

## **Final Report to the Florida Fish & Wildlife Conservation Commission**

**Reporting periods: May 16, 2002 through December 31 2002**

### **A System for Warning Boaters of the Presence of Manatees**

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#### **1. Summary of Activities**

The following is a summary of how the proposed tasks were met. In addition to performing the proposed tasks, dockside testing of the algorithms was completed on November 15, 2002, and the results from these tests are presented.

Task I: Perform a comprehensive review of existing literature

A comprehensive review of existing literature has been performed. Literature relating to the acoustic characteristics of manatee vocalizations has been studied. Also, literature pertaining various data and signal processing techniques has been performed.

Task II: Obtain Hydrophone Manatee Sounds

Hydrophone recordings of various manatee calls were obtained from both NAVSEA and Dr. David Mann, Ph.D. (Assistant Professor, USF College of Marine Science). These recordings provided a library of hundreds of manatee calls with varying background noise. This library of manatee vocalizations helped to create a basis for discriminating between manatee calls and the background sounds that occur within the manatee's natural habitat.

Task III: Perform Spectrum Analysis of the Recorded Sounds

Based on the sound measurements recorded in Task II, the data was processed using spectrum analyzers and software available within the Smart Structures and Acoustics Laboratory at the University of Florida. Using both the frequency content and the length of the calls, distinguishing characteristics of the manatee calls were identified.

Task IV: Create a Manatee Simulation

Three manatee detection algorithms were designed using the software MATLAB and Simulink. The manatee detection algorithms search for distinct characteristics that are present in sounds that are generated by a manatee. The systems have been tested and calibrated on the previously recorded manatee sounds within the laboratory.

Task V: Quantify Performance and Make Recommendations

The simulations have been tested using the manatee vocalizations provided from both NAVSEA and Dr. Mann. The results of these simulations and the conclusions based

upon these results are presented in the Accomplishments section. Additionally, the manatee detection algorithms were tested at the Florida Marine Research Institute's (FMRI) docks. Results from this test will also be presented.

## Task VI: Present Results

In accordance with Task VI, this final report has been prepared to summarize the research, its results, and the investigators' recommendations. Additionally a presentation was provided to the program manager on November 15, 2002 at FMRI.

## 2. Accomplishments

### 2.1. Description of Methods

Method 1 performs a Fast Fourier Transform (FFT) on the acoustic signal. The FFT separates the time domain signal into its frequency components. The maximum frequency component is separated from the rest and if this component is between an upper and lower boundary frequency and greater than a specified threshold, then the algorithm notifies the user that a manatee vocalization has been detected.

Method 2 filters out any signals that are not between 1.1kHz and 21kHz. The FFT of the signal is taken and the maximum component is separated. Method 2 looks for the maximum frequency component and the next two harmonics. The components must also last for a user specified length of time. If the frequency components are present and the time limit has been met, then method 2 outputs that a manatee vocalization has been detected.

Method 3 filters out any signals that are not between 1kHz and 18kHz. The autocorrelation of the signal is then taken. The autocorrelation helps to reduce random components of the signal. The FFT of this signal is then taken and split into four frequency bands (0→5kHz, 5→10kHz, 10→15kHz, 15→20kHz). The RMS of each band is then taken and a 100-point moving average is then subtracted from each one to reduce the effects of any constant sounds in the environment. Any portion of the signal that is shorter than a specified time limit is not considered. A set of four thresholds is then used to determine if a manatee vocalization is present. A separate threshold is used based upon the number of frequency bands that have significant amplitude present in them.

### 2.2. NAVSEA CD

Three methods for detecting manatee vocalizations were designed in MATLAB Simulink and implemented using a dSPACE DS1103 PPC controller board. Recordings from the NAVSEA CD were used for the design and laboratory testing of the three methods. The NAVSEA CD contained several hundred manatee vocalizations with varying background conditions. The first twenty tracks from the NAVSEA CD were used to test the three manatee detection algorithms. Methods 1 and 2 correctly identified approximately 560 out of 650 manatee vocalizations (see Figure 1). Method 1 produced false positive manatee detections 511 times during the NAVSEA recordings; however, method 2 was capable of reducing the number of false positive from 511 down to 40. Method 3 correctly identified slightly more manatee vocalizations, approximately 630, but did produce more false positives than method 2.

