Determination of West Indian manatee vocalization levels and rate

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The West Indian manatee (*Trichechus manatus latirostris*) has become endangered partly because of a growing number of collisions with boats. A system to warn boaters of the presence of manatees, based upon the vocalizations of manatees, could potentially reduce these boat collisions. The feasibility of this warning system would depend mainly upon two factors: the rate at which manatees vocalize and the distance in which the manatees can be detected. The research presented in this paper verifies that the average vocalization rate of the West Indian manatee is approximately one to two times per 5-min period. Several different manatee vocalization recordings were broadcast to the manatees and their response was observed. It was found that during the broadcast periods, the vocalization rates for the manatees increased substantially when compared with the average vocalization rates during nonbroadcast periods. An array of four hydrophones was used while recording the manatees. This allowed for position estimation techniques to be used to determine the location of the vocalizing manatee. Knowing the position of the manatee, the source level was determined and it was found that the mean source level of the manatee vocalizations is approximately 112 dB (*re* 1 μPa) @ 1 m.
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I. INTRODUCTION

Between 1995 and 2002 the percentage of mortalities of the West Indian manatee (*Trichechus manatus latirostris*) due to watercraft strikes has risen from 22% to 31% (Florida Department of Environmental Protection, 1996; Florida Fish and Wildlife Conservation Commission, 2002). This has led to increased research into manatee avoidance technologies. One type of manatee avoidance technology is based on detecting the presence of manatees with hydrophones listening for manatee vocalizations. The frequency of manatee vocalizations, the source level of the vocalizations, and the volume of the ambient background noise would all affect the feasibility of an acoustic detection system. The characteristics of manatee vocalizations would also need to be known. A comprehensive literature review on manatee vocalizations can be found in the work by Niezrecki *et al.* (2003). Typical manatee vocalizations have a duration between 0.25 and 0.5 s. The vocalizations usually contain a fundamental frequency and several higher harmonics. For a majority of the manatee calls, the first harmonic past the fundamental frequency dominates and contains a majority of the acoustic energy. The fundamental frequency ranges from 2 to 5 kHz and tends to be smaller than the first harmonic. The magnitude of the higher harmonics decreases as the frequency increases. The vocalizations can be variable and for some calls the fundamental frequency dominates over the first harmonic.

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Researchers have studied the rate at which manatee calls are made. Other than when they are feeding, manatees vocalize on average approximately one to five times within a 5-min period, depending on their activity (Bengston and Fitzgerald, 1985). Bengston and Fitzgerald observed manatee vocalization rates and the corresponding manatee behaviors. It was determined that vocalization rates are dependent on a manatee's behavior, with feeding and resting having lowest vocalization rates and mating and cavorting being the highest. It is also suggested that if manatee vocalizations are used for communicative and social purposes, then the vocalization rates may depend upon the number of manatees present. Nowacek compared the vocalization rates in Florida and Belize and found that the manatees vocalized at a rate of 1.29 and 0.09 to 0.75 vocalizations per animal per minute, respectively (Nowacek *et al.*, 2003). The high rate of vocalization at Crystal River is based on visual estimates of the number of manatees (~50) in the area. However, the visual estimate of the number of manatees is not an accurate assessment of the number of manatees in the river. Additionally, the behavior of the manatees during the measurement was not reported in their work and can affect the vocalization rate. Nowacek also estimated the mean received sound pressure levels of the peak frequency (in Crystal River) to be approximately 100 dB (*re* 1 μPa). The received values are recorded with the hydrophone at approximately 20 m from a group of 50 manatees. Additionally, the source levels from the hydrophones tagged on the Belize manatees were estimated to be between 106 and 115 dB.

This work contributes to the scientific knowledge of manatees by confirming the manatee vocalizations rates determined by prior researchers. More importantly, this is the first work to measure the source levels of manatee vocalizations by using triangulation techniques and to document the response of manatees to broadcasts of manatee vocalizations.

II. THEORETICAL DEVELOPMENT

In order to calculate the source levels, the location of the source and the sensors must be determined. Two different position estimation methods are used to determine the location of the vocalizing manatee. The first method used is based upon the differences in the time-of-flight of the signal and the equation of a circle. The second method also uses the differences in the time-of-flight, but uses the equation of a hyperboloid. Both methods are now reviewed.

