The frequency of peak energy also showed the same effect, with bottlenose dolphins (median = 6312 Hz) being significantly lower than the spotted dolphins (median = 7562 Hz).

Permutation tests were used to test for differences in these whistle measures between species (Kaplan, 1999). Figure 4 shows the resampled null hypothesis distribution created by the permutation test and the observed difference in whistle metrics between the two species. The observed differences were far greater than any value reported by the permutation test statistic. The probability that the observed difference would be drawn from the permutation statistics distribution is < 0.001. It is therefore concluded that all of

| TABLE II. Descriptive statistics of whistle frequency characteristics for the two species. |
|---------------------------------|-----------------|-----------------|
| Low frequency, 2.5th percentile | 2041; 268 Hz    |
| Low frequency, median           | 5263; 4050 Hz   |
| Low frequency, s.d.             | 1798; 1922 Hz   |
| Frequency of peak energy, median| 7562; 6312 Hz   |
| Frequency of peak energy, s.d.  | 1943; 2612 Hz   |
| High frequency, median          | 12561; 9250 Hz  |
| High frequency, 97.5th percentile| 20868; 18115 Hz |
| High frequency, s.d.            | 3843; 3807 Hz   |
| Duration, (s) 2.5th percentile  | 0.07; 0.08 s    |
| Duration, median                | 0.34; 0.27 s    |
| Duration, 97.5th percentile     | 1.43; 1.42 s    |
| Duration, s.d.                  | 0.38; 0.39 s    |
| N                               | 1273; 1695      |

FIG. 3. A logarithmic curve (black line) fit to calculated transmission loss data for 12 source-receiver pairs with varying depths (gray circles). These model results are for one modeling site but illustrate the observed variation in transmission loss depending upon the depth of the sound source and receiver.
the measured whistle characteristics are significantly different between these two species.

C. Source level results

The median source level for both bottlenose and spotted dolphins was 138 dB re 1 μPa at 1 m with a standard deviation of 8.0 (see Table III). Figure 5 shows the distribution of source level estimates for both species. There was a high level of variability in these estimates for both species.

IV. DISCUSSION

A. Whistle characteristics

The measured acoustic characteristics of the whistles differed significantly between the bottlenose and spotted dolphins, falling within the range of previously reported values for their respective species (e.g., Azevedo et al., 2007; Azevedo et al., 2010). Not unexpectedly, there are some differences in the whistle frequency range of the Florida sample and other locations. However, these have previously been

TABLE III. Descriptive statistics of source level estimates for the two species (dB re 1 μPa at 1 m).

<table>
<thead>
<tr>
<th></th>
<th>Spotted</th>
<th>Bottlenose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>138.4</td>
<td>138.2</td>
</tr>
<tr>
<td>s.d.</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>115.4</td>
<td>114.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>163.1</td>
<td>12.7</td>
</tr>
<tr>
<td>N</td>
<td>385</td>
<td>645</td>
</tr>
</tbody>
</table>

FIG. 4. The distribution of the test statistic from the permutation tests are presented along with the observed difference between the measures of minimum frequency, maximum frequency, and duration of whistles from the two species. For all measured, the observed differences (the single vertical bar) lies outside the distribution of the test metrics. Therefore the null hypothesis was rejected, and it was concluded that spotted dolphin whistles had significantly higher minimum and maximum frequencies as well as greater duration than bottlenose dolphin whistles.
shown to vary between populations (Ding et al., 1995; Azevedo et al., 2007; Baron et al., 2008) as well as with behavioral state (Hernandez et al., 2010). Furthermore, our equipment limited the maximum frequency that could be recorded. Thus the upper limit to the frequency range of the Florida dolphin whistles is undoubtedly higher than those values reported here. Nevertheless the reliable differences between species can help inform automatic classification models for odontocete whistles.

B. Source level

The source level estimates presented here are subject to potential errors in measurement. The location estimate was calculated using a linear array geometry. However, during field data collection, it is likely that there was some deviation from linearity during the recordings. A bent array could lead to either an overestimate or underestimate of range; this may have increased the range of source level values. It is worth noting that recordings made with a severely spatially distorted array would not produce a usable location.

The acoustic location software used in this study did not report range or bearing error values. Therefore a theoretical range error function of acoustically derived locations obtained with a towed array (von Benda-Beckmann et al., 2013) was used. This study considered a three-element array with an aperture of 15 m and evaluated range error as a function of range. As expected, the range error percentage increased with range. At a range of 75 m (five times the array aperture), von Benda-Beckmann et al. (2013) reported a range error of approximately 8%. At these relatively close distances, element position uncertainty was the dominant source of error.

In the current study, source levels for dolphins were calculated for dolphins less than 500 m from the array, approximately five times the aperture of the squid array, which had a minimum of eight functional elements. Given that location accuracy increases with the number of hydrophone elements (Torrieri, 1984), using the range error value of 8% from von Benda-Beckmann et al. (2013) is probably an overestimate of the actual range errors for the measurements in this study. Nevertheless, without direct error measurements from the software, this value was used to represent range error. Based on the maximum accepted range and the transmission loss modeling results, an 8% range error would produce no more than 1.3 dB of error in the final source level estimate.

Another factor that could have affected source level estimates were the transmission loss modeling results. Because the exact depths of both the array and vocalizing dolphins were unknown, transmission loss was predicted for 12 different combinations of both dolphin and array depths in five different water depths. The median of these results was used to produce the transmission loss curve for each modeling location. Only the shallowest location produced transmission loss measurements that were meaningfully different than the four deeper locations. The appropriate transmission loss model was chosen for each recording session, thus accounting for the effect of water depth. The maximum median average deviation (3.9 dB) of those 12 curves was used as the estimate of potential error in the source level estimates due to uncertainty in the transmission loss predictions.