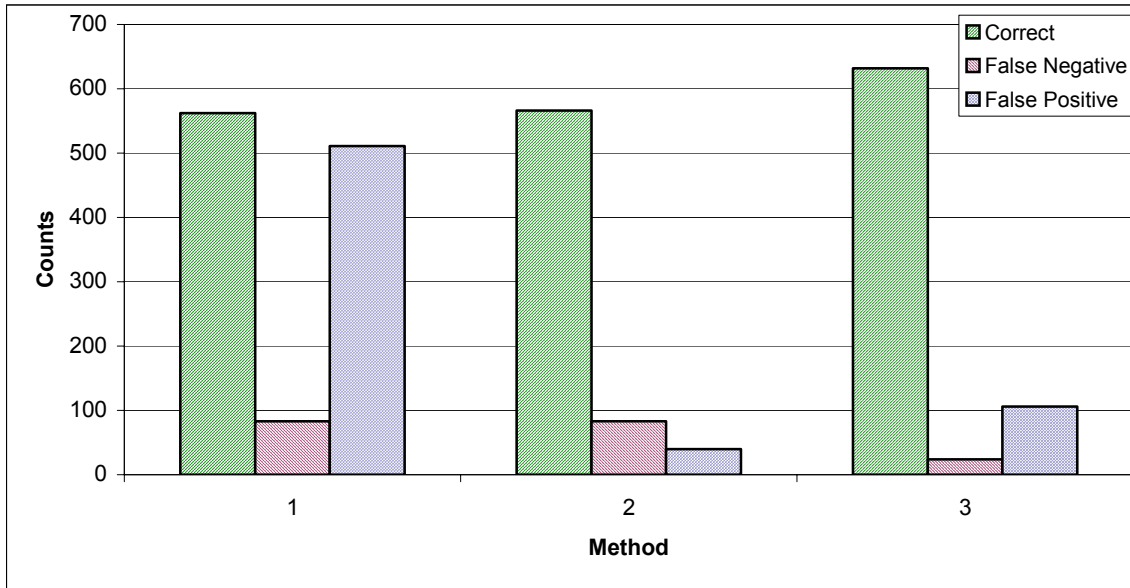


Figure 1: Totals from NAVSEA recordings

### 2.3. Dr. Mann's Loud and Quiet Tracks

Dr. Mann produced two recording tracks for the first test date on October 14, 2002, a loud track and a quiet track. The results for the loud track (see Figure 2) produced results analogous to that of the NAVSEA data. Method 3 distinguished the most manatee calls correctly; however method 2 had approximately half the number of false positives.

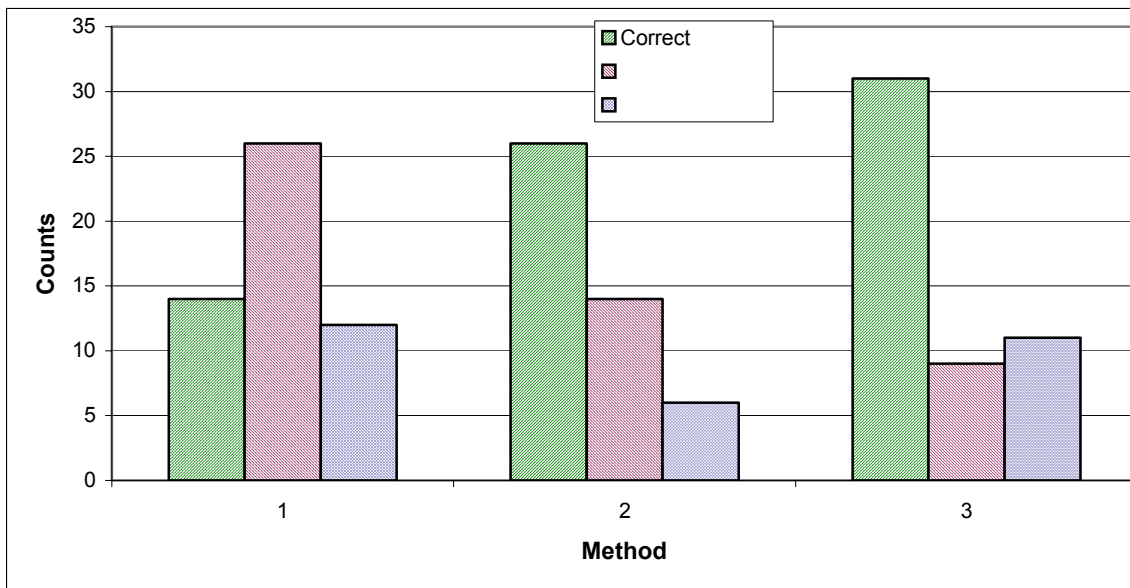


Figure 2: Totals for Dr. Mann's "loud track"

The results from the quiet track are displayed Figure 3. This track had less background noise than the loud track. In this case method 1 generated the most false positives and methods 2 and 3 produced nearly identical results, correctly identifying 32 and 34 of 38 manatee vocalizations, respectively. Neither, method 2 nor method 3 generated any false positives for this data.