A. Time-of-flight differences

One of the position estimation methods used in this experiment was developed by Mahajan and Walworth (Mahajan and Walworth, 2001). This method uses the time-of-flight differences from four sensors to locate a source on a plane. The signal arrival times (T_{j}) at the four sensors are used to calculate the three time-of-flight differences ($\Delta T_{1\mathrm{j}}$) between sensor 1 and the remaining three sensors, as shown in Eq. (1):

$$\begin{aligned} \Delta T_{12}&=T_2-T_1, \\ \Delta T_{13}&=T_3-T_1, \\ \Delta T_{14}&=T_4-T_1. \end{aligned} \tag{1}$$

The four sensors are located at measured positions (x_1,y_1) through (x_4,y_4) and the unknown location of the source is (u,v). The distance between sensor 1 and the source location is represented by d. The distance between the remaining sensors and the source is then equal to $d+c\Delta T_{1\mathrm{j}}$, where c is the speed of sound. Equation (2) is derived by using the equation of a circle four times around the source, one circle through each sensor:

$$\begin{aligned} (x_1-u)^2+(y_1-v)^2&=d^2, \\ (x_2-u)^2+(y_2-v)^2&=(d+c\Delta T_{12})^2, \\ (x_3-u)^2+(y_3-v)^2&=(d+c\Delta T_{13})^2, \\ (x_4-u)^2+(y_4-v)^2&=(d+c\Delta T_{14})^2. \end{aligned} \tag{2}$$

The first equation of a circle in Eq. (2) is expanded and substituted into the remaining three equations in place of d^2. The three resulting equations are then represented in Eq. (3), in matrix form:

$$\begin{bmatrix} 2x_1-2x_2 & 2y_1-2y_2 & -2c\Delta T_{12}^2 \\ 2x_1-2x_3 & 2y_1-2y_3 & -2c\Delta T_{13}^2 \\ 2x_1-2x_4 & 2y_1-2y_4 & -2c\Delta T_{14}^2 \end{bmatrix} \begin{bmatrix} u \\ v \\ d \end{bmatrix} = \begin{bmatrix} c^2\Delta T_{12}^2+x_1^2+y_1^2-x_2^2-y_2^2 \\ c^2\Delta T_{13}^2+x_1^2+y_1^2-x_3^2-y_3^2 \\ c^2\Delta T_{14}^2+x_1^2+y_1^2-x_4^2-y_4^2 \end{bmatrix}. \tag{3}$$

The source location (u,v) and the distance between sensor 1 and the source (d) can then be solved for by multiplying both sides of Eq. (3) by the inverse of the matrix, resulting in Eq. (4):

$$\begin{bmatrix} u \\ v \\ d \end{bmatrix} = \begin{bmatrix} 2x_1-2x_2 & 2y_1-2y_2 & -2c\Delta T_{12}^2 \\ 2x_1-2x_3 & 2y_1-2y_3 & -2c\Delta T_{13}^2 \\ 2x_1-2x_4 & 2y_1-2y_4 & -2c\Delta T_{14}^2 \end{bmatrix}^{-1} \times \begin{bmatrix} c^2\Delta T_{12}^2+x_1^2+y_1^2-x_2^2-y_2^2 \\ c^2\Delta T_{13}^2+x_1^2+y_1^2-x_3^2-y_3^2 \\ c^2\Delta T_{14}^2+x_1^2+y_1^2-x_4^2-y_4^2 \end{bmatrix}. \tag{4}$$

The time-of-flight differences ($\Delta T_{1\mathrm{j}}$) were determined by selecting characteristic points in the manatee vocalization and then comparing the times at which that point occurred at each of the hydrophones. The time-of-flight differences can then be substituted into Eq. (4) and u, v, and d can be determined.

B. Hyperbolic fixing

The second approach to locating the position of the source was performed using the program Ishmael (Mellinger, 2001). Hyperbolic fixing is the method chosen for position location in this approach. Hyperbolic fixing also uses time-of-flight differences to determine the location; however, it can rely on as little as three sensors to estimate the position of an unknown source in a plane. The following is an example of two-dimensional hyperbolic fixing, based on the three-dimensional case presented by Bertrand Fang (Fang, 1990). The time-of-flight differences ($t_{1\mathrm{j}}$) between sensor 1 and the remaining two are defined in Eq. (5):