The observed source levels for both species fall within the range of previous estimates for other species. The source level for wild white-beaked dolphins from Icelandic waters was estimated using a three-element towed array (Rasmussen et al., 2006). Two different acoustic location and measurement procedures were used that provided two different distance estimates and consequently resulted in two different source level estimates. The mean source level estimates were either 148 or 139 dB re 1 μPa at 1 m ± 12 dB, n = 36, max = 167 dB; respectively, for the two location methods. Wang et al. (2006) reported similar values for Baiji (Lipotes vexillifer). Mean source levels were 143.2 dB re 1 μPa at 1 m (s.d. = 5.8) with highest energy at 5.7 kHz.

Watkins and Schevill (1974) recorded wild spinner dolphins resting in Kealakekua Bay with a three-dimensional hydrophone array. This recording setup allowed the measurement of the dolphin’s location and source levels. Source
level estimates ranged from 109 to 125 dB re 1 μPa at 1 m. The authors concluded that the range of source levels indicated that individuals were adjusting their source levels. Spinner dolphins feed offshore at night and typically spend the day resting in near shore bay areas and remain in relatively close proximity. Therefore it is likely that these recorded source levels were lower than the maximum that the dolphins can produce.

Lammers and Au (2003) found evidence for a weak beam pattern in free-ranging spinner dolphins. The mean calculated source levels for dolphins moving with or toward the vessel were 153.9 ± 4.47 dB re 1 μPa at 1 m. Dolphins that were ahead of or heading away from the vessel had source levels of 150.2 ± 2.78 dB re 1 μPa at 1 m. Miller (2002) also found evidence for directionality in the higher frequencies (5–14 kHz) of killer whale calls. The mean differences were approximately 6 dB. The relatively low aspect dependence in source level of whistles makes them an excellent signal for autonomous monitoring.

Tyack (1985) recorded captive bottlenose dolphin whistles with a “vocalight” device attached to the dolphins. He reported source levels ranging from 125 to greater than 140 dB re 1 μPa at 1 m. Values higher than 140 exceeded the range of the instrument.

The only other reports of source level for wild bottlenose dolphins were obtained in the Moray Firth in Scotland (Janik, 2000) and Koombana Bay in Western Australia (Jensen et al., 2012). The Moray Firth had a mean source level of 158 dB re 1 μPa at 1 m and a maximum value of 169 dB re 1 μPa at 1 m. The Koombana Bay dolphins had a mean source level of 146.7 dB re 1 μPa at 1 m with a 95th percentile value of 158.0 dB re 1 μPa at 1 m. The mean value is 16 dB higher in Scotland and 5 dB higher in Australia than the median level determined off Florida. Despite a larger sample size (Florida, $N = 645$; Scotland, $N = 103$; Australia, $N = 180$), the range of variation was greater in the Florida sample (s.d. = 8.0) than either Scotland (s.d. = 6.4) or Australia (s.d. = 6.2). The Florida dolphin populations may simply have more variability in their source levels, or there may have been more measurement error in our source level estimates. All of these studies were subject to errors in transmission loss estimation. However, the Scotland study used a fixed array and the Australian study had direct GPS measurements of hydrophone locations. The towed array used in the current study was subject to potential variation in towed array shape that could have lead to errors in range estimation and therefore transmission loss and source level estimates. However, the magnitude of this potential error was limited by setting the maximum acceptable range to 500 m, approximately four times the array aperture.

While the variation in source level was greater in the Florida sample, the overall levels were lower than those from Australia and Scotland. Differences in the acoustic environment and the behavioral context may have contributed to the source levels produced during these recordings. Off Florida, dolphins were typically found in compact groups that were widely dispersed. It is conceivable that the dolphins we recorded were attempting to communicate only with other members of their compact group, and the relatively low source level observed there was sufficient for this behavior. Whistle frequency characteristics are known to vary with behavioral states (Díaz López, 2011). Perhaps the same is true of source level.

Another important consideration is the ambient noise level in each area. The ambient noise level in the Scotland recordings was too low to be measured directly. The 1/3-octave levels from Western Australia were concentrated between 95 and 100 dB re 1 μPa for the frequencies in the dolphin whistles (Jensen et al., 2012). These 1/3-octave levels were combined into a 2–40 kHz band level to produce a summed value of 109.8 dB re 1 μPa. The median broadband ambient noise level (2–40 kHz) in Florida was 101.1 dB re 1 μPa. The dolphin source level estimates from Australia were 5.0 dB higher than those recorded off Florida, but the ambient noise was 8.7 dB higher. Therefore some of the difference could be due to variation in ambient noise levels.

Right whales are known to increase the amplitude of their vocalizations in the presence of boats (Parks et al., 2011). It is also important to note that the recordings in the current Florida study were made from a vessel that would increase the local noise level. Thus our source level estimates are for an environment with increased noise. It is possible that vocalizations made when the vessel was not present could be at a lower level.

Finally, we found that the acoustic characteristics of spotted dolphin and bottlenose dolphin whistles recorded in the eastern Gulf of Mexico fall within the range of variability reported for these species elsewhere and for other delphinids. The source levels of bottlenose dolphins in this study were less than those in Australia and Scotland, but the ambient noise was also lower in Florida than in Australia. Variance in source levels measured at these locations may reflect different local ambient noise characteristics, varying behavioral states, or real differences in acoustic behavior between populations.

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