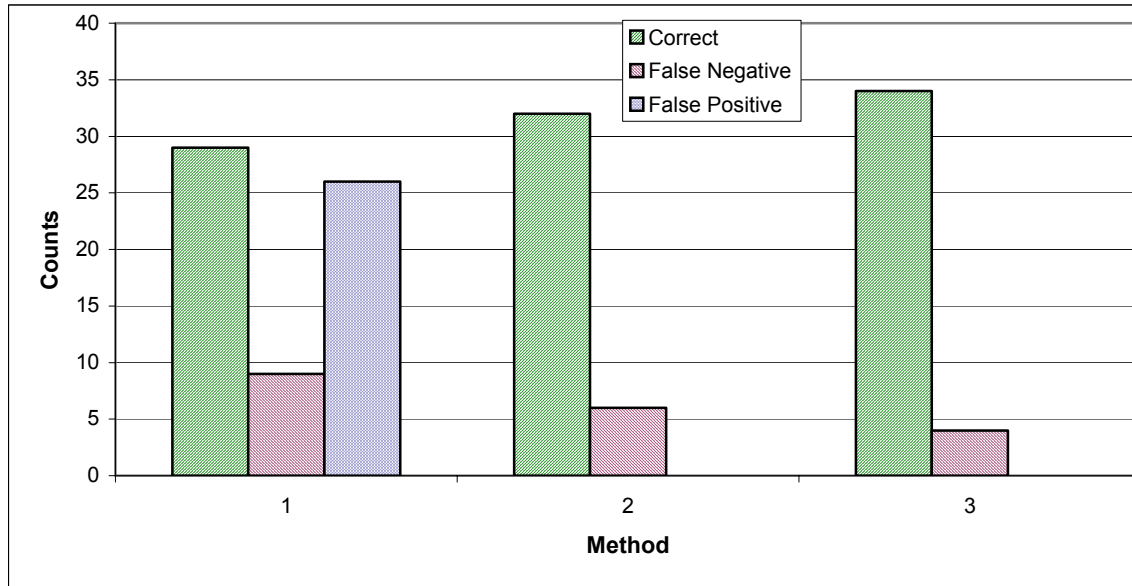


Figure 3: Totals for Dr. Mann's "quiet track"

#### 2.4. November 15, 2002 Field Test

On November 15, 2002 method 2 was evaluated dockside at FMRI's facilities. The results from this test are shown in Figure 4. The system was evaluated at a distance of 5m and 10m from the source. Method 2 identified 51 manatee vocalizations when the systems were tested at 5m and identified 27 vocalizations at 10m.

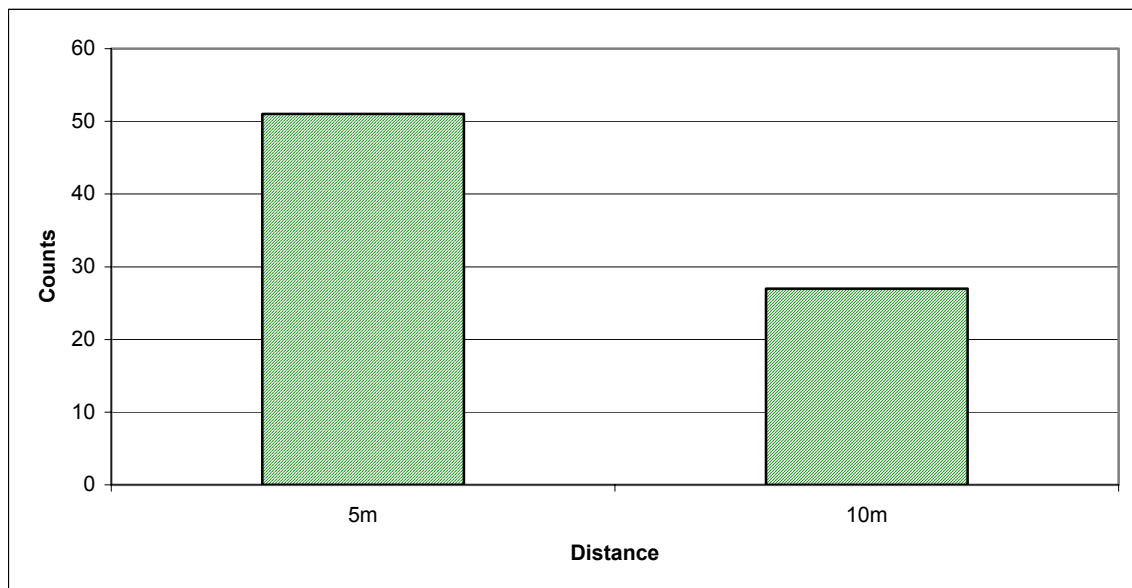


Figure 4: FMRI dockside testing of method 2, November 15, 2002

#### 2.5. Additional Laboratory Tests

Recordings were also taken at 5m and 10m from the underwater source that included manatee calls and background noise of the acoustic environment on November 15, 2002 at FMRI. These recordings were then used to test all three methods in the laboratory.

Method 1 correctly identified 41 of the manatee vocalizations at 5m and 9 at 10m (see Figure 5).

