EFFECT OF ANTHROPOGENIC NOISE ON THE MATING CALL OF THE PLAINFIN MIDSHIPMAN (*PORICHTHYS NOTATUS*) IN SAN FRANCISCO BAY

A thesis presented to the faculty of
San Francisco State University
in partial fulfillment of
the requirements for
the degree

Master of Science
in
Physics

by

Gaurav P. Rele

San Francisco, California

August 2015

Copyright by
Gaurav P. Rele
2015

CERTIFICATION OF APPROVAL

I certify that I have read *EFFECT OF ANTHROPOGENIC NOISE ON THE MATING CALL OF THE PLAINFIN MIDSHIPMAN (PORICHTHYS NOTATUS) IN SAN FRANCISCO BAY* by Gaurav P. Rele and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree: Master of Science in Physics at San Francisco State University.

Dr. Roger Bland
Professor of Physics

Dr. Susan Lea
Professor of Physics

Dr. Joseph Barranco
Associate Professor of Physics

EFFECT OF ANTHROPOGENIC NOISE ON THE MATING CALL OF THE PLAINFIN MIDSHIPMAN (*PORICHTHYS NOTATUS*) IN SAN FRANCISCO BAY

Gaurav P. Rele
San Francisco State University
2015

The most prominent features of underwater noise in the San Francisco Bay, measured over a period of 4 years, are the loud mating call of the plainfin midshipman (*Porichthys notatus*) and intense episodes of sounds from passing ships. This study observes the sounds from fish exposed to high levels of anthropogenic noise for any change in the mating call due to the passage of the ships. The dominant sources of underwater ship noise are two types of ships: scheduled ferries going between San Francisco and the town of Larkspur, and large commercial vessels. The intensity and frequency before and after the passage of the ships has been compared for both types of ship. No clear statistically significant evidence was found for a change in the behavior due to the passage of ships.

I certify that the Abstract is a correct representation of the content of this thesis.

Dr. Roger Bland, Chair, Thesis Committee Date

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my advisor Dr. Roger Bland for his continuous support, for his patience, motivation, and immense knowledge. He has become more of a mentor and a friend than a professor over the years. His dedication to his work will always serve as reminder to strive harder to achieve all the goals in life. I doubt that I will ever be able to convey my appreciation fully, but I owe him my eternal gratitude.

Special thanks to the rest of my thesis committee, Dr. Susan Lea and Dr. Joseph Barranco for their immense helpful career advice and guidance throughout my master's degree.

I would also like to thank my family for their continuous support. Their love, support and encouragement paved way for me to come to United States of America and pursue my higher education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Background

1.1 Underwater Sound

Sound plays an important role in communication in aquatic environments. Sound travels faster in water than in air and generally with little attenuation (Urick 1996). Fishes rely on sound for learning about their surrounding environment, for mating, and for detection of nearby predators or prey as well as general communication within the species (Au and Nachtigall, 1997; Edds-Walton, 1997; Zelick, Mann and Popper 1999; Fay and Popper 2000). Fishes tend to get a lot of information from the auditory scene (Bregman 1993), which consists of biotic sources (biological, eg. fish sounds) as well as abiotic sources (eg. waves, storms etc). From the time of steam engines, underwater anthropogenic (human-generated) sound has increased several fold (Andrew et al. 2002, Mcdonald et al. 2006). These sounds can be associated with ships, dredging, drilling, sonar, recreational vessels and other sources. The effects may range from temporary loss in hearing which hinders the fishes ability to communicate (eg. by masking their calls to other marine animals) to more substantial effects and even death (Richardson 2002).

This study focuses on the effects of anthropogenic ship noise in San Francisco Bay. The ships include large commercial vessels as well as smaller and faster ferries. Commercial shipping is known to account for a significant amount of anthropogenic underwater noise in the ocean (Richardson et al. 1995). The noise can arise from propeller cavitation or from on-board machinery. The marine vessels dominate the low frequency (below 1000 Hz) background noise in the frequency range of interest in this study (Wenz 1962, 1969, Gray and Greeley 1980, Ross 1993, Green and Moore 1995). While most research on the effects of underwater noise has been on marine mammals, these effects on fishes have rarely been studied (Myrberg, 1990; NRC 2003). High levels of background noise may cause some physiological damage as well as behavioral stress responses in fishes similar to those found in mammals (Welch and Welch, 1970). Our study examines the effects of anthropogenic ship noise on the plainfin midshipman (*Porichthys notatus*) in its natural habitat in the San Francisco Bay.

1.2 The Plainfin Midshipman

The plainfin midshipman (*Porichthys notatus*) is a nocturnally active marine fish distributed along the Pacific Coast of North America, from lower California to Puget Sound (Fish 1948). Plainfin midshipman are generally found in deep water during fall and winter season but migrate up to the shallow inter-tidal zone for the breeding season (spring and summer). The male plainfin midshipman seek shallow water near the shore, preferring boulders or small crevices below the rocky sides (Hubbs 1920). The males defend their nest from other males and generate a long mating call ("hum") to court females. The females deposit their eggs and leave while the male guards the nest until the embryos hatch and can swim on their own. The male continues to court other females to lay eggs in his nest in this period as well. The plainfin midshipman has two male reproductive species, called guarder type I and sneaker type II males (Bass 1996). The guarder males form the nest sites under a rock and guard them while courting females. The sneaker males are not big enough to have their own nest site and hence cannot court the females. Instead, they fertilize the eggs from guarding males by either sneaking deep into the nest when a female is present, or by fanning sperm into the nest from the periphery. The type I midshipman male uses sonic muscles attached to the swim bladder that rapidly expand and contract to produce its long-duration mating call (Greene 1924). The midshipman hums with a fundamental frequency ranging from 80 Hz to 120Hz, varying systematically with temperature (McKibben and Bass 1998).

1.3 Ship Noise

Marine vessels are one of the primary sources of underwater anthropogenic noise. The lower frequency noise generated by various electronic equipment, propellers or hulls tends to travel further. Various types of ships pass through the San Francisco

Bay at any given time of the day. They may include ferry ships, cargo ships, tankers, tug boats, pilot boats, military/law enforcement boats, pleasure boats and small boats used for fishing. The ferry ships are the most common type of ships in the bay.

1.3.1 Passenger Ferries

Two types of ship are operated by the Golden Gate Ferry. The fleet includes 3 Spaulding-class ships and 4 multi-hull ships (catamarans). The Spaulding-class ships are 169 feet long with a service speed of 20.5 knots, and the catamarans are about 140 feet long with a service speed of 36 knots (see Figure 1.1). The ferry service goes between the San Francisco Ferry Building and the town of Larkspur, typically 40 times a day on weekdays (see ferry schedule in Appendix A). A spectrogram (see Figure 1.2) shows the passage of a typical ferry while a midshipman is humming strongly, both before and after the passage of the ship. The large number of such passages makes ships of this type the prime candidates to monitor the effects on the mating call of the plainfin midshipman.

Figure 1.1: Typical ferry of the catamaran type used by the Golden Gate Ferry Service.(photo: google images)

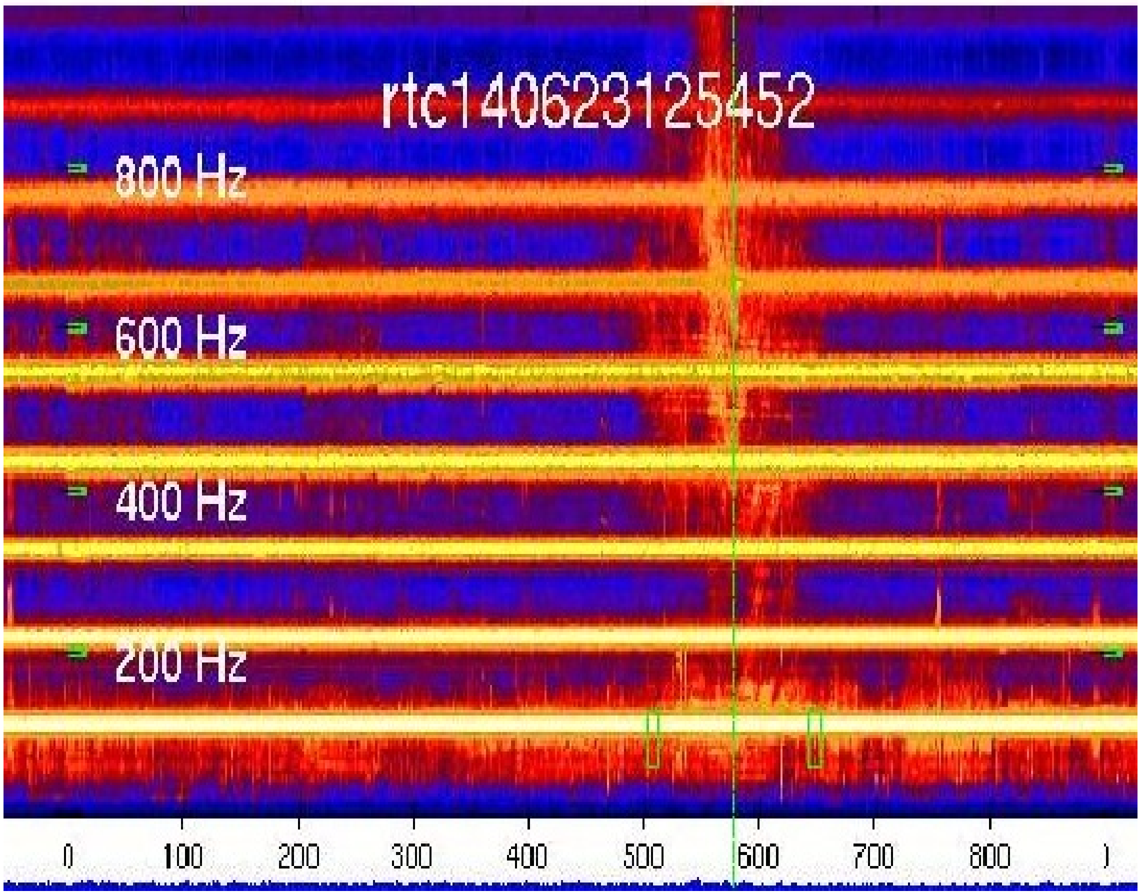

Figure 1.2: Spectrogram from a 15-minute hydrophone recording taken on June 23rd, 2014. The time (seconds) is on the x-axis and frequency (up to 1000 Hz) is on the y-axis. The horizontal lines represent the fundamental (near 100 Hz) frequency of the midshipman mating call and its overtones. The broadband signal near 600 seconds is the sound from a passing ferry. The green line shows the center of the detected ferry while green boxes indicate the frequency intervals where hum intensity is measured before and after the passage of the ship.

1.3.2 Large Commercial Vessels

Medium to large commercial shipping vessels generate underwater sounds mainly from the propeller cavitation with frequencies between 50 - 150 Hz (Ross 1976). Figure 1.3 shows a large commercial vessel as seen in the San Francisco Bay. The large ships are slower, intermittent and louder than the ferries, and the average time taken to pass the recording site is greater. Even though the number of these ships is fewer than the number of ferries, their higher intensity makes them a good candidate for analyzing the effect of ship noise on plainfin midshipman. Figure 1.4 shows a spectrogram with a large commercial vessel with midshipman humming. It can be seen that the humming stops before the passage of the ship in this case.

Figure 1.3: Typical large commercial vessel passing the study site.(photo: Gaurav Rele)

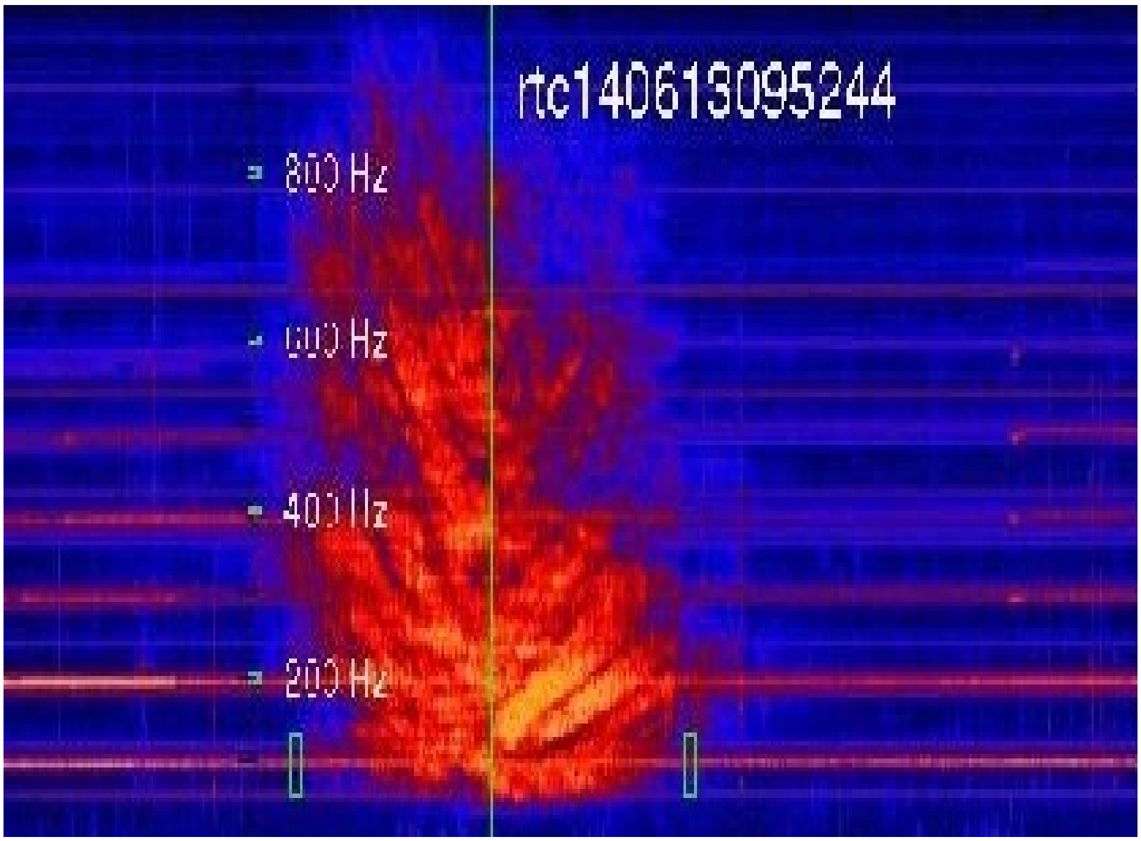

Figure 1.4: Spectrogram from a 15-minute hydrophone recording taken on June 13^{th}, 2014. The time (seconds) is on the x-axis and frequency (up to 1000 Hz) is on the y-axis. The horizontal lines represent the fundamental (near 100 Hz) frequency of the midshipman mating call and its overtones. The broadband noise near 250 seconds is the sound from a passing commercial vessel. The green line shows the center of the detected commercial vessel while green boxes indicate the frequency interval where hum intensity was measured before and after the passage of the ship.