$$\begin{aligned} t_{12}&=t_1-t_2, \\ t_{13}&=t_1-t_3. \end{aligned} \tag{5}$$

To simplify the equations the sensors are placed at specific locations in the coordinate system: sensor 1 at (0,0), sensor 2 at $(x_2,0)$, and sensor 3 at (x_3,y_3). The unknown position is located at (u,v). The distance between the sensors and the unknown location is given by Eq. (6), where c is the speed of sound and $R_{1\mathrm{j}}$ is the difference in distance from the source to sensor 1 and the remaining two sensors:

$$\begin{aligned} \sqrt{u^2+v^2}-\sqrt{(u-x_2)^2+v^2}&=c\cdot t_{12}=R_{12}, \\ \sqrt{u^2+v^2}-\sqrt{(u-x_3)^2+(v-y_3)^2}&=c\cdot t_{13}=R_{13}. \end{aligned} \tag{6}$$

Equation (7) is derived by squaring both sides of Eq. (6) and rearranging the terms:

$$\begin{aligned} \frac{R_{12}^2-x_2^2+2x_2x}{2R_{12}}&=\sqrt{u^2+v^2}, \\ \frac{R_{13}^2-x_3^2-y_3^2+2x_3x+2y_3y}{2R_{13}}&=\sqrt{u^2+v^2}. \end{aligned} \tag{7}$$

The first equation in Eq. (7) is then substituted into the second and then solved for v in terms of u, resulting in Eq. (8),

$$v=g\cdot u+h, \tag{8}$$

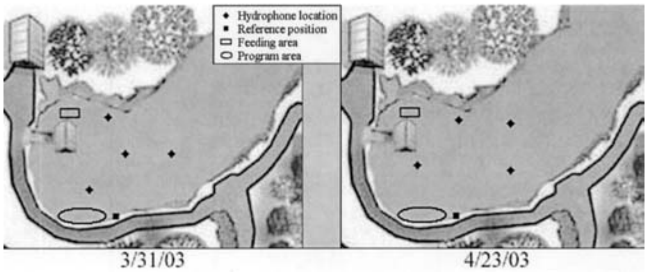

FIG. 1. Hydrophone locations in Homosassa Springs (top view).

where

$$g = \frac{R_{13}x_2/R_{12} - x_3}{y_3},$$

$$h = \frac{x_3^2 + y_3^2 - R_{13}^2 + R_{13}R_{12}(1-(x_2/R_{12})^2)}{2y_3}.$$

The unknown value u can then be obtained by substituting Eq. (8) into Eq. (7) resulting in Eq. (9),

$$d \cdot u^2 + e \cdot u + f = 0, \tag{9}$$

where

$$d = \left(\frac{x_2}{R_{12}}\right)^2 - g^2 - 1,$$

$$e = x_2\left(1 - \left(\frac{x_2}{R_{12}}\right)^2\right) - 2g \cdot h,$$

$$f = \frac{R_{12}^2}{4}\left(1 - \left(\frac{x_2}{R_{12}}\right)^2\right)^2 - h^2.$$

Equation (9) can then be solved for u and then used in Eq. (8) to determine v. Equation (9) will lead to two possible solutions. A single solution can be obtained by either ruling out one of the solutions as an impossibility or by using a forth sensor to eliminate the ambiguity. The number of solutions was reduced to one, because four hydrophones were used during the recording process.

Ishmael uses a cross-correlation method to determine the time-of-flight differences (t_{1j}). The hydrophone signals from sensors 2–4 are each cross-correlated with hydrophone signal 1. The time-delay which results in the maximum cross-correlation is taken to be the time-of-flight difference.

III. EXPERIMENTAL DESCRIPTION

Approximately 11 h of manatee vocalizations were recorded in Homosassa Springs Wildlife State Park on 31 March and 23 April 2003. Homosassa Springs contains nine female manatees and no male manatees. The manatees in Homosassa Springs range in age from 9 to 37 years. They can not leave the park and wild manatees can not enter the park due to a physical barrier in the spring run that prohibits their interaction.

For each test, four hydrophones were placed within the spring, as shown in Fig. 1, and recorded using a Teac RD-135T DAT recorder with a sample rate of 48 kHz. A pole at the edge of the spring was used as a reference point and the distances to each hydrophone were recorded. The distance between the hydrophones was also recorded, so that the relative positions could then be calculated.