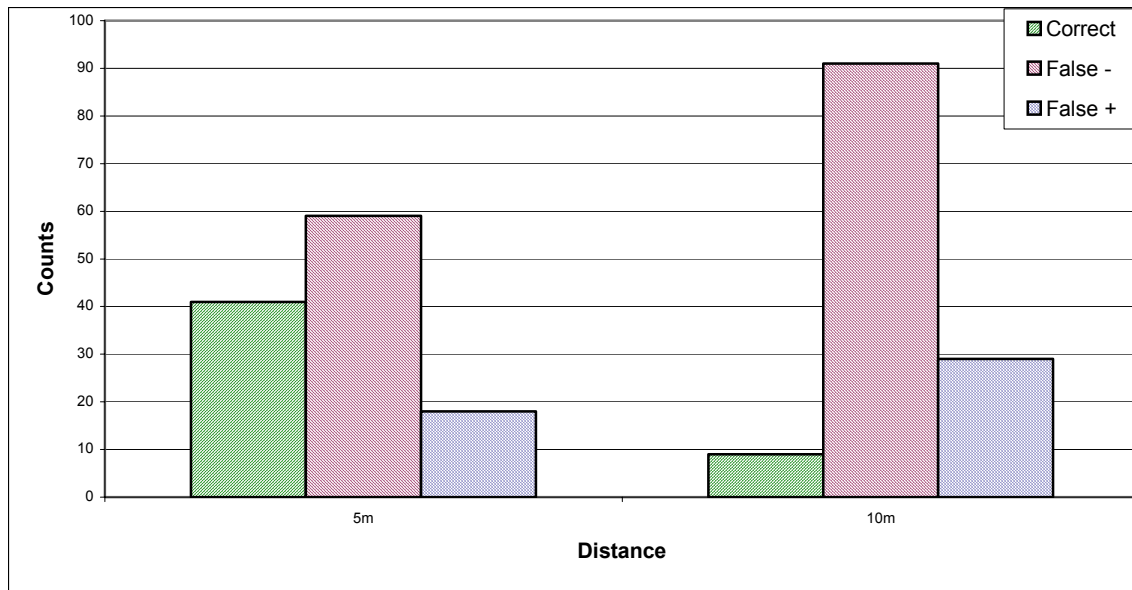


Figure 5: Method 1 laboratory test of November 15<sup>th</sup> recordings

Method 2 correctly distinguished 58 manatee vocalizations at 5m and 25 vocalizations at 10m (see Figure 6). Method 2 falsely detected manatee vocalizations 18 times at 5m and 38 times at 10m. Method two has an adjustable threshold level. By increasing this value the false detections were reduced to 0 in the 5m test and 5 in the 10m test (see Figure 7).

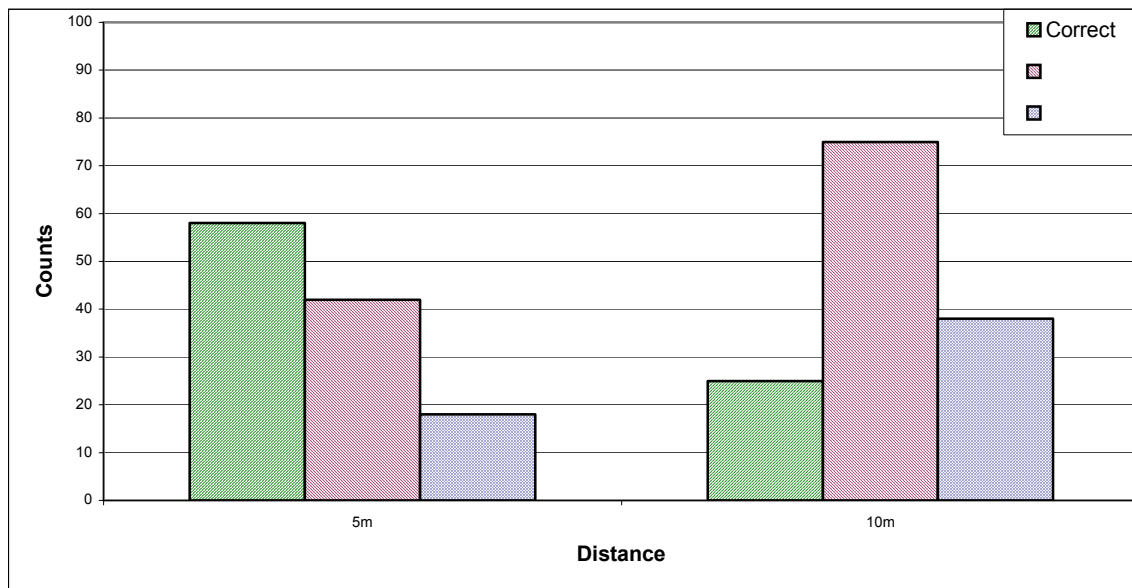


Figure 6: Method 2 laboratory tests of November 15<sup>th</sup> recordings with lower threshold

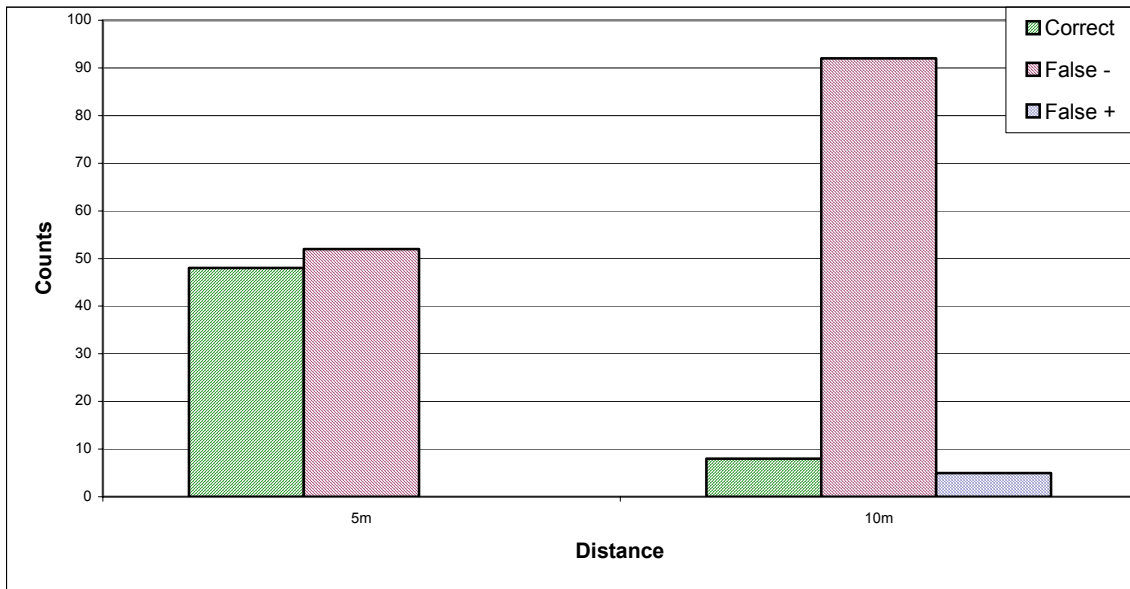


Figure 7: Method 2 laboratory tests of November 15<sup>th</sup> recordings with higher threshold