Chapter 2

Data Acquisition

2.1 Recording Sound at the Romberg Tiburon Center

Romberg Tiburon center (RTC) is a San Francisco State University marine laboratory setup to study underwater marine ecology in the San Francisco Bay and Estuary. The sound is detected by a hydrophone (Aquarian Acoustics model H2a)[1] deployed from the RTC research pier (latitude 37°55'30"N, longitude 122°26'47"N)(see Figure 2.1). The hydrophone is housed in an open cylindrical PVC pipe with a concrete base (see Figure 2.2). The hydrophone sensitivity is approximately -180 dB re 1 V/μPa. The signal is amplified and then filtered with an eight-pole Butterworth anti-aliasing filter. A Lab View [2] based acquisition system digitizes the signal at 2000 Hz, saving the data in 15 minute WAVE files. The data is then transferred to a computer on the SFSU campus for further analysis.

[1] www.aquarianaudio.com

[2] http://www.ni.com/labview/

Figure 2.1: The Romberg Tiburon Center with the research pier shown in the upper right hand corner. The hydrophone is deployed from the end of the research pier at a depth of about 10 meters.

Figure 2.2: The hydrophone housing as deployed from the RTC research pier. The hydrophone (inside the PVC pipe) is deployed on the bottom at a depth of 10 meters. Autonomous loggers record temperature and salinity.

2.2 Analysis at the SFSU Campus

Once the files are downloaded to the SFSU server, a spectrogram is generated for each 15 minute time series and posted online in near real time. The analysis of the data on campus is carried out using MATLAB[3].

A number of steps are required to go from raw data to the results of analysis (see Figure 2.3). The raw wave (*.wav) files contain artifacts, 'glitches' that are difficult to separate from the ship signals and the midshipman's hum. Some of the most common glitches observed are due to crabs scratching on the hydrophone mount and to cable strumming due to tidal currents. These glitches are removed by a filtering process producing the *.rdg files. For the purposes of ship detection, the humming signal is then removed from the deglitched (*.rdg) files by replacing the selected humming frequency bands with the adjacent background to produce a deglitched and dehummed signal (*.rdh). These files are then used to search for ship peaks using a matlab algorithm. This algorithm uses 3 15-minute wave files concatenated together to find smooth quasi-gaussian peaks centered within the middle 15-minute file storing the results in *.shp files (ship files). The wave files are separately analyzed for the hum with results stored in *.tff files (humming files). This research begins with these files as a starting point.

The ship file is used in the script callshp (see Appendix B) to input all the variables

[3]http://www.mathworks.com/products/matlab/

to find and analyze the ships for the midshipman humming intensity before the ship passes and after the ship has passed. The script calls a function findfile (see Appendix B) to concatenate three 15 minute wave files to generate a 45 minute time series for each ship before proceeding to find the intensities. Another function findareashp (see Appendix B) finds the intensity of the midshipman hum before and after the ship has passed using the 45 min wav file by analyzing a 10 second interval at the distance of 2σ from the center of the ship signal, where σ is the half width of the peak of the ship signal. The distance of 2σ has been chosen to prevent the ship noise from biasing the humming intensity calculations. The output is *.shg file (shg file) with variables from the *.shp files and the intensities, width and frequencies added from both sides. In order to identify the change in the midshipman humming before and after the passage of the ship, we use the asymmetry co-efficient α defined using the equation,

$$\alpha \equiv \frac{I_L - I_R}{I_L + I_R} \tag{2.1}$$

where

I_L is the intensity before the ship passes (on the left of the center as seen on the spectrogram)

I_R is intensity after the ship passes (on the right of the center as seen on the spectrogram)

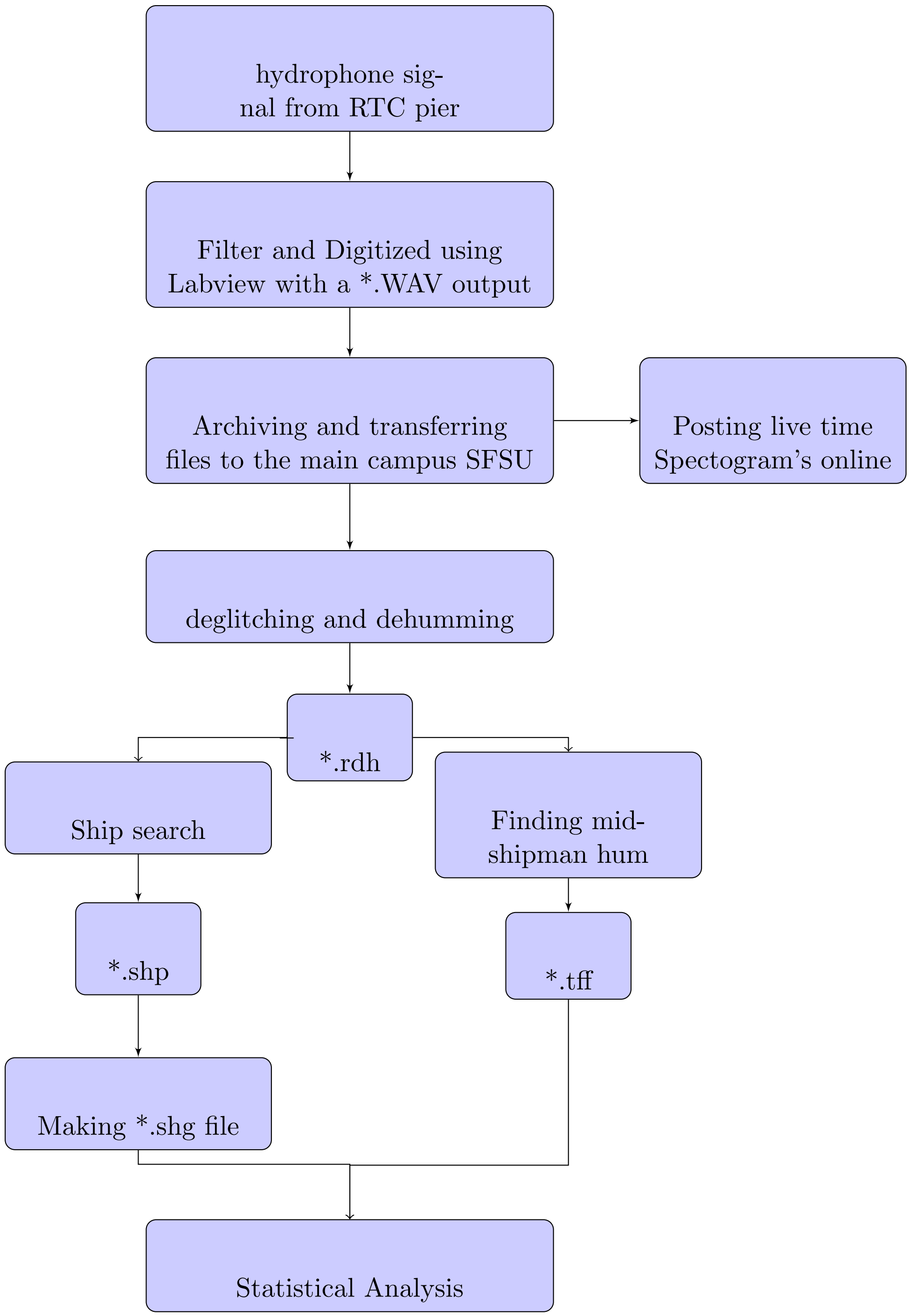

Figure 2.3: Flow chart of the data acquisition and statistical analysis.

Chapter 3

Data Analysis and Results

3.1 The Midshipman Hum

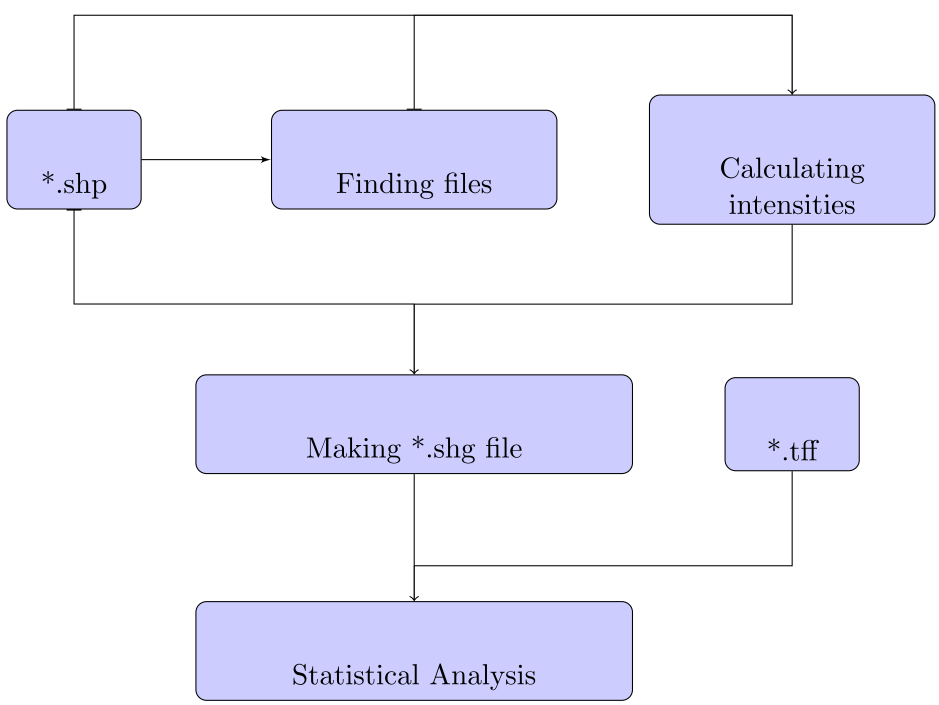

Figure 3.1: Flow chart of the data and statistical analysis.

The flowchart (Figure 3.1) shows the steps taken to analyze the midshipman hum. An example of the analysis of intensity before and after the ship has passed is given as follows,

STEP I : Read the data from the ship search algorithm (*.shp)

The data from the ship search is stored in a file once a month in the following format rtc(year)(month)00(type of ship).shp. These files are read in to the program before starting the analysis.

STEP II: Finding the right wave file containing the ship.

The data consists of 96 wave files per day over a period of 4 years. A program filefile (see Appendix B) uses the time stamp of the center of the given ship and its width (σ) to search through all the files using their names to determine the 3 15-minute files for analysis. The outputs given by the function are the names of the 3 contiguous files along with their path as well as an error flag. If the function does not find one of the 3 files or if the files are not contiguous then it returns an error. If the file is flagged then no further analysis is done on the given ship.

STEP III: Read in the 3 wave files

The wave files are read in using the information from STEP II . The ship center lies in the middle 15 minute wave file. However, we are interested in finding the intensity at a distance of 2σ which may lie in the first 15-minute file or the 3rd

15-minute file. Hence, the three wave files are read in together for analysis. The wave file is 2700 seconds long with a sampling rate of 2000 Hz. An example is given in Figure 3.2 showing the 3 contiguous files used for analysis.