At different times during the day a Lubell LL-98 underwater speaker was used to broadcast different calls to the manatees. Since a controlled sound exposure for manatees has never been reported in the literature, the authors believed that the broadcast test was worth performing. A diver would place the speaker in the spring, and before broadcasting any sounds, the diver would swim away and the manatees were allowed time to see and inspect the speaker. This allowed the researchers to observe the manatees' response to the sounds which were broadcast, while minimizing the manatees' response from visual stimulation. For a period of at least 15 min prior to broadcast, the manatees showed no interest in the speaker. The speaker was moved between broadcast sessions so that the manatees would not become accustomed to the broadcasts being produced at one specific location within the spring.

Several events occur in Homosassa Springs Wildlife State Park daily. Several manatee programs take place in which a person enters the water and discusses the manatees. During the program, the nine manatees are in the vicinity of the oval shown in Fig. 1 and are fed carrots and vitamins. There is also a feeding area, represented by the black rectangle, and a manatee show. Twice daily, the manatees are fed a mixture of vegetables here. The broadcasting times were chosen so that they would not overlap with either the manatee programs or the feeding times. There is also a floating observation center in the center of the spring located next to the feeding area.

The recordings were later replayed in the laboratory and the number of audible manatee vocalizations was determined for every 5-min period. Knowing that there are nine manatees present in the spring at all times, and knowing the total number of vocalizations, the average vocalization rate per manatee can be determined.

IV. CALIBRATION

Four High Tech, Inc. (HTI) hydrophones were used during the recording of the manatee vocalizations: two model HTI-90-U hydrophones and two model HTI-96-MIN hydrophones. The four HTI hydrophones were recently purchased and calibrated by the manufacturer. The manufacturer's calibration was verified in a pool and in the Homosassa River.

First, the manufacturer's calibration was verified by comparing their voltage output with that of two B&K 8104 hydrophones. A 1-kHz tone was generated with a Lubell LL-98 underwater loudspeaker in a 50-m Olympic pool. Each individual hydrophone was mounted in a stand sequentially, approximately 10 m from the loudspeaker. The outputs from the two B&K hydrophones were then averaged and used to determine the sensitivity of the four HTI hydrophones. Each hydrophone was tested separately and placed in the same location as the B&K hydrophone (± 0.005 m), for a fixed source level from the speaker. No significant variations in the sound levels were detected within ± 0.5 m of the measurement location, as the hydrophones were moved about the calibration location.

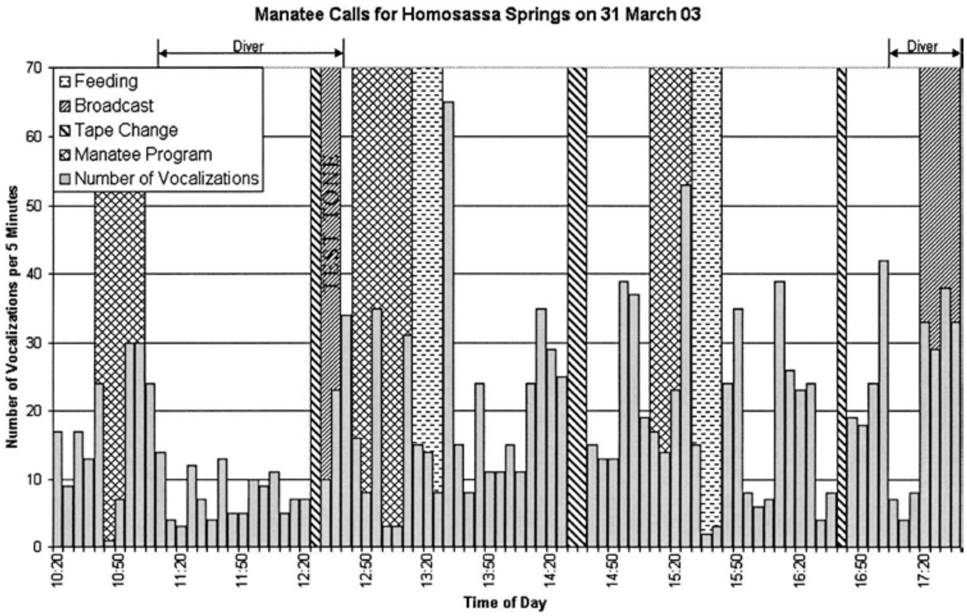

FIG. 2. Number of manatees vocalizations at Homosassa Springs on 31 March 2003.