Method 3 verifies that a call exists for a specified length of time. This time is adjustable by the operator and the dockside data tracks were evaluated using two different setups. Initially, the length of call was specified to be short in length (see Figure 8) and then lengthened (see Figure 9). With a shorter call length method 3 was capable of correctly detecting over 70% of the manatee vocalizations correctly at 5m and 37% at 10m. With this setting method 3 had a false positive rate of 11% and 18% at 5m and 10m, respectively. When the method 3 is instructed to look for longer length calls, it correctly identified 62% of the manatee vocalizations at 5m and 21% at 10m. By setting method 3 to look for longer length calls the false detection dropped to 0 at 5m and 1 at 10m.

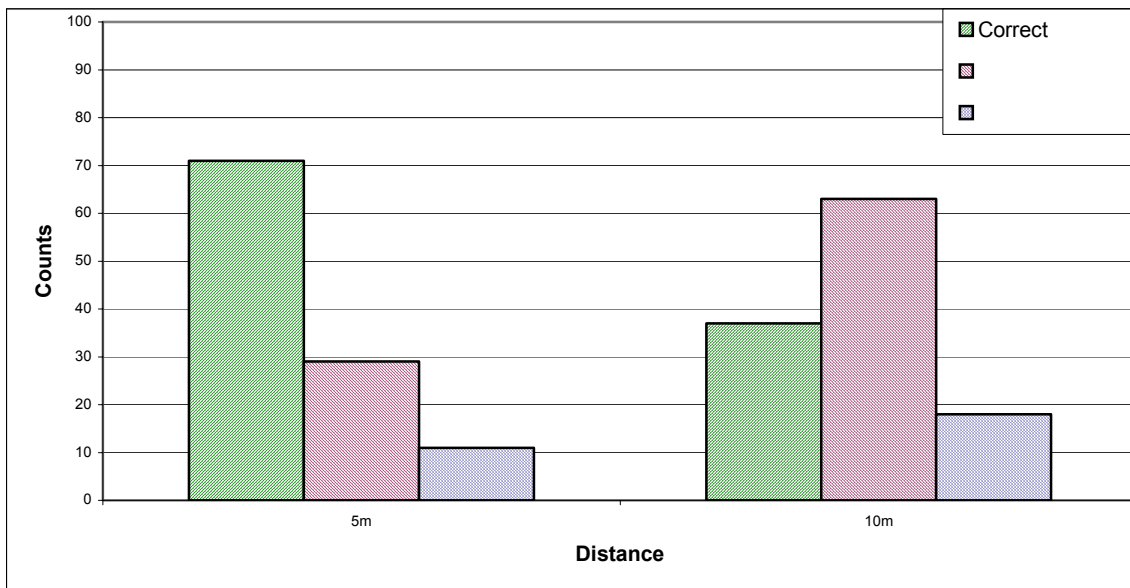


Figure 8: Method 3 laboratory tests of November 15<sup>th</sup> recordings with short vocalization length

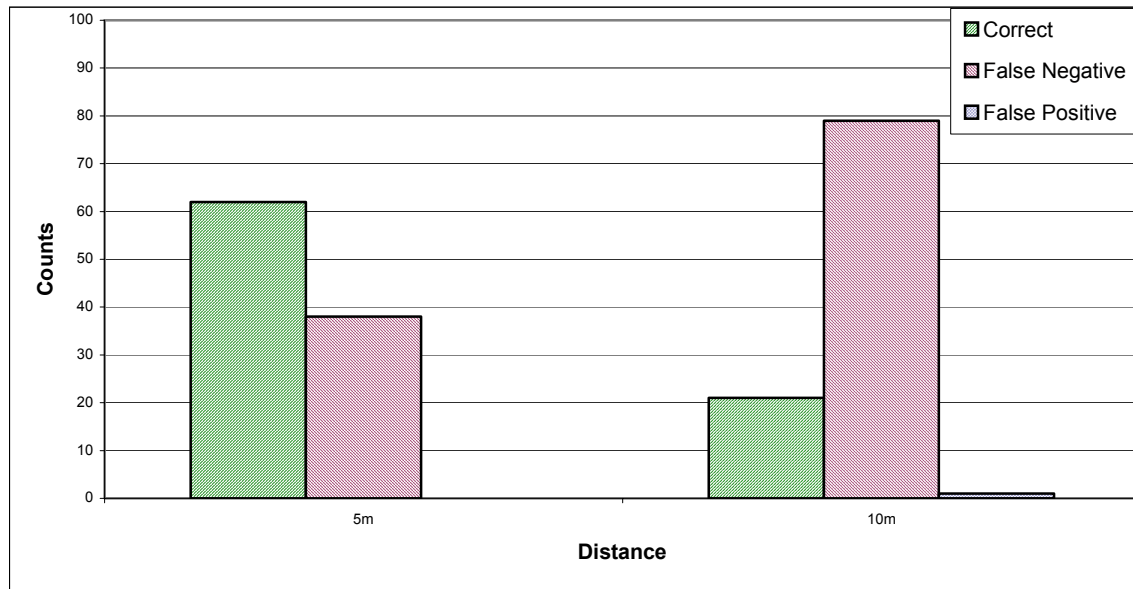


Figure 9: Method 3 laboratory tests of November 15<sup>th</sup> recordings with longer vocalization length

### 3. Problems Encountered

Several problems were encountered during the dockside testing process on November 15, 2002. The speaker used to reproduce the manatee vocalizations during the dockside testing did not have a flat frequency response.