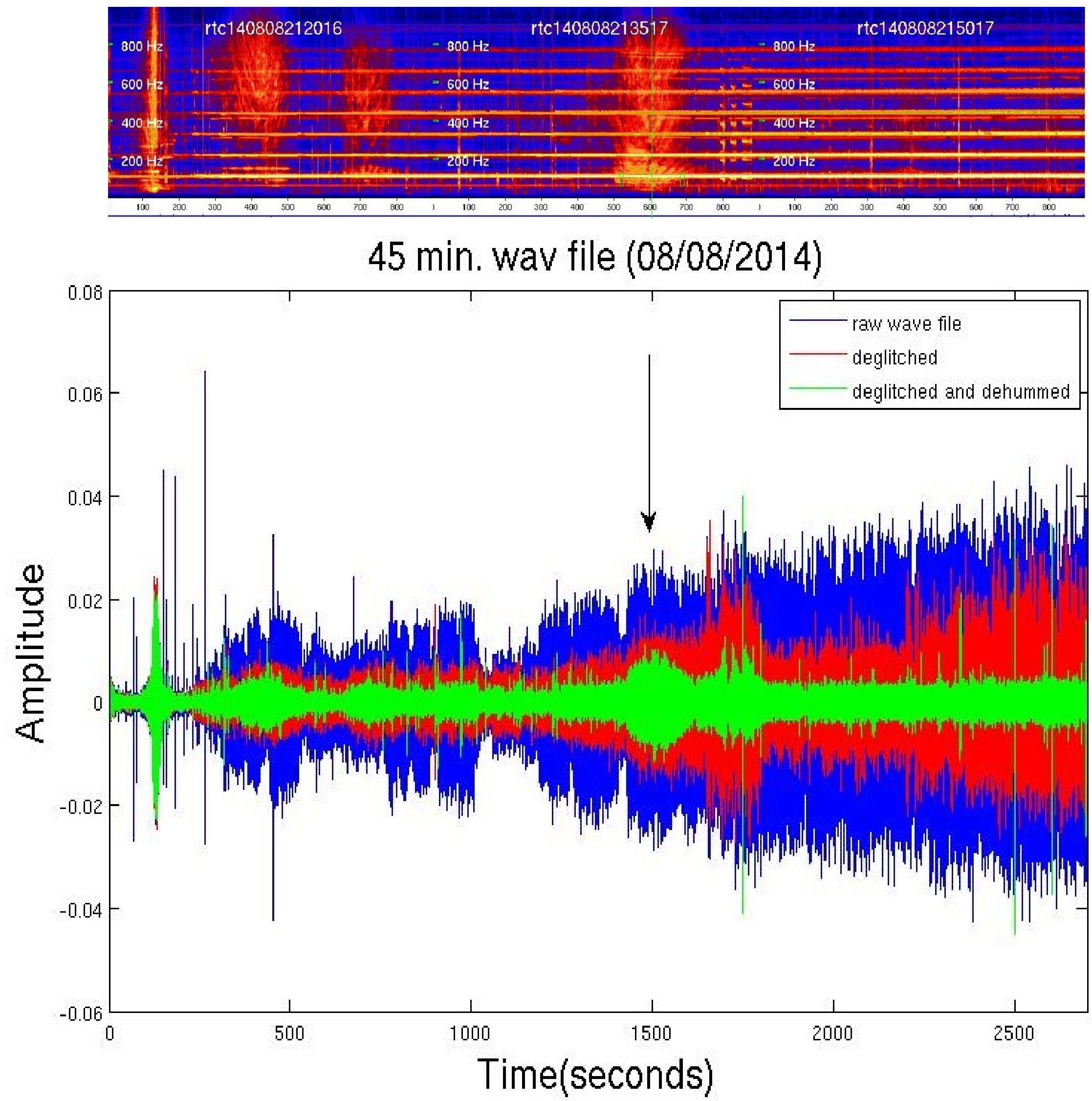

Figure 3.2: Spectrogram and sound amplitude for a 45 minute time series. The deglitched (red) and deglitched and dehummed (green) signals are also shown. The arrow indicates the position of the peak corresponding to the ship in the spectrogram.

STEP IV: Calculating humming intensities before and after the passage of the ship.

Figure 3.3 shows the power spectrum of the ship calculated for a 10 second in-

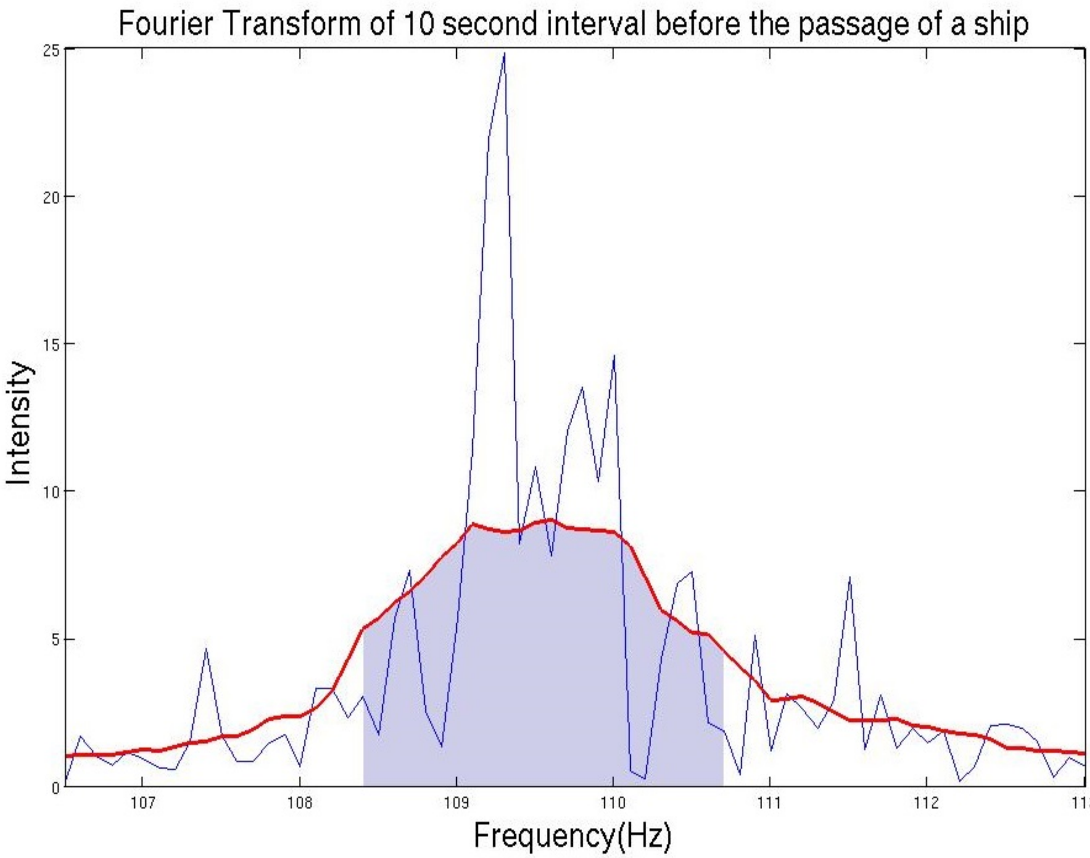

Figure 3.3: The power spectrum from the Fourier transform of a 10-second time series just before the passage of a ship. The red curve is a smoothed version used to find the sound intensity and peak frequency.

terval at 2 σ (peak width) before the passage of the ship. The sharp peak at 109.2

Hz may due to one individual midshipman humming along with other midshipman. A smooth curve is shown in red with the intensity given by the area under the curve.The value of the peak is taken as the maximum of the curve between 60 Hz and 130 Hz. A similar intensity is calculated after the ship has passed for comparison. This method, with a different smoothing is also used for large commercial vessels that pass through the bay. A new file (*.shg) is created to include the humming intensities, width and peak frequency before and after the passage of the ship along with all the other variables from the ship search algorithm.

STEP V: Statistical Analysis

In order to compare the humming intensity before and after the ship has passed, a subsample has to be selected which is unbiased and clean. For statistical analysis, the asymmetry co-efficient as given above is calculated using the intensities. The humming file is used to flag those ships for the presence of a midshipman hum during each ship passage. The ships that passed the criteria above are used for the final analysis. A set of more progressive criteria is used to find a cleaner sample for final analysis.

3.2 Sound From Ferries

The analysis for the ferries starts with a sample of 177,874 ship peaks detected by the ship-search algorithm described above. The first step for getting a cleaner sample of ferries is to use the flags from the ship-search algorithm. The ship search algorithm sets an error flag for peaks with very unrealistic shapes and also calculates the signal to noise ratio s2n and a goodness of fit parameter r-squared. These flags are used in the first sample. Most Golden Gate ferries run on a schedule (see Appendix A) during the weekdays. We define the first sample (Sample 1) as those with original peaks with error flag zero, signal to noise greater than 0.5, goodness of fit parameter greater than 0.8 and running on weekdays. These criteria reduce the number of ships from the original 177,874 ships to 61,565 ships.

Using the spectrograms to identify good ferry signals, the width was determined to lie between 45 seconds and 90 seconds. A lower limit on the peak height was chosen to remove small signals. These two criteria tend to reduce the number of small ships and commercial vessels in the sample. Applying these criteria to the first sample gives the second data sample consisting of 14,994 ships. Figure 3.4 shows the scatter plot of peak height (proportional to the square root of sound intensity) vs peak width. There is a variable cut-off on the peak height as a function of full width which can be seen from the red points on the graph.

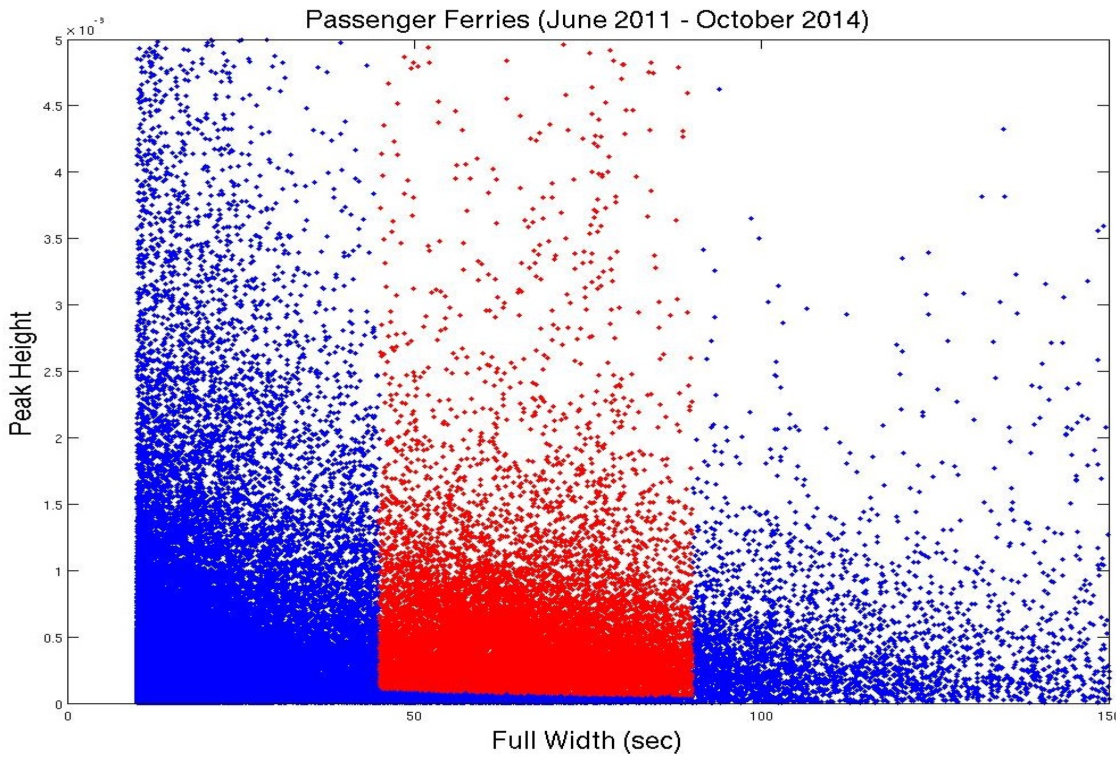

Figure 3.4: Peak height vs time for the ship to pass (full width of the ships), for all well measured ship signals, on weekdays only. The points from sample 1 are plotted in blue while the sub-sample (sample 2) are over-plotted in red.

