A comparison of received noise levels to source type, speed and distance in the Haro Strait of Washington State

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Michael Grabstein
922 N. Weber Apt. 1
Colorado Springs, CO 80903
M_grabstein@ColoradoCollege.edu

Abstract

The acoustic environment that Killer Whales (Orcinus orca) live in is not fully understood. This study set out to gain a greater understanding of the whales habitat by looking at received noise levels and their relation to source type, speed and distance. Sound recordings were collected from a variety of vessels, on May 9, 2006 in the Haro Strait, using a calibrated hydrophone produced by InterOceans Inc. Results show that, despite significantly higher received power levels from large commercial vessels, a maximum recorded level of 138.61 dB re 1microPascal, the percent power at high frequencies is significantly lower than that of small vessels. Data also illustrates that low frequency noise, from large commercial vessels, is disproportionately absorbed as a function of distance. This phenomena first observed in this study is an area of suggested future research.

I. Introduction

The Haro Strait, see Fig. 1 for map, and its surrounding bays and inlets have hosted a plethora of marine life long before humans set sail. Now much of the local marine life is in serious danger; species populations have depleted across the board. Currently the animal of greatest concern in the waters of the Haro Strait is the Orca whale; the Southern Resident Orcas, who spend the majority of their time in and around the Haro Strait, were placed on the Endangered species list this past December. This area now is not only a favorite location for recreational boaters, sailors, marine observers and the like; it is a crowded shipping channel with tankers, tugs and other large commercial vessels in nearly constant motion. It is well documented that noise from whale watching boats and other close boat marine mammal interactions often causes behavioral changes in these animals (Erbe,2002). One study reported that during a six month period from spring to fall whale watching boats closely accompany the Orcas for nearly 90% of daylight hours (Griffin, Bain 2005). These figures show that for approximately 25% of the Orcas' life they are accompanied by this intense boat presence.

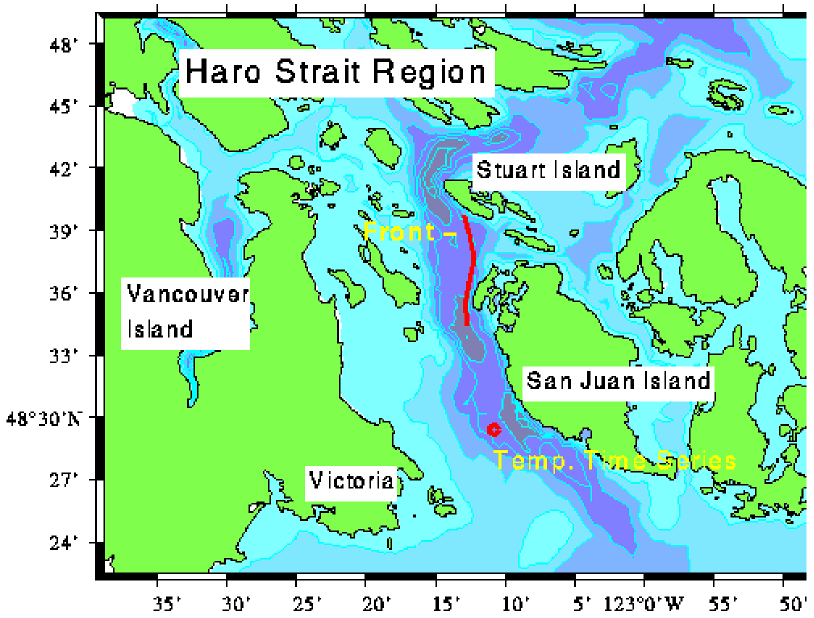


Fig.1. The Haro Strait and surrounding territories

While there is a sharp decrease in the number of whale watching boats in the winter, the tankers, tugs and other large commercial vessels of the Haro strait continue to make their standard number of trips during these winter months. The large vessels fill the Haro strait with sound pollution for the entirety of the year.