The frequency content of the manatee vocalizations differed significantly between the NAVSEA recordings and Dr. Mann's recordings. The manatee vocalizations recorded on the NAVSEA CDs consisted of calls with fundamental frequencies between 2 and 4 kHz. The manatee vocalizations provided by Dr. Mann had fundamental frequencies between 8 and 12 kHz. This adversely affected the performance of one of the detection algorithms on November 15, 2002, since it was not designed for this frequency range.

The dockside recordings on November 15, 2002 contained a DC voltage offset as well as a square wave. Both of these had to be removed from the files before any analysis could be done with the recordings.

The recording levels of the 'wav' files generated by Dr. Mann were less than 5% of the usable range. The 'wav' files had to be re-recorded at an increased volume before any of the recordings could be used.

### 4. Suggested Future Work

Future work to determine the feasibility of acoustically detecting manatees would include field-testing to determine sound power levels of typical manatee vocalizations. This would determine at what distance manatees could be detected by acoustic methods. The researchers would also like to investigate the vocalization of manatees in the infrasonic frequency range.

The detection algorithms could be improved to reduce or eliminate the shrimp snapping from the background noise. Also, the ability to detect other manatee sounds (chewing, digestion, and flatulence) could be added to make the algorithms more robust. The researchers would like to explore several other advanced signal processing techniques, which are expected to produce improved results.



## REVIEW OF RELATED LITERATURE

The reasons for developing a manatee detection system as well as statistics concerning manatee injuries and deaths are discussed in this chapter. A review of previous work related to manatees and their vocalizations is presented as well. Finally, the approach taken in the development of the manatee detection systems is discussed.

### **1.1 Need for Manatee Detection Systems**

A major focus of wildlife conservation in the last twenty years in the state of Florida has been the identification and preservation of the West Indian Manatee (*Trichechus manatus latirostris*). A manatee surfacing for air is shown in Figure 1-1. Manatees are often injured or killed by collisions with watercraft traffic on Florida's many rivers and waterways. The number of collisions is so frequent that manatees are routinely identified by the scars they receive from these boat strikes. The risk of a collision increases greatly in the winter when water temperatures drop below 20°C and manatees migrate to warmer inland waters, such as Crystal River, Blue Springs, St. Johns River, and industrial plant discharges. These warm water habitats can be dangerous places for manatees as many of them are also popular locations for boating and water recreation.



Figure 1-1. Manatee surfacing for air  
(<http://www.fcsc.usgs.gov/pics/manatee/manateethumb.html>, 2003).

In response to the growing evidence of the negative effects of boating on the manatee population, the state legislature passed the Florida Manatee Sanctuary Act in 1978, which allows for the creation and enforcement of boating restrictions in manatee habitats. This act has been used to create many “idle-speed” and “no-wake” zones throughout Florida’s many waterways. These zones have created conflict throughout the years between environmentalists, who feel that more zones should be added in order to protect more habitats, and boaters, who want fewer restrictions on the waterways they use for both commercial and recreational purposes. Despite all the protective efforts in the last twenty years, the number of manatee deaths per year continues to rise at a troubling rate. The number of deaths is so great that the Endangered Species Act of 1973 classifies the manatee as a species “in danger of extinction without human protection.” In surveys

conducted throughout Florida in January 2001, the manatee population was estimated at 3,276. Since scientists began documenting manatee deaths in 1974, the number of manatee deaths per year has exceeded 10% of the estimated total population ([http://www.floridamarine.org/products/product\\_info.asp?id=1544](http://www.floridamarine.org/products/product_info.asp?id=1544), 2003). The number of manatee deaths caused by collisions with watercraft per year from 1976 to 2001 is shown in Figure 1-2. It can be seen that this number has steadily increased over the last twenty years. The percentage of total manatee deaths caused by boat collisions and other human related factors can also be seen in Figure 1-2. It can be seen that 36% of all manatee deaths are caused by collisions with watercraft with an additional 9% being caused by other human-related factors, such as being crushed in floodgates and canal locks (Gerstein, 2002). These numbers show a need for a different approach to protecting manatees and their habitats.