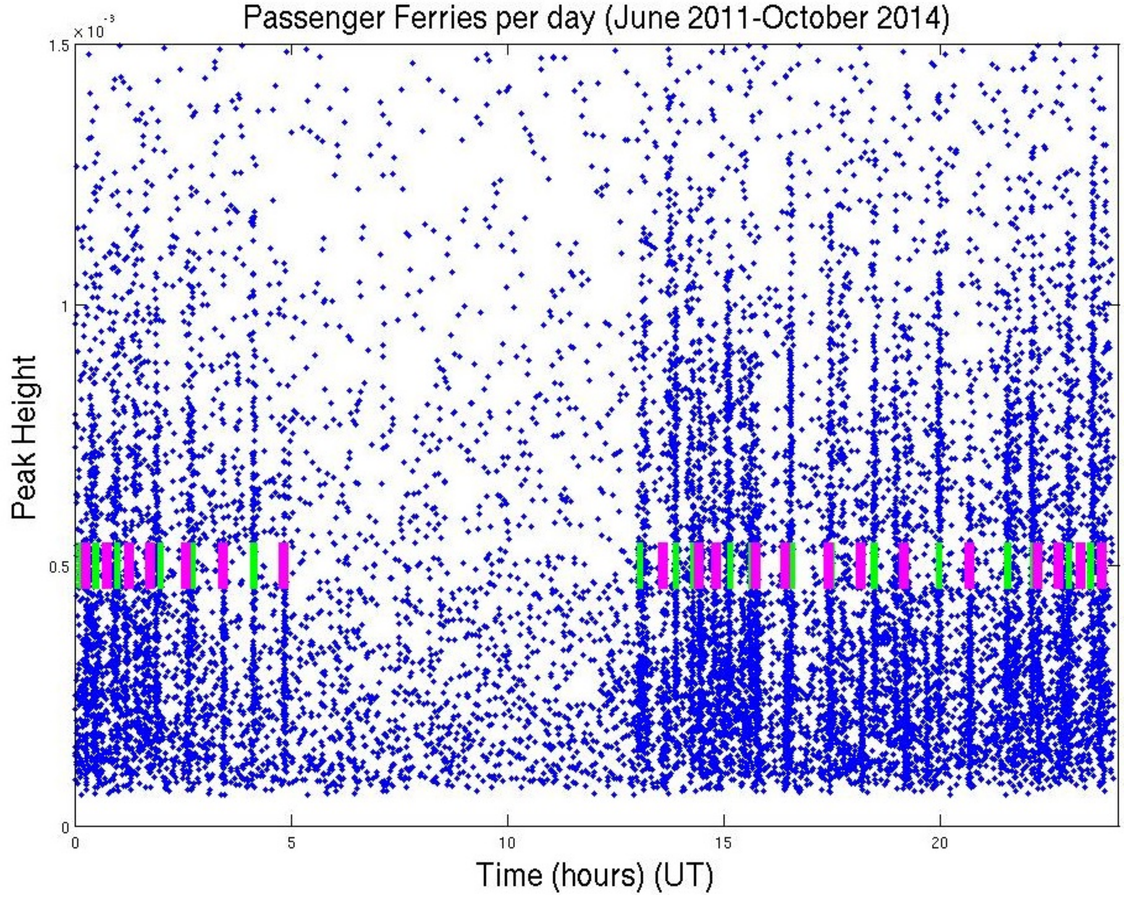

Figure 3.5: Peak height vs hour of the day in universal time. The ships are seen to be lining up after a specific interval which corresponds to a regular schedule for the ferries in the SF bay.

Figure 3.5 shows a scatter plot of peak height vs time of the day for all events in sample 2. Figure 3.5 provides a check for the inclusion of ferries in the sample according to the Golden Gate Ferry Schedule (see Appendix A). The green and magenta bars indicate arrival times with a width of 6 minutes as predicted from the

Golden Gate ferry schedule at the nearest point to the study site. The green bars on the graph mark the ferries going south from Larkspur to San Francisco while the magenta bars mark all the ferries going north from San Francisco to Larkspur. From the ferry schedule, it is seen that the ferries run between 5.45 am and 11 pm. Figure 3.5 also shows ships arriving at random times during the night indicating that these ships are not ferries. Therefore, we can remove these ships from the sample. Adding this criterion to sample 2 gives the third sample (Sample 3) with 13,545 events. Using the Golden Gate ferry schedule as a criterion along with sample 3, we get 58 % ships lying in the ferry band with 4,123 ferries going north and 4,408 ferries going south.

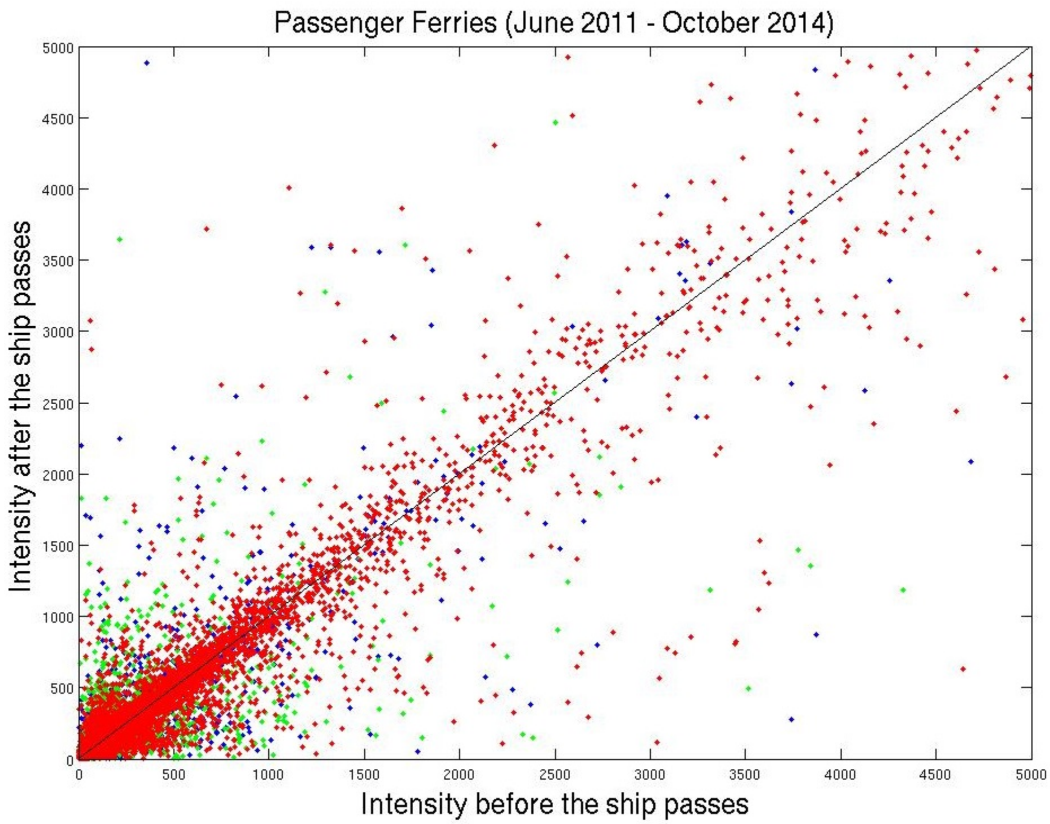

Figure 3.6: The Intensity of the midshipman hum before and after the passage of ships is compared in the plot above. The red points are all events in the final sample.The black line corresponds to midshipman hum intensities being equal before and after the passage of the ships.

Figure 3.6 shows the scatter plot of the humming intensity before and after the ship passes for all the events of the sample 3. The blue points are all events in sample 3. To prevent other ships from biasing the calculations, another condition was to introduce a flag to remove any other ships closer than 2 standard deviations from the ship in question. This reduced the sample from 13,545 ships to 12,118 ships (green points) (Sample 4). For comparing the humming intensity, another flag is created to check for the presence of the midshipman hum when the ferry is passing by the study site. Adding this condition to others would be the sample 5 (red points in the graph) with 9,364 ships. The ships lying inside the Golden Gate ferry schedule in sample 5 make up the 'Ferry Sample'. This sample consists of ferries going south as well as ferries going north. The south bound ferry sample (N-S Ferry) and north bound ferry sample (S-N Ferry) is taken from the ferry sample by selecting the times only for south bound ferries and north bound ferries respectively.

In addition to finding the change in the humming intensity, the midshipman might also change their frequency due to the passage of the ships. The frequency line in Table 3.1 tabulates the change in frequency rather than intensity before and after the passage of the ships, for all ships in sample 5.

Figure 3.6 is approximately symmetrical indicating that the number of ships with intensity higher before the ship passes is almost equal to the number of ships with intensity lower before the ship passes. To make it quantitative, the humming intensities before and after the passage of the ship are compared. The asymmetry co-efficient is found from the humming intensities for all the ships that passed the criteria using the following equation,

$$\alpha = \frac{I_L - I_R}{I_L + I_R} \tag{3.1}$$

Finding the asymmetry coefficient α will help understand the impact of ships on the midshipman hum. If $\alpha < 1$, the midshipman reduces the humming intensity when the ship passes.. On the other hand, if $\alpha > 1$, the midshipman hums louder because of the ships. Table 3.1 gives the number of ships in a series of increasingly restrictive samples as well as sub-samples based on ferry arrival times. For each sample, the total numbers for which the humming intensity decreases and increases are shown along with the difference in numbers and percent change. The errors are statistical only. Table 3.1 shows samples from 1-5 have increasingly restrictive conditions in

Condition	Total	Humming Decreases ($\alpha > 1$)	Humming Increases ($\alpha < 1$)	Difference	Percent Change
Sample 1	61565	31267	30298	969 $\pm$ 248	1.6 $\pm$ 0.4
Sample 2	14994	7472	7522	-50 $\pm$ 122	-0.3 $\pm$ 0.8
Sample 3	13545	6741	6804	-63 $\pm$ 116	-0.5 $\pm$ 0.9
Sample 4	12118	6052	6066	-14 $\pm$ 110	-0.1 $\pm$ 0.9
Sample 5	9364	4732	4632	100 $\pm$ 96	1.0 $\pm$ 1.0
Ferry Sample	5362	2666	2696	-30 $\pm$ 73	-0.6$\pm$ 1.4
N-S Ferry	2984	1369	1615	-246 $\pm$ 54	-8.2$\pm$ 1.8
S-N Ferry	2787	1498	1289	209 $\pm$ 52	7.5 $\pm$ 1.9
Frequency	9364	4408	4285	123 $\pm$ 93	1.3$\pm$ 1.0

Table 3.1: Statistical analysis of changes before and after the passage of ships for an increasingly restrictive series of sub-samples of ships. The last sub-sample measures the change in frequency, while all other samples measure the change in humming intensity.

order to find the change in humming intensity. The change in the humming intensity is not statistically significant for most samples. However, in three cases, Sample 1, N-S Ferry and S-N Ferry sub-samples, there is a 4-5 standard deviation effect. While this result might be due to the ferry passage, it might also due to a systematic effect depending on the direction of the ferry.

3.3 Sounds From Large Commercial Vessels

The analysis for large commercial vessels uses parameters that were optimized for detection of slower vessels, giving a different set of peaks. As in the ferry analysis, we use the flag from the ship search algorithm as the first step for finding a clean sample. In the case of large commercial vessels, this flag includes minimum criteria for the signal-to-noise ratio and a goodness-of-fit parameter. This flag is also aimed at removing peaks that are artifacts left behind by the ship search algorithm with a very few of them actually representing ships. This reduces the number of peaks from the original 98,458 to 30,661 ships (Sample 1). The commercial vessels are fairly slow and take more time to pass as compared with the ferries. It was determined through the use of spectrograms that the large ships take about 130 seconds to 350 seconds to pass (full width of the signal). This criterion was added to sample 1 along with a lower limit on the peak height. This brought the sample down from 30,661 to 3,520 ships (Sample 2). Figure 3.7 shows a scatter plot of peak height vs full width of the peak with the blue points representing sample 1 and with sample 2 over-plotted in red.

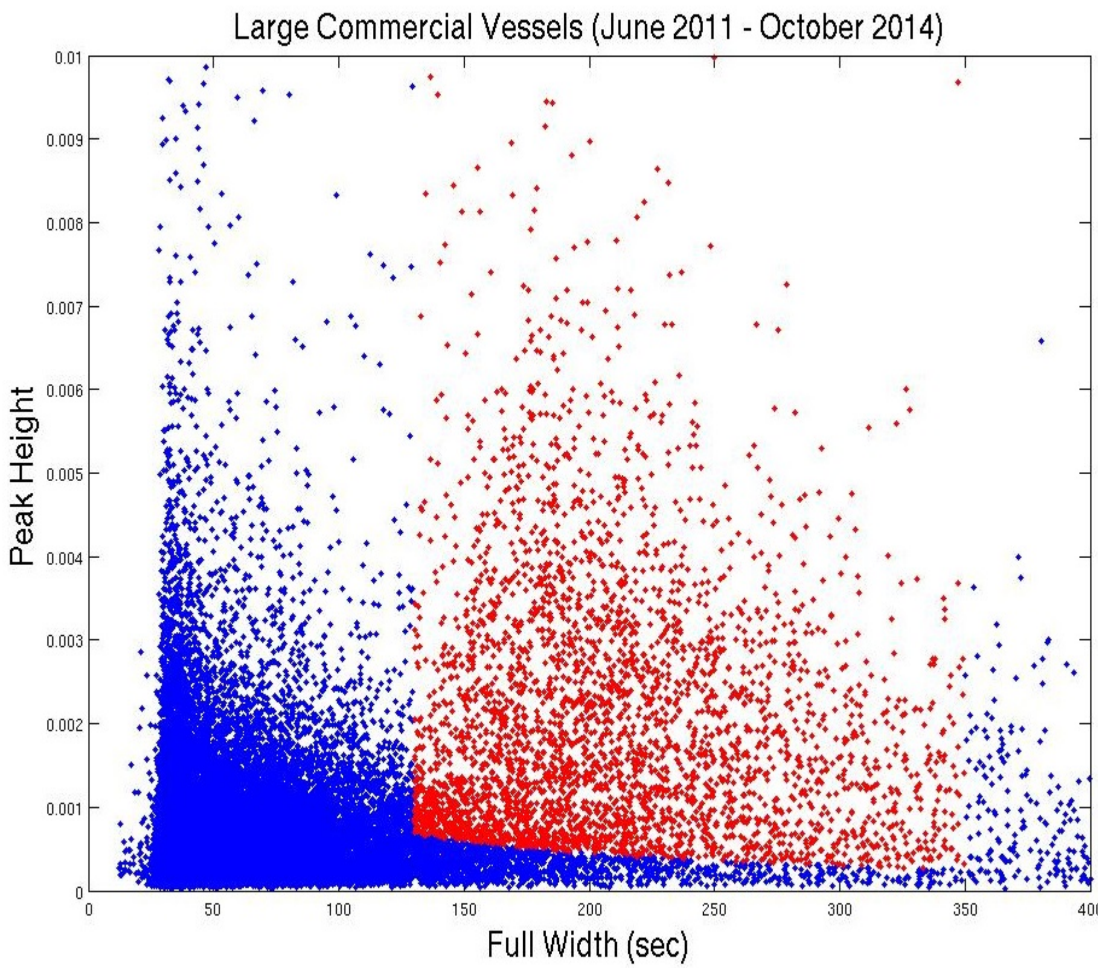

Figure 3.7: Peak height (proportional to square root of sound intensity) vs full width, for all well measured ship signals. The points from sample 1 were plotted in blue while the sub-sample (sample 2) is shown in red.