Second, the calibration was verified using a swept-sine broadcast in a spring at Homosassa River. The swept-sine broadcast was performed between 0.3 and 10 kHz with the hydrophones placed approximately 25 m away from the source. For this test, the hydrophones were tested simultaneously and were collocated. The separation between hydrophones was approximately 20 cm. B&K 8104 hydrophones were used as the comparison hydrophones. The B&K 8104 hydrophones have a flat response over this range and have been calibrated by the manufacturer. The calibration of the B&K hydrophones was verified using a B&K Type 4229 pistonphone, with an accuracy of $\pm 0.1\%$. The two calibration tests demonstrated that the four HTI hydrophones were within ± 1 dB of the manufacturer's specifications.

V. RESULTS

A. Homosassa Springs—31 March 2003

At Homosassa Springs on 31 March 2003, approximately 7 h of manatee vocalizations were recorded. The recordings started at 10:20 a.m. and continued until 5:40 p.m. The number of manatee vocalizations heard on the recording was then counted for every 5-min period (see Fig. 2). In addition to the manatee program and the feeding times, the times during tape changes and broadcast periods are marked. Several times during the day a diver was also present in the spring. These times are also labeled along the top of Fig. 2.

On this date, two different sets of broadcasts were performed. Between 12:30 p.m. and 12:40 p.m. a 5-kHz harmonic test tone was broadcast at low levels to verify that the speaker and all four hydrophones were operational. The second broadcast involved manatee vocalizations that had previously been recorded at Blue Spring State Park. Approximately 50 to 100 manatees were in the vicinity of Blue Spring the day the authors' recordings were made. Because of the large number of animals present at the time of recording, the vocalizations could be any variety of manatee calls. These recorded calls were broadcast between 5:20 p.m. and 5:40 p.m.

During the day when no broadcasting was taking place, it was observed that the manatees vocalized at an average rate of 1.88 calls/manatee/5 min (see Table I). There was negligible change (1.83 calls/manatee/5 min) in the manatees' vocalization rate in response to the speaker test tone signal. When the Blue Spring recordings were broadcast in Homosassa Springs, the manatee vocalization rate doubled (3.69 calls/manatee/5 min). However, it should be noted that there were some 5-min periods in which the vocalization rates were just as high. This typically occurred when Homosassa park program was transpiring and the manatees were receiving carrots during the show. It is important to point out that the influence of the diver being present with the manatees was not investigated. These particular manatees are very accustomed to divers since divers are present in the spring

TABLE I. Manatee vocalization rates on 31 March 2003 at Homosassa Springs.

	Excluding broadcasting	5-kHz test tone	Broadcast of Blue Springs calls
Average no. of calls/5 min	16.88	16.50	33.25
Total time recorded (min)	390	10	20
Total no. of calls	1317	33	133
Average no. of calls/manatee/5 min	1.88	1.83	3.69
Standard deviation	1.40	1.02	0.41

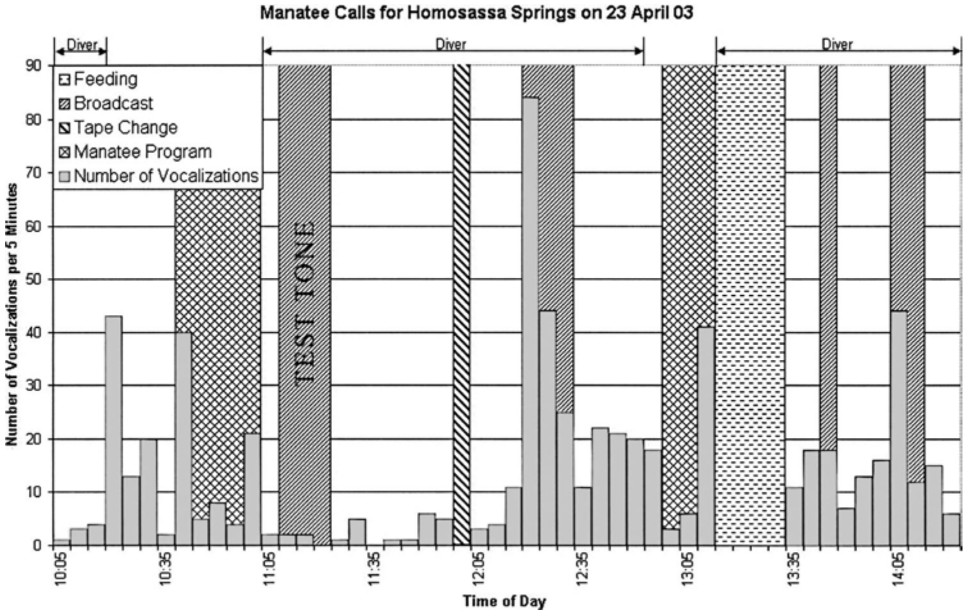

FIG. 3. Number of manatees vocalizations at Homosassa Springs on 23 April 2003.