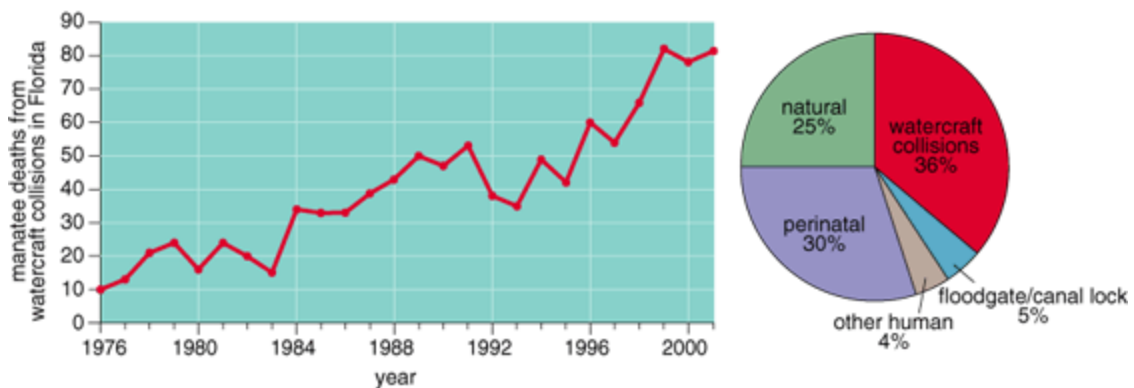


Figure 1-2. Number of manatee deaths from watercraft collisions from 1976 to 2001 and percentage breakdown of total manatee deaths (Data from the Florida Fish and Wildlife Conservation Commission) (Gerstein, 2002).

## 1.2 Review of Related Work

Schevill and Watkins, in 1965, were among the first researchers to describe the calls of the West Indian manatee and to add the manatee to the list of aquatic mammals known to produce sounds. They described the manatee's calls as being squeaky and

rather ragged. They found these calls to last between 0.15 and 0.5 seconds and to be 10-12 dB above the background noise. They also found the fundamental tones of the manatee's calls to be between 2.5 and 5 kHz but sometimes as low as 600 Hz. Schevill and Watkins also found that the first harmonic is often much more intense than the fundamental (Schevill and Watkins, 1965).

Hartman continued this research in 1969 and became the first biologist to study the West Indian manatee in their underwater habitat. Hartman found the vocabulary of manatees to be highly variable and to include chirp-squeaks, squeals, and screams. All of these calls were found to be produced in a variety of unrelated circumstances (Hartman, 1969).

In 1982, Cathy Steel created a detailed characterization of captive manatee sounds and separated them into nine different categories. Steel determined that the sounds of adult females were lower in tone than those of adult males. She also found that the squeaks of the manatees are non-harmonic and contain more noise than the harmonic squeals. She also determined that the calls of manatees change as they age, with infants making vocalizations that are squeaky and have a chirp-like quality. As the manatees age and become juveniles, their calls become much clearer and begin to develop a harmonic pattern but still retain their chirp-like quality. Steel determined the patterns that are associated with vocalizations. She found that vocalizations occur under many different circumstances, including manatees approaching one another, submergence from breathing, and especially during play. Both individuals as well as manatees interacting with one another were found to make sounds. A close bond was seen between infants and their mothers with the pairs communicating on a frequent basis. Steel also noted a rise in

amplitude in calls when the manatees were under conditions of distress, alarm, or annoyance (Steel, 1982).

Perhaps the most extensive catalog of manatee recordings was created by Thomas O'Shea between 1981 and 1984. This work was done while O'Shea was working with the United States Geological Survey (O'Shea, 1981-1984). These recordings were used to quantify the performance of the detection algorithms discussed in the following chapters.

In 1985, Bengston and Fitzgerald studied the role of manatee vocalizations and the frequency of manatee calls in different situations. They determined that manatees call infrequently when feeding and most frequently when cavorting and mating. Bengston and Fitzgerald determined that manatee calls seem related to social factors rather than navigation as was previously believed by some scientists. They noted that the frequency at which the vocalizations occurred increased as the level of excitement and social interaction of the animals increased. The two observed that manatees vocalize rapidly when approached and joined by new manatees. It was determined that vocalizations typically occur one to five times every five minutes depending on the situation. The only exception to this is during feeding when the rate of vocalization is much lower (Bengston and Fitzgerald, 1985).

In 1991, Ellen Marie Richard-Clark divided manatee calls into 7 distinct categories: squeaks, squeals, lilt, whistles, chirps, peeps, and rusty pumps. She defined each type of call by the number of dominant frequency bands and their duration. Squeaks have three or four frequency bands and typically last less than 0.25 seconds. Squeals, which are the most common, consist of two to five bands, contain no frequency modulation, and last 0.25 seconds or longer. Lilt contains the largest number of dominant

bands, ranging from six to nine, and last between 0.13 and 0.35 seconds. Whistles contain one band, have no modulation, and are relatively short, about 0.2 seconds. Chirps have two or three bands and possess frequency modulation while peeps are the shortest of calls, lasting only 0.15 seconds or less. The last category of call is the rusty pump, which consists of one band, has no modulation, and has a very hollow sound. Richard-Clark also discovered a difference between the breeding populations of manatees on the east and west coasts of Florida. She found that manatees on the east coast produce slightly higher frequency calls than those on the west coast. This implies that there is a barrier between the east and west coast breeding populations (Richard-Clark, 1991).

Another important area of research with manatees has been in determining their hearing potential and the creation of audiograms. Gerstein and others looked at the hearing potential of manatees and created one of the first manatee audiograms. They found the maximum hearing sensitivity of manatees to be around 50 dB (re 1 $\mu$ Pa) at approximately 16 kHz with the best hearing falling between 6 and 20 kHz. It was observed that the sensitivity decreased by approximately 40 dB per octave for frequencies over 26 kHz and 20 dB per octave from 0.8 to 0.4 kHz. At 0.4 kHz, thresholds exceeded 100 dB (re 1 $\mu$ Pa), which was 60 dB above the background level (Gerstein *et al.*, 1999).