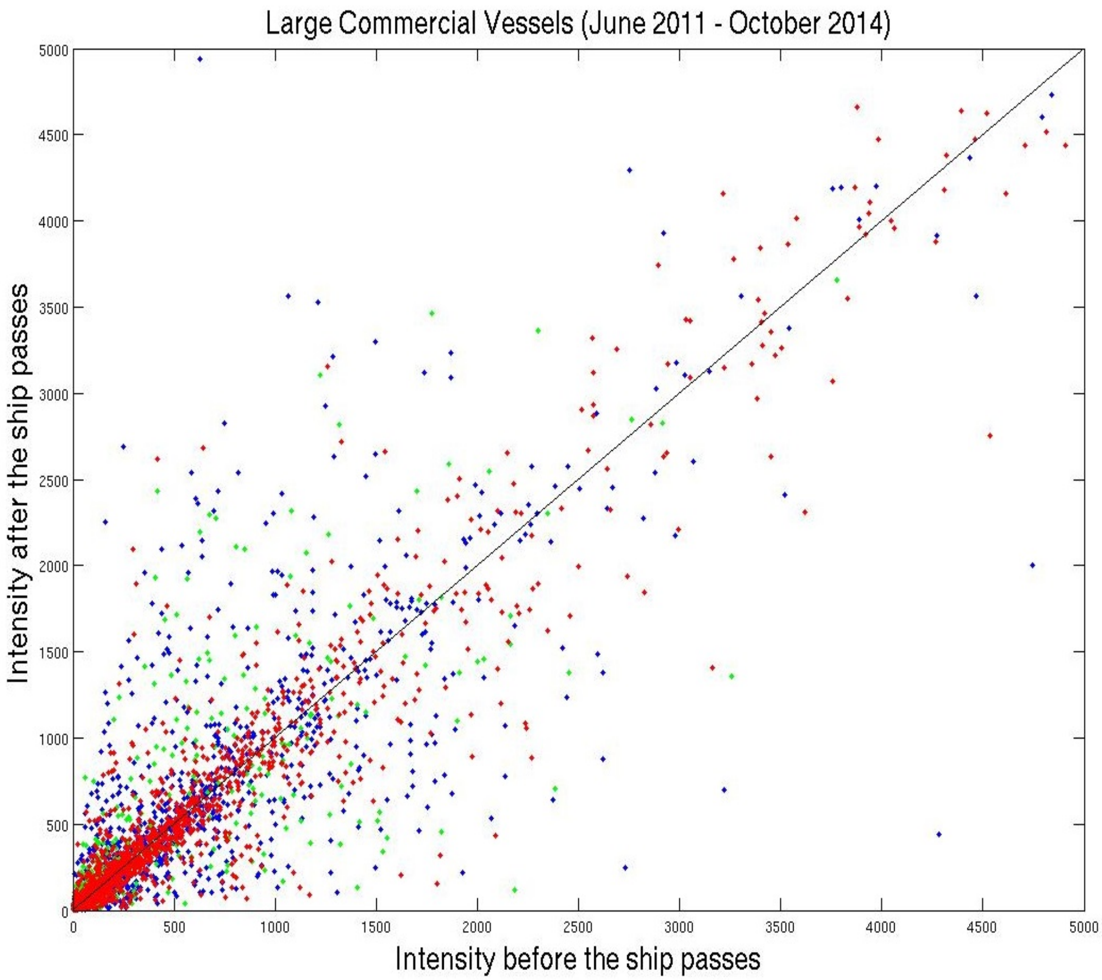

Figure 3.8: The intensity of the midshipman hum before and after the passage of ships is compared in the plot above. The final sample (red) consists of all the ships that passed the criteria for large commercial vessels.

Figure 3.8 shows the scatter plot of humming intensity before and after the passage of the ships. To prevent the sound from other ships from biasing the calculations, another condition was to set an error flag if the signal caused an overlap with another ship. This reduced the sample from 3,520 ships to 2,187 ships (sample 3, green points in figure 3.8). For comparing the humming intensity, another error flag is created to check for the presence of the midshipman hum when the ferry is passing by . Adding this condition to the other gives the sample 4 (red points in the graph). The total number of ships in the this sample is 1597 ships.

The asymmetry coefficient before and after the ship has passed is calculated using the humming intensities as done above in the ferry analysis. The statistics are given as follows, Table 3.2 shows results from samples 1-4 with increasingly restrictive

Condition	Total	Humming Decreases ($\alpha > 1$)	Humming Increases ($\alpha < 1$)	Difference	Percent Change
Sample 1	30661	15042	15619	-577 $\pm$ 175	-1.8 $\pm$ 0.5
Sample 2	3520	1701	1819	-118 $\pm$ 49	-3.3 $\pm$ 1.7
Sample 3	2187	1085	1102	-17 $\pm$ 46	0.8$\pm$2.1
Sample 4	1597	822	775	47 $\pm$ 40	2.9$\pm$2.5
Frequency	1597	775	745	30 $\pm$ 39	1.9$\pm$2.4

Table 3.2: Statistical analysis of changes before and after the passage of ships for an increasingly restrictive series of sub-samples of ships. The last sub-sample measures the change in frequency while all other samples measure the change in humming intensity.

conditions. The change in the humming intensity is not statistically significant for most samples. However, sample 1 has a 3 standard deviation effect, not reproduced in the more restrictive sub-samples.

Chapter 4

Conclusion

The mating call of the midshipman in the presence of ferries and large commercial vessels has been studied in order to look for effects of ship noise on the behavior of the fish. Anthropogenic ship noise is the main source of underwater noise in San Francisco Bay. The mating call of the midshipman is stronger during the night but can continue throughout the day. The study covers the mating season of midshipman (June to October) over 4 consecutive years. The sample after all selection criteria consists of 9364 ferries and 1597 large commercial vessels. The typical sound intensity (dB re 1 μPa) ranges from 105 dB to 120 dB for the ferries and 118 dB to 130 dB for the large commercial vessels. The typical sound intensity of midshipman hum is between 90 dB and 130 dB, which is in a similar range to sounds from both the ferries and large commercial vessels. The ferries run 40 times during the day, while the tankers are more intermittent and are heard during both day and night. The intensity of the mating calls of the midshipman type I males before and after the passage of the ship is used as an indication of disturbance caused by these ships in San Francisco Bay. A significant increase or decrease in intensity would correspond to the midshipman being disturbed by the passage of the ships.

For the ferries and large commercial vessels, a 2 % effect is seen in sample 1 due to the passage of the ships. While this effect is significant, it is a small percent change most likely caused by a bias due to an unconsidered factor in the initial sample. The asymmetry coefficient for the final sample of ferries is 100 $\pm$ 96 (1.0 $\pm$ 1.0 percent) and for the large commercial vessels, 30 $\pm$ 39 (1.9 $\pm$ 2.4 percent). In neither case is the difference greater than 2 standard deviations which is a reasonable requirement for a significant result. For the ferries, an additional criterion was introduced by selecting only ferry times agreeing with the Golden Gate Ferry schedule. The asymmetry for the entire ferry sample was -0.6 $\pm$ 1.4 percent.

By contrast, the sub-sample with ferries going south showed an asymmetry of -8.2 $\pm$ 1.8 percent. This five standard-deviation effect corresponds to the intensity of humming increasing after the ship passes. For the sub-sample with ferries going north, the effect was reversed with an asymmetry of 7.5 $\pm$ 1.9 percent. This four standard-deviation effect corresponds to humming decreasing after the passage of the ships. From these effects (S-N ferry and N-S ferry), we might conclude that the midshipman changed their humming intensity due to the passage of the ships. However, the opposite sign of the asymmetry for the N-S ferry and S-N ferry is difficult to understand as an effect of the noise, possibly indicating the presence of some other factor that hasn't been considered. Such a response by the midshipman due to the ship noise corresponds to a significant modification of their behavior and indicates the need for further studies.The midshipman frequency was also calculated before and after the passage of the ships. For the ferries the asymmetry is 1.3±1.0 percent and for the large commercial vessels, the asymmetry is 1.9± 2.4 percent. In both cases, the effect is not more than 2 percent and not statistically significant.

In a study of the brown meagre fish (*Sciaena umbra*), boat noise was found to cause an enhancement of vocalization (Picciulin et al. 2012). However, the conditions in which the study was recorded were different from this study in the size of the ships and the distance of the ships from the fish.

Appendix A : Golden Gate Ferry Schedule

Depart Larkspur	Arrive San Francisco	Depart San Francisco	Arrive Larkspur
5:45	6:15	6:20	6:50
6:35	7:05	7:35	8:05
7:00	7:30	7:35	8:05
7:30	8:00	-	-
7:50	8:20	8:30	9:05
8:20	8:50	9:10	9:45
8:40	9:15	-	-
9:15	9:50	10:10	10:45
10:10	10:45	10:55	11:30
11:10	11:45	11:55	12:30
11:40	12:15	12:25	1:00
12:40	1:15	1:25	2:00
2:15	2:50	3:00	3:30
2:50	3:25	3:30	4:00
–	–	4:00	4:30
3:40	4:15	4:30	5:00
4:10	4:45	5:00	5:30
–	–	5:30	6:00
5:10	5:45	6:00	6:30
5:40	6:15	6:30	7:00
6:40	7:10	7:20	7:50
7:25	8:00	8:10	8:40
8:50	9:25	9:35	10:05

Table 4.1: Golden Gate Ferry Schedule.

Appendix B : Source Code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% callshp.m
%
%This file is called to generate the *.shg files used for analyzing the
    ship noise
% It uses the wave files for the period specified by the user to also
   generate the intensity
% before and after the ship passes
%
%by Gaurav P. Rele
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Input for the time period
iday=01;
imonth=06;
iyear=2011;
eyear = 2011;
buffer0=input(sprintf('Starting day (%d):  ',iday),'s');
if length(buffer0)>0 iday=buffer0; end
buffer1=input(sprintf('Starting month (%d):  ',imonth),'s');
if length(buffer1)>0 imonth=buffer1; end
buffer2=input(sprintf('Starting year (%d):  ',iyear),'s');
if length(buffer2)>0 iyear=buffer2; end
emonth= input('enter the ending month: ','s');
eday = input('enter the last day of the end month: ','s');
buffer3 = input(sprintf('Ending year(%d)',eyear),'s');
if length(buffer3)>0 eyear=buffer3; end
type = input('Type of file [ 01-Ferry, 04-old]','s');
iwrite= input('do you want to write in a file[1=write, 0=Do not write]:
      ','s');
startday = datenum(str2num(iyear),str2num(imonth),str2num(iday));


for cyear= str2num(iyear):str2num(eyear)
  cstryear= num2str(cyear)
```

```
imonth = '6';
lastmonth = '10';
if cyear == str2num(eyear) lastmonth=emonth; end
for cmonth=str2num(imonth):str2num(lastmonth)
if (cmonth>10 | cmonth<6) continue; end
infile=strcat('/usr/local/data3/rtc/shp/',cstryear,'/rtc',cstryear
    (3:4),num2str(cmonth,'%02d'),'00',sprintf('%02s',type),'.shp');
infid=fopen(infile,'r'); % opens the file with parameter read (r) or
    write(w)
npt=fread(infid,1,'int32'); % integer 32 bit reading one point
matlabday=fread(infid,npt,'float64');  %npt is dimension of array,
    date
year2000=fread(infid,npt,'float32'); %same as above
waterday=fread(infid,npt,'float32');
erf=fread(infid,npt,'float32');
xcen=fread(infid,npt,'float32');
xsig=fread(infid,npt,'float32');
ycen=fread(infid,npt,'float32');
ybkg=fread(infid,npt,'float32');
pcen=fread(infid,npt,'float32');
ptot=fread(infid,npt,'float32');
s2n=fread(infid,npt,'float32'); %signal to noise ratio
r2=fread(infid,npt,'float32'); %statistical measure of the fit

  % TFF file input
infiletff = strcat('/usr/local/data3/rtc/tff/',cstryear,'/rtc',
    cstryear(3:4),num2str(cmonth,'%02d'),'00.tff');
infidtf=fopen(infiletff,'r');
npttf=fread(infidtf,1,'int32');
waterdaytf =fread(infidtf,npttf,'float32');
fcentf=fread(infidtf,npttf,'float32');
sigftf=fread(infidtf,npttf,'float32');
s2ntf=fread(infidtf,npttf,'float32');
pwrtf=fread(infidtf,npttf,'float32');
pdbtf=fread(infidtf,npttf,'float32');
erftf=fread(infidtf,npttf,'int32');