run on a daily basis to clean the windows of the viewing area and to conduct research.

Prior to the broadcast (vocalizations recorded at Blue Spring), the manatees ignored the speaker and did not appear to be interested in its presence. Once the broadcasting began, six of the nine manatees converged onto the speaker to investigate the sound. The manatees were extremely active during the broadcast and congregated to within a few meters of the speaker. It was obvious to the researchers that the manatees were well aware of the broadcast. Once the broadcast ended the manatees dissipated and resumed their normal activity. The three manatees that did not respond were located at the other end of the spring run and it was likely that they could not hear the broadcast signal. This response was not observed during the speaker test or at any other time during the day.

B. Homosassa Springs—23 April 2003

Another four hours of manatee vocalizations were recorded at Homosassa Springs on 23 April 2003 between 10:05 a.m. and 2:25 p.m. and four different broadcasts were performed (see Fig. 3). The speaker test was performed at 11:10 a.m. and the Blue Spring calls were broadcast at 12:20 p.m. The final two broadcasts used recordings made by O'Shea (O'Shea, 1981–1984). The third broadcast period (1:45 p.m.) used recordings that O'Shea describes as a frightened calf and the final broadcast period (2:05 p.m.) used various manatee calls recorded by O'Shea at 1 m from the manatee.

The average vocalization rate excluding broadcast periods was 1.09 calls/manatee/5 min (see Table II). The speaker test tone was performed shortly after the manatees finished feeding and was at the quietest part of the day. The manatees again ignored the sounds of the speaker test tone and averaged only 0.15 calls/manatee/5 min. The average manatee vocalization rate during the broadcast (recorded at Blue Spring) session increased to approximately five times the rate when no broadcasts were occurring, 5.67 calls/manatee/5 min. When the calls of a frightened calf were broadcast to the female manatees, the vocalization rate was 2.00 calls/manatee/5 min and the various 1-m recordings produced vocalization rate of 3.11 calls/manatee/5 min.

For each of the broadcasts, the manatees reacted in a similar manner as described for the test on 31 March. When the speaker test tone was broadcast the manatees showed no interest in the speaker. However, when the three sets of prerecorded manatee vocalizations were broadcast, five, six, and eight manatees congregated to within a few meters of the speaker for the second, third, and forth broadcasts, respectively. When the distressed calf vocalizations were broadcast the female manatees encircled the speaker with their tails inside the circle and their heads looking outward.

TABLE II. Manatee vocalization rates on 23 April 2003 at Homosassa Springs.

	Excluding broadcasting	5-kHz test tone	Broadcast of Blue Springs calls	Broadcast of frightened calf calls	Broadcast of misc. O'Shea calls
Avgerage no. of calls/5 min	10.26	1.33	51.00	18.00	28.00
Total time recorded (min)	210	10	15	5	10
Total no. of calls	431	4	153	18	56
Avgerage no. of calls/manatee/5 min	1.14	0.15	5.67	2.00	3.11
Standard deviation	1.24	0.13	3.35	N/A	2.51