This research led Gerstein to create an acoustic device to alert manatees of approaching boats. This device takes advantage of the optimum hearing abilities of manatees found during Gerstein's research. The device would be placed on the front of boats and would create a highly directional, low-intensity signal to alert manatees to the boat's presence. It is believed that the manatees will associate this sound with boats and learn to maneuver out of the way. The prototype of this device featured a through-the-

hull-mounted parametric transducer that created a 20 kHz parametric wave. This frequency was chosen because it can be detected by manatees and dolphins but is below the hearing range of fish (Gerstein, 2002).

Research has also been done on the other members of the Order Sirenia. Two sets of researchers, Evans & Herald and Sonoda & Takemura, each looked at the vocalizations of the Amazonian manatee (*Trichechus inunguis*). They found the calls to be similar to those of the West Indian manatee with the exception of call duration and fundamental frequency. The fundamental frequency of the Amazonian manatee was found to be between 6 and 8 kHz compared to 2.5 and 5 kHz for the West Indian manatee. The duration of a typical Amazonian manatee call was found to be around 0.1 and 0.2 seconds while that of the West Indian manatee falls between 0.2 and 0.3 seconds (Evans and Herald, 1970; Sonoda and Takemura, 1973).

In 2002, Sousa-Lima and others presented their findings regarding the characteristics among the different sexes and age groups of the Amazonian manatee. They recorded 14 individually housed Amazonian manatees and measured seven variables to separate the vocalizations based on fundamental frequency and call duration. Sousa-Lima found that the vocalizations of females were usually shorter with greater fundamental frequencies than males. It was also found that calves had shorter call durations and higher fundamental frequencies than sub adults and adults, which indicates an inverse relationship between overall length and fundamental frequency. The vocalizations of mothers and their calves were found to share similar characteristics (Sousa-Lima, *et al.*, 2002).

Research has also been done on the other extant species of Sirenia, the dugong. In 1975, Nair and Lal Mohan analyzed the sounds of the dugong. They found that the typically dugong vocalization contained a fundamental frequency between 3 and 8 kHz with a typical duration between 0.1 and 0.5 seconds. Nair and Lal Mohan described the most common type of vocalization to be a burst of squeaks between 5 and 20 in number and lasting 1 to 8 seconds (Nair and Lal Mohan, 1975).

Anderson and Barclay continued this research in 1995 when they analyzed the acoustical signal characteristics of individually identifiable wild dugongs. They classified the vocalizations as chirp-squeaks, barks, and trills. Chirp-squeaks were found to be frequency-modulated ranging between 3 and 18 kHz and lasting 60 milliseconds. Trills were categorized as lasting between 100 and 2200 milliseconds, being frequency-modulated, and having two to four harmonics between 3 and 18 kHz, as well. Lastly, barks were described as being broadband signals between 0.5 and 2.2 kHz, with up to five harmonics, and lasting 30 to 120 milliseconds (Anderson and Barclay, 1995). This research shows the similarity between dugong vocalizations and those of the manatees discussed earlier.

This previous work illustrates the typical characteristics of manatee vocalizations that were used to design the detection systems discussed in the remainder of this paper. The typical manatee vocalization has a fundamental frequency between 2 and 5 kHz with an average duration of 0.15 and 0.5 seconds. There are typically between two and five harmonics with the first harmonic usually having a higher intensity than the fundamental. A spectrogram of a typical manatee vocalization is shown in Figure 1-3. The spectrogram



contains more calls than a single manatee would produce in the shown time so it can be assumed that multiple manatees were present or the time has been compressed.

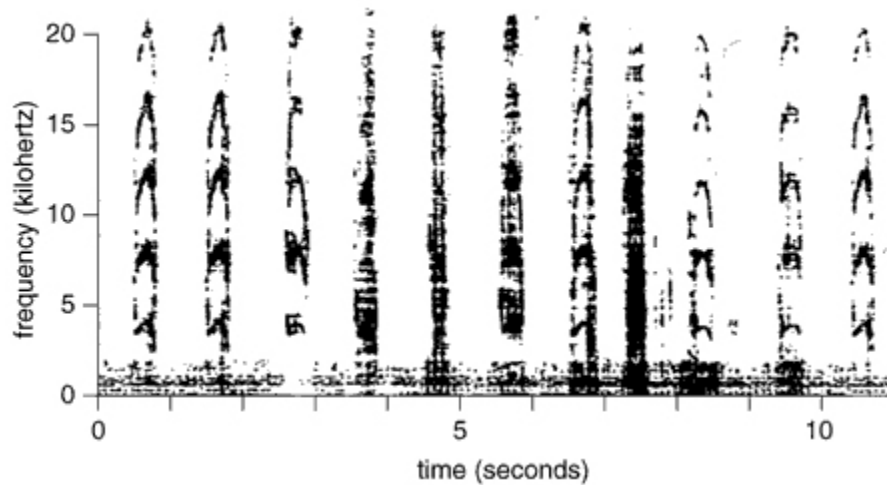


Figure 1-3. Spectrogram of typical manatee vocalizations showing a broadband signal with several harmonics (Gerstein, 2002).

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