%Defining the arrays for the output from the findareashp file below
arLft=zeros(npt,1);
arRt=zeros(npt,1);
wdl=zeros(npt,1);
wdr=zeros(npt,1);
```

```
        fmaxL=zeros(npt,1);
        fmaxR=zeros(npt,1);

%%%%%%changing thhe code for normalization of ycen %%%%%%
  mld1 = datenum(2012,06,28,18,17,30);
  mld2 = datenum(2012,07,03,14,40,00);
  hsens = -180;
  gain1 = 39.0;
  gain2 = 27.1;
  gain3 = 18.2;
  factor1 = 10^((gain3 - gain1)/20);
  factor2 = 10^((gain3 - gain2)/20);
  ycen(matlabday <mld1) = ycen(matlabday<mld1) * factor1;
  ycen(matlabday >mld1 & matlabday < mld2) = ycen(matlabday > mld1 &
     matlabday < mld2) * factor2;
  ptot = 20*log10(ycen) + 20-gain3-hsens;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

  for i=1:npt
    %based on the day the time can be shifted forward in a month since
       *.shp files are inputted for a whole month
    if (startday > matlabday(i))
      continue;
    end
    if erf(i)>3
      fprintf('Shp error \n');
      continue;
          end

    %Findfile.m outputs the 3 contiguous files with an error flag for
       analysis
    [infile1,infile2,infile3,error] = findfile(matlabday(i),xcen(i));

    erf(i) = erf(i) + error;

    if erf(i)>3
      fprintf('Error detected after findfile value: %d \n',erf(i));
      continue;
          end

          %if erf(i) <= 3
```

```
            %inf1 = infile1(length(infile1)-18 : end);
              %inf2 = infile2(length(infile2)-18 : end);
              %inf3 = infile3(length(infile3)-18 : end);
              %fprintf('inf1:%s inf2:%s inf3:%s    ',inf1,inf2,inf3);
        %end

  %The Analysis program which outputs the intensity
  [arLft(i),arRt(i),wdl(i),wdr(i),erfar,fmaxL(i),fmaxR(i)]=
      findareashp(infile1,infile2,infile3,xcen(i),xsig(i),erf(i),4);
  erf(i) = erf(i) + erfar;

  %has never happened, but just in case
  if arLft(i)==0|arRt(i)==0
    erf(i) = erf(i) + 1024;
  end

  firstpause;

  fprintf ('al=%4.2f aR=%4.2f   erf= %d   erfar= %d    err=%d  \n',arLft
      (i),arRt(i),erf(i),erfar,error);
end

%creating the output file *.shg
if str2num(iwrite)==1
  outfile=strcat('2srtc',cstryear(3:4),num2str(cmonth,'%02d'),'00',
      sprintf('%02s',type),'.shg');
  outfid=fopen(outfile,'w');
  fwrite(outfid,npt,'int32');
  fwrite(outfid,matlabday,'float64');
  fwrite(outfid,year2000,'float32'); %same as above
  fwrite(outfid,waterday,'float32');
  fwrite(outfid,erf,'float32');
  fwrite(outfid,xcen,'float32');
  fwrite(outfid,xsig,'float32');
  fwrite(outfid,ycen,'float32');
  fwrite(outfid,ybkg,'float32');
  fwrite(outfid,pcen,'float32');
  fwrite(outfid,ptot,'float32');
  fwrite(outfid,s2n,'float32'); %signal to noise ratio
  fwrite(outfid,r2,'float32'); %statistical measure of the fit
  fwrite(outfid,arLft,'float32');
  fwrite(outfid,arRt,'float32');
```

```
    fwrite(outfid,wdl,'float32');
    fwrite(outfid,wdr,'float32');
    fwrite(outfid,fmaxL,'float32');
    fwrite(outfid,fmaxR,'float32');
    fclose(outfid);
  end
  end
end
pause off
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% findfile.m
%
%takes the input of matlabday and centre of the ship to outputs 3
    contiguous file names(left,middle,right)
% with their full paths along with the error flag
%matlabday is the specific datenum  of the the peak of the ship
%
%by Gaurav P. Rele
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [infile1,infile2,infile3,erf] = findfile(matlabday,xcen)
iverbose=0;
erf = 0;
infile1 = ' ';
infile2 = ' ';
infile3 = ' ';
ifpath= '/usr/local/data3/rtc/wav/';
if iverbose>=4 fprintf('matlabday: %f; xcen: %f\n',matlabday,xcen), end

shpcen15 = (xcen*5)/86400;

mld2 = matlabday -xcen*5/86400 + 900/86400; % Start of middle file.
[iy2,im2,id2,ih2,imin2,sec2]=datevec(mld2);
isec2= round(sec2);
if isec2==60
  mld2 = mld2 + (1.25 - mod(sec2,1))/86400; % Start of middle file.
  [iy2,im2,id2,ih2,imin2,sec2]=datevec(mld2);
  isec2 = round(sec2);
end
infile2=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav', ...
  ifpath,iy2,im2,id2,mod(iy2,100),im2,id2,ih2,imin2,isec2);
if exist(infile2)~=2
  fprintf('Middle file %s not found.\n',infile2);
  erf=erf+32;
  %buffer = input('press any key to continue','s');
  return
end

%Check for the left file
mld1 = mld2-900/86400; % matlabday of the start of the first file.
[iy1,im1,id1,ih1,imin1,sec1]=datevec(mld1);
```

```
isec1=round(sec1);
infile1=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav', ...
  ifpath,iy1,im1,id1,mod(iy1,100),im1,id1,ih1,imin1,isec1);
if exist(infile1)~=2
  %fprintf('%s not found; check string 1 second eariler.\n',infile1)
  mld1 = mld2 - 901/86400;
  [iy1,im1,id1,ih1,imin1,sec1]=datevec(mld1);
  isec1= round(sec1);
  infile1=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav',
      ...
      ifpath,iy1,im1,id1,mod(iy1,100),im1,id1,ih1,imin1,isec1);
    if isec1==60
    mld1 = mld1 + (1.25 - mod(sec1,1))/86400; % Start of middle file.
    [iy1,im1,id1,ih1,imin1,sec1]=datevec(mld1);
    isec1 = round(sec1);
    infile1=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav',
        ...
      ifpath,iy1,im1,id1,mod(iy1,100),im1,id1,ih1,imin1,isec1);
  end

  if exist(infile1)~=2
    fprintf('iy1: %d; im1: %d; id1: %d; ih1: %d; imin1: %d; sec1: %f;
        isec1: %d\n', ...
    iy1,im1,id1,ih1,imin1,sec1,isec1)
    fprintf('Cant find left file %s \n',infile1);
    %buffer = input('press any key to continue','s');
    erf=erf+32;
    return
  end
end

%Check for the right file
mld3 = mld2 + 900/86400;
[iy3,im3,id3,ih3,imin3,sec3]=datevec(mld3);
isec3=round(sec3);
infile3=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav', ...
  ifpath,iy3,im3,id3,mod(iy3,100),im3,id3,ih3,imin3,isec3); % Start of
      middle file.
[iy2,im2,id2,ih2,imin2,sec2]=datevec(mld2);
if exist(infile3)~=2
  mld3 = mld2 + 901/86400;
  [iy3,im3,id3,ih3,imin3,sec3]=datevec(mld3);
```

```
  isec3=round(sec3);
  infile3=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav',
     ...
    ifpath,iy3,im3,id3,mod(iy3,100),im3,id3,ih3,imin3,isec3);
  if isec3==60
    mld3 = mld3 + (1.25 - mod(sec3,1))/86400; % Start of middle file.
    [iy3,im3,id3,ih3,imin3,sec3]=datevec(mld3);
    isec3 = round(sec3);
    infile3=sprintf('%s%04d/%02d/%02d/rtc%02d%02d%02d%02d%02d%02d.wav',
        ...
    ifpath,iy3,im3,id3,mod(iy3,100),im3,id3,ih3,imin3,isec3);
  end

  if exist(infile3)~=2
    fprintf('iy3: %d; im3: %d; id3: %d; ih3: %d; imin3: %d; sec3: %f;
       isec3: %d\n', ...
    iy3,im3,id3,ih3,imin3,sec3,isec3)
    fprintf('Cant find right file %s\n',infile3);
    erf=erf+32;
    %buffer = input('press any key to continue','s');
    return
  end
end


file1=dir(infile1);
file2=dir(infile2);
file3=dir(infile3);

names1= file1.bytes;
names2= file2.bytes;
names3= file3.bytes;

if names1<3600044||names2<3600044||names3<3600044
  erf = erf + 64;
  fprintf(' names are out of bound \n');
  return;
end

%Check for the appropriate size of the file
[m1 d1] = wavfinfo(infile1);
[m2 d2] = wavfinfo(infile2);
```

```
[m3 d3] = wavfinfo(infile3);
if length(m1)*length(m2)*length(m3) == 0
  erf = erf+ 128;
  fprintf('Error in wav file\n');
  %buffer = input('press any key to continue','s');
  return;
end

if iverbose>=2
  fprintf ('infile1: %s\n infile2:%s\n infile3:%s\n error: %d\n',
     infile1,infile2,infile3,erf);
end
return
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% findareashp.m
%
% we are trying to analyse if the ships have any effect on the hums
    through analysing a  hum signal before and after the ship passes.
%use the program to call the function with parameters of the file name,
     center, width of the ship sound and it
%gives the power before and after ie left and right of the curve
%
%by Gaurav P. Rele
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [arLft,arRt,wdl,wdr,erfg,maxfreql,maxfreqr] = findareashp(
    infile1,infile2,infile3,shpcen,shpwdth,erf,iverbose)

iv4=iverbose>=4;
iv3=iverbose>=3;
iv2=iverbose>=2;
iv1=iverbose>=1;
iv0=iverbose>=0;
erfg = 0;
if iv4
  %fprintf('infile1: %s\ninfile2: %s\ninfile3: %s\n',infile1,infile2,
      infile3)
  %fprintf('shpcen: %f; shpwdth: %f; erf: %f\n',shpcen,shpwdth,erf)
end

shpcent = round(shpcen*5);  %converting xcent in to seconds
shipwdth=round(2*(shpwdth*5)); %converting wdth in to seconds 2 sigma

%reading in the 3 wav files
[y1,sampFreq] = wavread(infile1);
[y2,sampFreq] = wavread(infile2);
[y3,sampFreq] = wavread(infile3);
z1=y1';
z2=y2';
z3=y3';
z = [z1,z2,z3];
y = z';

shpminus= shpcent - shipwdth;
shpplus = shpcent + shipwdth;
```

```
shpminus1 = shpminus +5;
shpminus2 = shpminus - 5;
shpplus1 = shpplus + 5;
shpplus2 = shpplus -5;

if iv1
  %fprintf('shpcent: %f; shpwdth: %f; shpminus1:%f;shpminus2:%f;
      shpplus1=%f;shpplus2=%f;  ',shpcent,shipwdth,shpminus1,shpminus2,
      shpplus1,shpplus2)
end

i1=shpminus2*sampFreq;
i2=shpminus1*sampFreq;
i3=shpplus2*sampFreq;
i4=shpplus1*sampFreq;

if iv1
  %fprintf('i1, i2, i3,i4 = %d, %d, %d, %d\n',i1,i2,i3,i4)
end

%Error flag sets the
if i1<=0||i2<=0||i3>5400000||i4>5400000
  arLft=0;
  arRt=0;
  wdl=0;
  wdr=0;
  maxfreql=0;
  maxfreqr=0;
  fprintf('out of limits')
  erfg=erfg + 256;
  return;
end
if iv1
  %fprintf('i1, i2, i3,i4 = %d, %d, %d, %d  ',i1,i2,i3,i4);
end

% the analysis for the 10 second interval after the ship has passed
shpleft = y(shpminus2*sampFreq:shpminus1*sampFreq);
%figure(1);plot(shpleft);
leftfft= fft(shpleft);
absleft = abs(leftfft);
```

```
% absleft(1:700)=0;
% absleft(1300:length(absleft))=0;
%figure(2);plot(absleft);buffer=input('press any key','s');
 hleftfft = absleft(1:(floor(length(absleft)/2)));
 hleftfft(1191:1211) = mean([mean(hleftfft(1181:1191)) mean(hleftfft
    (1216:1226))]);
 hleftfft(591:611) = mean([mean(hleftfft(581:591)) mean(hleftfft
    (616:626))]);
%figure(3);plot(hleftfft);%buffer=input('press any key','s');
%title('hleftfft: abs(fft)')
lpwr = hleftfft.^2;  % power for the left hand side 10 seconds
sampPts = length(y);
freq = (0:(sampFreq*10 -1)/2)/10; % 10 because its the number of
    seconds
dl = smooth(hleftfft,50);
%figure(4)
%plot(freq,dl);
[lymax,lxmax] = max(dl(621:1300));
cl = find(dl(621:1300) > lymax/2);
maxfreql= 62 + lxmax/10;
cl1 = 620 + cl;
if length(cl)== 0
   arLft=0;
   arRt=0;
   wdl=0;
   wdr=0;
   maxfreql=0;
   maxfreqr=0;
   erfg=erfg + 512;
   return;
end
wdl1=cl(1)+620;
wdl2= cl(length(cl)) + 620;
wdl = (wdl2 - wdl1);
arLft = trapz(dl(cl1));