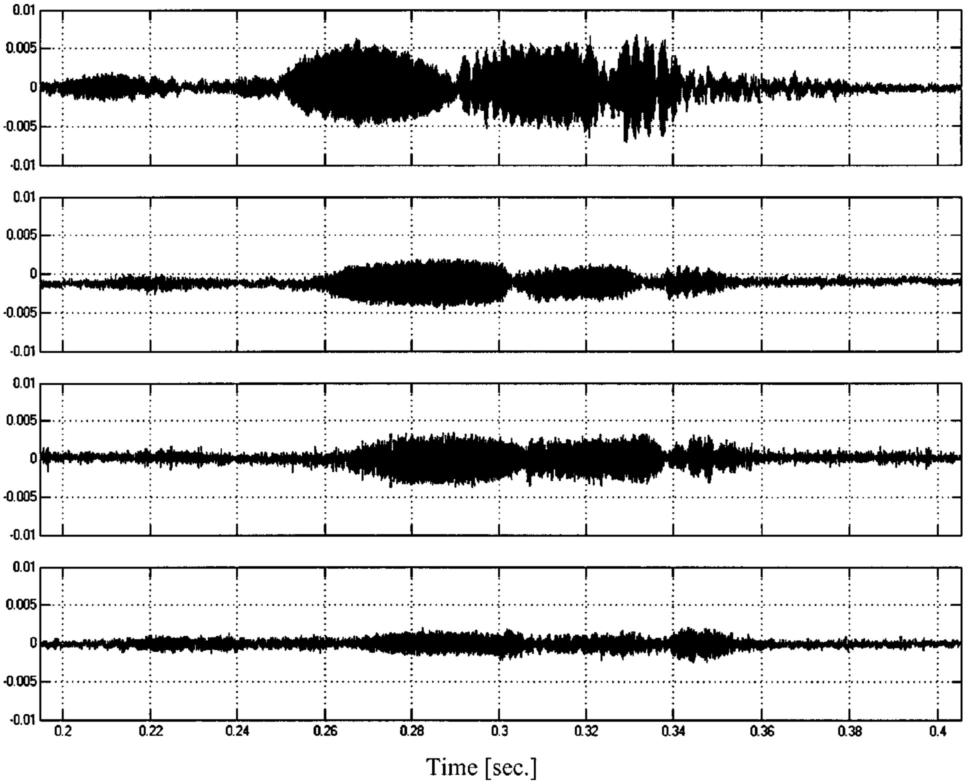

FIG. 4. Sample manatee call on four hydrophones.

C. Triangulation and source level

The manatee vocalizations are triangulated using the two methods previously described, and the estimated positions from each of the methods are compared. The estimated location is considered to be accurate when the position from Ishmael and from Mahajan's method differed by less than 3 m. Because Ishmael uses the cross-correlation between the signals and not a point comparison, the estimated position given by Ishmael was used as the location of the manatee.

The original recordings (see Fig. 4) were passed through a 500-Hz high-pass filter to reduce any low-frequency background noise. The fundamental frequency of manatee vocalizations is typically between 2 and 5 kHz, so the high-pass filter will not significantly alter the spectral content of the manatee vocalizations. The signals were then placed into buffers with a length of 1024 and the rms pressure was then calculated. The maximum sound pressure level during the manatee vocalization was recorded as the peak level.

The source level is the calculated sound pressure level at 1 m from the manatee's estimated position based upon each of the four hydrophones. The results from 50 manatee vocalizations are shown in Fig. 5. Because each of the 50 manatee vocalizations was recorded on four hydrophones and each hydrophone is being used to determine the source level, 200 results are presented. Since the majority of the spring is less than 2 m in depth, the source level was based upon the assumption of cylindrical spreading. The mean source level for the 50 manatee vocalizations was found to be 112.5 dB. All sound pressure levels are based upon the standard underwater reference pressure of 1 μPa.

The mean source level for each vocalization was determined by averaging the source rms pressure values calculated from each of the four hydrophones. The average source level values for the 50 manatee vocalizations are presented in Fig. 6. Based upon the average values for each vocalization, the mean source level for the 50 manatee vocalizations was found to be 113.2 dB.

The authors performed this research with the assumption that the manatee vocalizations can be represented as sources with no directivity in an environment that can be characterized by a cylindrical spreading model. While much of the data fit this model within a few decibels, there were instances where the source level estimates deviated significantly (up to 22.8 dB). The mean difference between the highest and lowest source level calculated using two different hydrophone measurements is 8.6 dB. To verify that this difference is not attributed to the sensitivity of any particular hydrophone being offset, the values for the source level estimates were averaged for each hydrophone. The average source level