% the analysis for the 10 second interval after the ship has passed
shpright = y(i3:i4);
%plot(shpright);check properties of a file

 rtfft= fft(shpright);
```

```
absrt = abs(rtfft);
%plot(absrt);

hrtfft = absrt(1:(floor(length(absrt)/2)));
hrtfft(1191:1211) = mean([mean(hrtfft(1181:1191)) mean(hrtfft
    (1216:1226))]);
hrtfft(591:611) = mean([mean(hrtfft(581:591)) mean(hrtfft(616:626))]);
%plot(hrtfft);

rpwr = hrtfft.^2;  % power for the left hand side 10 seconds
rpwrdb = 10*log10(rpwr);
freq = (0:(sampFreq*10 -1)/2)/10; % 10 because its the number of
    seconds
dr = smooth(hrtfft,50);
%figure(2)
%plot(freq,dr);
[rymax,rxmax] = max(dr(621:1300));
cr = find(dr(621:1300) > rymax/2);
maxfreqr = 62 + rxmax/10;
cr1 = 620 + cr;
if length(cr)== 0
  arLft=0;
  arRt=0;
  wdl=0;
  wdr=0;
  maxfreql=0;
  maxfreqr=0;
  erfg=erfg + 512;
  return;
end
wdr1=cr(1) + 620;
wdr2= cr(length(cr)) +620;
wdr = (wdr2 - wdr1) ;
arRt = trapz(dr(cr1));

%fprintf(' %4.3f %4.3f %4.3f %4.3f \n',arLft,wdl,arRt,wdr)

% The comparison for the poster presentation
%lpwrdb = 10*log10(lpwr);
%plot(freq,lpwrdb);%buffer=input('press any key','s');
%ftest = freq > 62.0 & freq < 130.1;
%hold on
```

```
%plot(freq(ftest),lpwrdb(ftest),'r');
%plot(freq,rpwrdb,'g');
%plot(freq(ftest),rpwrdb(ftest),'c');
%xlabel('Frequency(Hz)','fontsize',20);
%ylabel('Power(dB)','FontSize',20);
%title('Pwr vs frequency','FontSize',20);
%legend('10 Sec interval(Left)','Frequencies considered(left)','10 Sec
    interval(right)','Frequencies considered(right)')
%hold off

%hasnt happened but just in case
if (arLft==0|arRt==0)
  buffer = input('press any key to continue','s');
end

return
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% calc.m
%
%The analysis algorithm uses the shg files to generate the asymmetry
    coefficient for comparison
%
%by Gaurav P. Rele
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
iday=01;
imonth=06;
iyear=2011;
eyear = 2014;
buffer0=input(sprintf('Starting day (%d):  ',iday),'s');
if length(buffer0)>0 iday=buffer0; end
buffer1=input(sprintf('Starting month (%d):  ',imonth),'s');
if length(buffer1)>0 imonth=buffer1; end
buffer2=input(sprintf('Starting year (%d):  ',iyear),'s');
if length(buffer2)>0 iyear=buffer2; end
emonth= input('enter the ending month: ','s');
eday = input('enter the last day of the end month: ','s');
buffer3 = input(sprintf('Ending year(%d)',eyear),'s');
if length(buffer3)>0 eyear=buffer3; end
type = input('Type of file [ 01-Ferry, 04-old]','s');

%initializing arrays to make one giant array of all the points for
    analysis from the *.shg file
npt=0;
matlabday=zeros(0,0);
year2000=zeros(0,0);
waterday=zeros(0,0);
erf=zeros(0,0);
xcen=zeros(0,0);
xsig=zeros(0,0);
ycen=zeros(0,0);
ybkg=zeros(0,0);
pcen=zeros(0,0);
ptot=zeros(0,0);
s2n=zeros(0,0);
r2=zeros(0,0);
arlft=zeros(0,0);
arRt=zeros(0,0);
wdl=zeros(0,0);
```

```
wdr=zeros(0,0);
fl=zeros(0,0);
fr=zeros(0,0);
hour = zeros(0,0);

%initializing arrays to make one giant array of all the points for
    analysis from the *.tff file
npttf=0;
waterdaytf =zeros(0,0);
fcentf=zeros(0,0);
sigftf=zeros(0,0);
s2ntf=zeros(0,0);
pwrtf=zeros(0,0);
pdbtf=zeros(0,0);
erftf=zeros(0,0);
matlabdaytf = zeros(0,0);

%Concatenating the shp file variables and tff file variables from each
    month to one array for each variable  eg: month1 + month2..month15=
     month
for cyear= str2num(iyear):str2num(eyear)
  cstryear= num2str(cyear);
  imonth = '6';
  lastmonth = '10';
  if cyear == str2num(eyear) lastmonth=emonth; end
  for i = str2num(imonth):str2num(lastmonth)
  infile=strcat('/usr/local/data3/rtc/shp/',cstryear,'/rtc',cstryear
      (3:4),sprintf('%02d',i),'00.shp');
  infile = strcat('2srtc',cstryear(3:4),sprintf('%02d',i),'00',sprintf(
      '%02s',type),'.shg');
  infid=fopen(infile,'r'); % opens the file with parameter read (r) or
      write(w)
  npt1=fread(infid,1,'int32'); % integer 32 bit reading one point
  matlabday1=fread(infid,npt1,'float64');  %npt is dimension of array,
      date
  year20001=fread(infid,npt1,'float32'); %same as above
  waterday1=fread(infid,npt1,'float32');
  erf1=fread(infid,npt1,'float32');
  xcen1=fread(infid,npt1,'float32');
  xsig1=fread(infid,npt1,'float32');
  ycen1=fread(infid,npt1,'float32');
  ybkg1=fread(infid,npt1,'float32');
```

```
pcen1=fread(infid,npt1,'float32');
ptot1=fread(infid,npt1,'float32');
s2n1=fread(infid,npt1,'float32'); %signal to noise ratio
r21=fread(infid,npt1,'float32'); %statistical measure of the fit
arlft1=fread(infid,npt1,'float32');
arRt1=fread(infid,npt1,'float32');
wdl1=fread(infid,npt1,'float32');
wdr1=fread(infid,npt1,'float32');
fl1=fread(infid,npt1,'float32');
fr1=fread(infid,npt1,'float32');
hour1 = mod(matlabday1,1);

infiletff = strcat('/usr/local/data3/rtc/tff/',cstryear,'/rtc',
    cstryear(3:4),sprintf('%02d',i),'00.tff');
infidtf=fopen(infiletff,'r');
npttf1=fread(infidtf,1,'int32');
waterdaytf1 =fread(infidtf,npttf1,'float32');
fcentf1=fread(infidtf,npttf1,'float32');
sigftf1=fread(infidtf,npttf1,'float32');
s2ntf1=fread(infidtf,npttf1,'float32');
pwrtf1=fread(infidtf,npttf1,'float32');
pdbtf1=fread(infidtf,npttf1,'float32');
erftf1=fread(infidtf,npttf1,'int32');

npt=npt+npt1;
matlabday=[matlabday ;matlabday1];
year2000=[year2000 ;year20001];
waterday=[waterday ;waterday1];
erf=[erf ;erf1];
xcen=[xcen ;xcen1];
xsig=[xsig ;xsig1];
ycen=[ycen ;ycen1];
ybkg=[ybkg ;ybkg1];
pcen=[pcen ;pcen1];
ptot=[ptot ;ptot1];
s2n=[s2n ;s2n1];
r2=[r2 ;r21];
arlft=[arlft ;arlft1];
arRt=[arRt ;arRt1];
wdl=[wdl ;wdl1];
wdr=[wdr ;wdr1];
fl = [fl ;fl1];
```

```
    fr=[fr; fr1];
    hour = [hour ;hour1];

    npttf=npttf +npttf1;
    waterdaytf =[waterdaytf; waterdaytf1];
    fcentf=[fcentf ;fcentf1];
    sigftf=[sigftf ;sigftf1];
    s2ntf=[s2ntf ;s2ntf1];
    pwrtf=[pwrtf ;pwrtf1];
    pdbtf=[pdbtf; pdbtf1];
    erftf=[erftf ;erftf1];
    matlabdaytf = [matlabdaytf; waterdaytf + datenum(cyear,0,0,0,0,0)];
  end
end

% Defining two new error flags 1. No ship nearby and 2. Hum Present
%Hum present is taken from the tff file which has one error flag for
    each file. Hence it has
%to be changed to the appropriate size ie npt(number of ships)
erftff=zeros(npt,1);
frhummiddle = zeros(npt,1);
frhumleft = zeros(npt,1);
frhumright = zeros(npt,1);
erfNoShp2Sig=ones(npt,1);
mdplus = matlabday + (10*xsig+5)/86400; % 2 sigma to the right
mdminus = matlabday - (10*xsig+5)/86400;% 2 sigma to the left
count=1; %counter for TF error array conversion to SHP array size
for i=1:npt
  i1 = max(1,i-20);
  i2 = min(npt,i+20);
  %for loop is for the hum present error
  for j=max(count,1):npttf
      if matlabdaytf(j) > matlabday(i)
        if erftf(j-1)~=0
          erftff(i)=1;
        end
        count = j-2;
        break
      end
  end
  % No ship near by error
  shlft= mdminus(i1:i2)> mdplus(i);
```

```
  shrt = mdplus(i1:i2)< mdminus(i);
  erfNoShp2Sig(i) = sum(~(shrt|shlft) & r2(i1:i2)> 0.8);
end

fstime % script for the ferry times comparison returning "testf"
    variable
test = hour> 0.5411 & hour< 0.5453 & erf<3 & s2n>1;
test0 = erf<3;
figure(6)
plot(xsig(test),ycen(test),'.');
test = hour> 0.5411 & hour< 0.5453 & erf<3 & s2n>1& weekday(matlabday)
    <7 & weekday(matlabday)>1;


% Ferry Tests (ft)
if str2num(type)==01
  %ft0 = erf < 4 & s2n>0.5 & r2>0.8 & erftff==0 & (hour < 0.25 | hour>
      0.5417) & (weekday(matlabday)<7 & weekday(matlabday)>1);
  %ft1 = erfNoShp2Sig==1;
  %ft2 = xsig > 3.5 & xsig < 13;
  %ft3 = ycen < 0.12./xsig;
  %ft4 = testf;
  %ft5 = (fr> 70 & fl>70);
  %ft6 = (fr<117 & fl<117);
  %ft = ft0&ft1&ft2&ft3;
  %morning = ft & hour < 0.7917;
  %evening = ft & hour > 0.7917;

  ft0 = erf < 4 & s2n > 0.5 & r2 > 0.8 & (weekday(matlabday) < 7 &
      weekday(matlabday) > 1);
  ft1 = ft0 & (xsig> 3.5 & xsig<13) & ycen<0.12./xsig & ycen > 10^(-4);
  ft2 = ft1 & (hour< 0.25 | hour> 0.5417);
  ft3 = ft2 & erfNoShp2Sig == 1;
  ft4 = ft3 & erftff == 0;
  ft = ft4;
  morning = ft & hour < 0.7917;
  evening = ft & hour > 0.7917;

  ferrycut = erf < 4 & s2n>0.5 & r2>0.8 & erftff==0&xsig > 3.5 & xsig <
       13 & ycen < 0.12./xsig & (weekday(matlabday)<7 & weekday(
      matlabday)>1);
  plot(24*hour(ferrycut),ycen(ferrycut),'.')
```

```
hold on
plot(24*([lfnswminus lfnswplus]'),[0.001 0.001],'g','Linewidth',10)
plot(24*([lfsnwminus lfsnwplus]'),[0.001 0.001],'m','Linewidth',10)
xlim([-0.015 24*1.005]);
xlabel('Time (hours) (UT)','fontsize',15);
ylabel('Intensity','fontsize',15);
title('Passenger Ferries per day (June 2011-October 2014)','fontsize'
    ,15);
hold off

test1 = ft0;
ast1 = (arlft(test1) - arRt(test1))./(arlft(test1) + arRt(test1));
Nt1plus = length(ast1(ast1>0));
Nt1min = length(ast1(ast1<0));
Ntot1 = length(ast1);
difft1 = Nt1plus - Nt1min;
sigdifft1 = sqrt(Nt1plus + Nt1min);

testA = ft1;
astA = (arlft(testA) - arRt(testA))./(arlft(testA) + arRt(testA));
NtAplus = length(astA(astA>0));
NtAmin = length(astA(astA<0));
NtotA = length(astA);
difftA = NtAplus - NtAmin;
sigdifftA = sqrt(NtAplus + NtAmin);


testB = ft2;
astB = (arlft(testB) - arRt(testB))./(arlft(testB) + arRt(testB));
NtBplus = length(astB(astB>0));
NtBmin = length(astB(astB<0));
NtotB = length(astB);
difftB = NtBplus - NtBmin;
sigdifftB = sqrt(NtBplus + NtBmin);

testC = ft3;
astC = (arlft(testC) - arRt(testC))./(arlft(testC) + arRt(testC));
NtCplus = length(astC(astC>0));
NtCmin = length(astC(astC<0));
NtotC = length(astC);
difftC = NtCplus - NtCmin;
sigdifftC = sqrt(NtCplus + NtCmin);
```

```
%final Sample
testC1 = ft4;
astC1 = (arlft(testC1) - arRt(testC1))./(arlft(testC1) + arRt(testC1)
    );
NtC1plus = length(astC1(astC1>0));
NtC1min = length(astC1(astC1<0));
NtotC1 = length(astC1);
difftC1 = NtC1plus - NtC1min;
sigdifftC1 = sqrt(NtC1plus + NtC1min);

testD = morning;
astD = (arlft(testD) - arRt(testD))./(arlft(testD) + arRt(testD));
NtDplus = length(astD(astD>0));
NtDmin = length(astD(astD<0));
NtotD = length(astD);
difftD= NtDplus - NtDmin;
sigdifftD = sqrt(NtDplus + NtDmin);

testAB = evening;
astAB = (arlft(testAB) - arRt(testAB))./(arlft(testAB) + arRt(testAB)
    );
NtABplus = length(astAB(astAB>0));
NtABmin = length(astAB(astAB<0));
NtotAB = length(astAB);
difftAB= NtABplus - NtABmin;
sigdifftAB = sqrt(NtABplus + NtABmin);

testff = testf&ft;
astf = (arlft(testff) - arRt(testff))./(arlft(testff) + arRt(testff))
    ;
Ntfplus = length(astf(astf>0));
Ntfmin = length(astf(astf<0));
Ntotf = length(astf);
difftf = Ntfplus - Ntfmin;
sigdifftf = sqrt(Ntfplus + Ntfmin);

fprintf('Total Ships: %d \n',npt);
fprintf('Condition  Ntotal Nleft NRight\tDiff\n');
fprintf('Sample 1      :%d\t %d\t %d\t %f %c %f \n',Ntot1,Nt1plus,
    Nt1min,difft1,177,sigdifft1);
```

```
  fprintf('Sample 2      :%d\t %d\t %d\t %f %c %f \n',NtotA,NtAplus,
     NtAmin,difftA,177,sigdifftA);
  fprintf('Sample 3      :%d\t %d\t %d\t %f %c %f \n',NtotB,NtBplus,
     NtBmin,difftB,177,sigdifftB);
  fprintf('Sample 4      :%d\t %d\t %d\t %f %c %f \n',NtotC,NtCplus,
     NtCmin,difftC,177,sigdifftC);
  fprintf('Final Sample  :%d\t %d\t %d\t %f %c %f \n',NtotC1,NtC1plus,
     NtC1min,difftC1,177,sigdifftC1);
  fprintf('Morning       :%d\t %d\t %d\t %f %c %f \n',NtotD,NtDplus,
     NtDmin,difftD,177,sigdifftD);
  fprintf('Evening       :%d\t %d\t %d\t %f %c %f \n',NtotAB,NtABplus,
     NtABmin,difftAB,177,sigdifftAB);
  fprintf('Ferry Time    :%d\t %d\t %d\t %f %c %f \n',Ntotf,Ntfplus,
     Ntfmin,difftf,177,sigdifftf);
end


%tanker type (used the same variable name )
if str2num(type)==04
  %ft0 = erf ==0 & erftff==0;
  %ft1 = erfNoShp2Sig==1;
  %ft2 = xsig > 13 & xsig < 35;
  %ft3 = ycen > 0.15./xsig;
  %ft5 = (fr> 70 & fl>70);
  %ft6 = (fr<117 & fl<117);
  %changes for thesis
  ft0 = erf==0;
  ft1 = ft0 & (xsig> 13 & xsig<35) & ycen>0.12./xsig;
  ft2 = ft1 & erfNoShp2Sig==1;
  ft3 = ft2 & erftff==0;

  test1 = ft0;
  ast1 = (arlft(test1) - arRt(test1))./(arlft(test1) + arRt(test1));
  Nt1plus = length(ast1(ast1>0));
  Nt1min = length(ast1(ast1<0));
  Ntot1 = length(ast1);
  difft1 = Nt1plus - Nt1min;
  sigdifft1 = sqrt(Nt1plus + Nt1min);

  %testA = test1&ft1;
  testA = ft1;
  astA = (arlft(testA) - arRt(testA))./(arlft(testA) + arRt(testA));
```

```
    NtAplus = length(astA(astA>0));
    NtAmin = length(astA(astA<0));
    NtotA = length(astA);
    difftA = NtAplus - NtAmin;
    sigdifftA = sqrt(NtAplus + NtAmin);

    %testB = testA& ft2;
    testB = ft2;
    astB = (arlft(testB) - arRt(testB))./(arlft(testB) + arRt(testB));
    NtBplus = length(astB(astB>0));
    NtBmin = length(astB(astB<0));
    NtotB = length(astB);
    difftB = NtBplus - NtBmin;
    sigdifftB = sqrt(NtBplus + NtBmin);

    %testC = testB&ft3;
    testC = ft3;
    astC = (arlft(testC) - arRt(testC))./(arlft(testC) + arRt(testC));
    NtCplus = length(astC(astC>0));
    NtCmin = length(astC(astC<0));
    NtotC = length(astC);
    difftC = NtCplus - NtCmin;
    sigdifftC = sqrt(NtCplus + NtCmin);

    fprintf('Total Ships: %d',npt);
    fprintf('Condition   Ntotal Nleft NRight\tDiff\n');
    fprintf('Sample 1      :%d\t %d\t %d\t %f %c %f \n',Ntot1,Nt1plus,
        Nt1min,difft1,177,sigdifft1);
    fprintf('Sample 2      :%d\t %d\t %d\t %f %c %f \n',NtotA,NtAplus,
        NtAmin,difftA,177,sigdifftA);
    fprintf('Sample 3      :%d\t %d\t %d\t %f %c %f \n',NtotB,NtBplus,
        NtBmin,difftB,177,sigdifftB);
    fprintf('Sample 4      :%d\t %d\t %d\t %f %c %f \n',NtotC,NtCplus,
        NtCmin,difftC,177,sigdifftC);
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% specshow.m
%
%This file is called to generates the spectograms(*.jpg) for the 3
    contiguous files
% that the filefile algorithm finds and shows the ship that is being
    analyzed
% in the spectogram. This also takes a flag for finding the ships that
% the user wants to see based on the test/criteria as determined by the
    user
%It also prints out matlabday , erf, xcen, ycen, xsig, arlft, arRt, r2,
    s2, ybkg,
%pcen,ptot, fleft , fright at the bottom of the image.
%
%by Gaurav P. Rele
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [] = specshow(test,matlabday,erf,xcen,ycen,xsig,arlft,arRt,r2
    ,s2n,ybkg,pcen,ptot,fl,fr)

for i=1:length(test)
  if test(i)==1
    if erf(i)>3
      fprintf('erf for no. %d is %d  \n',i,erf(i));
      continue;
    end

    [infile1,infile2,infile3, error] = findfile(matlabday(i),xcen(i));

    inf1 = strcat('/usr/local/data3/rtc/jpg/',infile1(26:51),'00.jpg');
    inf2 = strcat('/usr/local/data3/rtc/jpg/',infile2(26:51),'00.jpg');
    inf3 = strcat('/usr/local/data3/rtc/jpg/',infile3(26:51),'00.jpg');
    img1 = imread(inf1);
    img2 = imread(inf2);
    img3 = imread(inf3);
    img = [img1 img2 img3];
    figure(1)
    imshow(img,'InitialMagnification','fit');
    hold on
    [ht,lngth,wdth] = size(img);
    plot(5*xcen(i)*lngth/(60*45),0:307,'g')
```

```
    hleft = rectangle('position',[(5*xcen(i)-2*5*xsig(i)-5)*lngth
        /(60*45) 870*258/1000 10*lngth/(60*45) 70*258/1000],'EdgeColor'
        ,'g','LineWidth',1);
    hright = rectangle('position',[(5*xcen(i)+2*5*xsig(i)-5)*lngth
        /(60*45) 870*258/1000 10*lngth/(60*45) 70*258/1000],'EdgeColor'
        ,'g','LineWidth',1);
    text(50,295,['ycen=',num2str(ycen(i)),'      xsig=',num2str(5*xsig(i)
        ),'        erf=',num2str(erf(i)),'      arlft=',num2str(arlft(i)),'
            arRt=',num2str(arRt(i))])
    hold off
    figure(2)
    plot(xsig(erf<3),ycen(erf<3),'.');
    hold on
    plot(xsig(test& erf<3),ycen(test&erf<3),'.r');
    %plot(arlft(i),arRt(i),'om');
    %xlabel('Left area');ylabel('Right Area');title('Plot of Arlft vs
        ArRt');
    plot(xsig(i),ycen(i),'om','markersize',15);
    xlabel('Half Width (not in secs)');ylabel('Peak height');title('
        Plot of Shp width vs Peak Height');
    %plot(6,0:0.00001:max(ycen(test)),'m');ylim([0 max(ycen(test))]);
    %plot(0:max(xsig(test)),0.17./(0:max(xsig(test))),'k');ylim([0 max(
        ycen(test))]);
    %plot(0:max(xsig(test)),0.077./(0:max(xsig(test))),'k');ylim([0 max
        (ycen(test))]);
    hold off
    fprintf('\n              matlabday    erf    xcen    ycen\txsig\t arlft\t
        arRt\tr2\t s2n\t ybkg\tpcen\tptot\tfleft   \t fright')
    fprintf('\n%s %4d %6.2f %.6f %.3f %3.3f %3.3f\t %.3f\t %.3f\t %.6f\
        t%.6f\t%.6f',datestr(matlabday(i)),erf(i),xcen(i),ycen(i),xsig(
        i),arlft(i),arRt(i),r2(i),s2n(i),ybkg(i),pcen(i),ptot(i),fl(i),
        fr(i));
    buffer = input('  press any key to continue','s');
  end
end
return
```

Bibliography

Andrew, R.K., B.M. Howe, and J.A. Mercer (2002). "Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast". *Acoustics Research Letters Online* 3, pp. 65–70.

Au, W. and P. Nachtigall (1997). "Acoustics of echolocating dolphins and small whales." *Marine and Freshwater Behavior and Physiology* 29, pp. 127–162.

Bass, A. (1996). "Shaping brain sexuality". *American Scientist*.

Bland, RW (2011). *Acoustic data archive from RTC pier, San Francisco State University Center for Computing in the Life Sciences*. URL: `http://bayacoustics.sfsu.edu/rtcpier/html/archive/html`.

Bregman, A. (1993). *Auditory scene analysis: Hearing in complex environments*.

Edds-Walton, P. (1997). "Acoustic Communication Signals of Mysticete Whales". *The International Journal of Animal Sound and its Recording* 8, pp. 47–60.

Fish, M. (1948). "Sonic Fishes of the Pacific". *Woods Hole Oceanographic Institution, Woods Hole, MA*.

Fay, R. and A. Popper (2000). "Evolution of hearing in vertebrates: the inner ears and processing". *Hearing Research* 149, pp. 1–10.

Gray, L. M. and D. S. Greeley (1980). "Source level model for propeller blade rate radiation for the world's merchant fleet". *Journal of Acoustical Society of America* 67, pp. 516–522.

Greene, C. W. (1924b). "Physiological reactions and structure of the vocal apparatus of the California singing fish, *Porichthys notatus*". *Americal Journal of Physiology* 70, pp. 496–499.

Hubbs, C. (1920). "Bionomics of Porichthys Notatus Girard". *The American Naturalist*.

McDonald, M.A., J.A. Hildebrand, and S.M. Wiggins (2006). "Increases in deep ocean ambient noise in the Northeast Pacificwest of San Nicolas Island, California". *Journal Acoustical Society of America* 120(2), pp. 711–718.

Myrberg Jr, A. A. (1990). "The effects of man-made noise on the behavior of marine animals". *Environment International* 16, pp. 575–586.

NRC (2000). *Marine Mammals and Low Frequency Sound: Progress Since 1944*. National Academy Press.

Picciulin, Marta et al. (2012). "Brown meagre vocalization rate increases during repetitive boat noise exposure: A possible case of vocal compensation". *Acoustical Society of America* 132, pp. 3118–3124.

Richardson, W.J. et al. (1995). *Marine Mammals and Noise*, pp. 101–158.

— (1995). *Marine Mammals and Noise*, pp. 101–158.

Ross, D. G. (1976). *Mechanics of Underwater Noise.*

— (1993). "On ocean underwater ambient noise". *Acoustics Bulletin Jan/Feb*, pp. 5–8.

Urick, R. (1996). *Principles of Underwater Sound 3rd Edition.*

Wenz, G. M. (1962). "Acoustic ambient noise in the ocean: spectra and sources". *Journal of the Acoustical Society of America* 34, pp. 1936–1956.

— (1969). "Low-frequency deep-water ambient noise along the Pacific Coast of t he United States." *U.S. Navy Journal Underwater Acoustics* 19, pp. 423–444.

Welch, B. L. and A. S. Welch (1970). *Physiological Effects of Noise*. Plenum Press: New York.

Zelick, R., D. Mann, and A. Popper (1999). "Acoustic communication in fishes and frogs." *Springer Handbook of Auditory Research* 11, pp. 363–411.