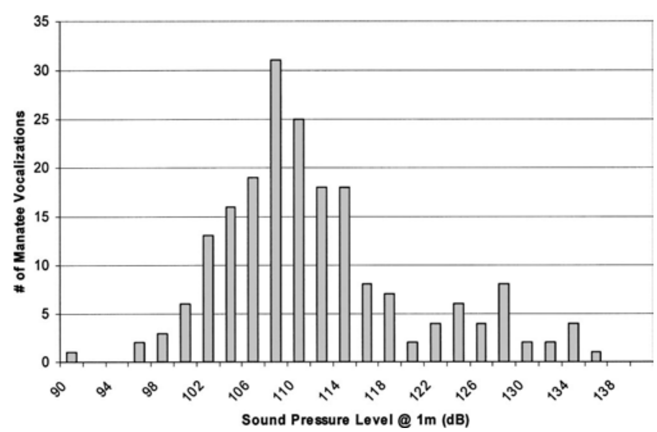

FIG. 5. Source level for 50 manatee vocalizations received on four hydrophones.

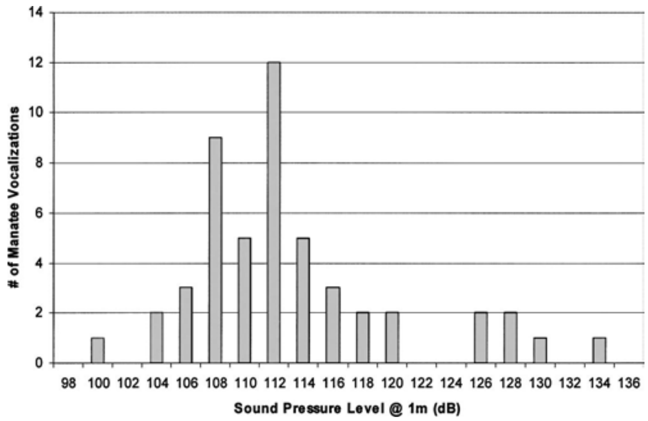

FIG. 6. Average source level for 50 manatee vocalizations.

value for each hydrophone was within ± 1.25 dB of each other. These observations led the authors to believe that other factors may be involved in the acoustic spreading of the manatee vocalizations. The spring geometry may have acoustic mode shapes that will affect the acoustic levels within the spring. Another possibility in the measured differences may be attributed by the directivity of the manatee vocalization itself.

VI. CONCLUSIONS

Within this paper, the vocalization rates of the nine female West Indian manatees present in Homosassa Springs Wildlife State Park were recorded on 31 March and 23 April 2003. The average vocalization rates were determined to be 1.83 and 1.09 calls/manatee/5 min. These results are consistent with previous studies performed with the West Indian manatee.

The manatees' response to several broadcast calls was observed. On both occasions when the recorded Blue Spring manatee vocalizations were broadcast into Homosassa Springs, the vocalizations rates increased (approximately two to five times the average nonbroadcast rates). The distressed calf recording and the various O'Shea recordings evoked similar vocalization responses in the Homosassa manatees (approximately two to three times the average nonbroadcast rates). In addition to responding vocally to the broadcasts the manatees responded physically. During all broadcast sessions between five and eight of the nine manatees present congregated within a few meters of the speaker. The physical responses of the manatees varied between the different broadcasts. When the distressed calf vocalizations were broadcast the female manatees encircled the speaker with their tails inside the circle and their heads looking outward. When the recorded Blue Spring vocalizations were broadcast, the manatees approached the speaker and became increasingly active. The manatees started splashing in the water and repeatedly rolled above the speaker.

The manatees' responses to the broadcasted vocalizations show that they can detect the source location of the call. Also, the responses to the broadcast calls led the authors to believe that the vocalizations are clearly a form of communication for the manatee. The manatees displayed an increased vocalization rate when unfamiliar calls were broadcast. Different physical responses were observed for the various manatee vocalizations.

The mean source level of the manatees' vocalizations was determined based upon 50 recorded and triangulated manatee vocalizations. The mean source level was determined using two different methods. The mean source level using each hydrophone separately was determined to be 112.5 dB. When the rms pressure from the four hydrophones was averaged for each vocalization the mean source level was determined to be 113.2 dB.

Ideally the source level determined from the four hydrophones would be nearly identical, if the sound source had no directivity. Because this was not found to be true, the manatees probably have some directivity in their vocalizations, however this remains to be verified. It is also likely that the discrepancies are due to the geometry and geology of the spring. Homosassa Spring is barren of vegetation and has a sandy bottom; however numerous large rocks are present throughout the spring area that could generate acoustic modes and cause a deviation from the cylindrical spreading model used.

ACKNOWLEDGMENTS

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