The *Proposed Conservation Plan for Southern Resident Killer Whales (Orcinus orca)*, of 2005, states “inventories of acoustic conditions are needed throughout the range of the southern residents, but especially in areas of high vessel traffic, such as the San Juan Islands”. This conservation plan highlights many areas that need more research to better understand the sound characteristics of the area. Section B6.2.4 explains that the acoustic environment, within the orcas’ habitat, is not well understood, items of key importance for future research are those related to vessel sound production and sound propagation. This project focused on both of these concerns, specifically in the area of received noise levels and sound propagation of sound from large commercial vessels as well as how these levels compares to noise levels of small vessels.

Christine Erbe in her 2002 study, *Underwater Noise of Whale-Watching Boats and Potential Effects on Killer Whales (Orcinus Orca), Based on an Acoustic Impact Model*, tried to connect both source noise and sound propagation to animal response or impact. In the summer of 1999, Erbe made underwater recordings, outside of Victoria, of whale watching boats as they passed at high speeds on their way into Haro Strait. She also made some recordings of single boats at low speeds in controlled situations. Using a sound propagation model that accounted for absorption to sediment, frequency dependent absorption and local bathymetry, Erbe found boat source levels ranging from 145 to 169 dB re 1 microPascal at 1meter.

An unpublished study by Rachael Griffin and David Bain, *Sound Exposure of Southern Resident Killer Whales in the Southern Strait of Georgia*, discuss the ambient noise levels in the presence of both whale watching boats and Orcas. For this study they made 200 1 minute recordings of the ambient sound level while in the presence of both orcas and whale watching boats. The results showed an ambient noise level range of 106 to 146 dB RMS // 1miroPa, with a median level of 128dB. Based on observations taken during the recordings, the paper concludes that the Orcas have a 20% decrease in their average annual foraging area due to the increase in ambient noise levels.

All of these studies are of critical importance to understanding how the sound levels in and around the Haro Strait affect the Orcas' behavior and health. But there is still much more learn especially with regards to noise levels created by tankers the constant presence of the Haro strait. One study conducted by B. Wursig and C.R. Greene, discusses Tanker noise levels at the Aviation Fuel Receiving Facility outside of Hong Kong on the Sha Chau Island. This study focused on sounds made during loading and unloading activities at the Aviation Fuel Receiving Facility. The Airport Authority stipulated that there should not be received sound levels at or beyond 300m, from the facility, at frequencies above 300Hz with more than 110dB re 1 micro Pa. This stipulation was based on past research (Wursig and Greene, 2001) of bottlenose dolphin which showed they are primarily sensitive to sounds above 300Hz.

To conduct his research Greene used 2 hydrophones with different sensitivities. In case the primary hydrophone was overloaded, the other, less sensitive one would still be within its range of sensitivity. The hydrophones were deployed, 7m down, beneath a spar buoy to prevent depth fluctuation due to water conditions. Recordings were made at distances between 80-2000m from Aviation Fuel Receiving Facility in water of 8-10m deep. Although long recordings were taken, only 8.5 second sections, those of interest, were used for analysis. The results showed that sounds around the Aviation Fuel Receiving Facility did not exceed the stipulation set by the Airport Authority. The loudest noise recorded, from a tanker at a distance of 100m, was 141dB at 100Hz. It was found that due to bathometry (very shallow water), low frequency sound was not transmitted well and the Aviation Fuel Receiving Facility activities primarily produced sound of this category. In more open water, as found in the Haro Strait, propagation conditions will very be different from that encountered in Wursig and Greene’s study.

Underwater sound propagation is a major issue that is yet to be fully understood. Depending on water depth, local bathymetry, sea bottom characteristics and distance to source different propagation models are necessary. In deep water such as in the Haro Strait, spherical spreading is the expected propagation model. This model predicts that source power will be proportional to -20 Log(distance from source to receiver), (Urick, 1983). Another common model is that of cylindrical spreading which implies that power will be proportional to -10 Log(distance). This model is often used to describe spreading in shallow water or when depth is significantly less than source distance.

In this study concepts will be pulled from all of the above projects while focusing on something not yet done, measuring received sound levels of large commercial vessels, to help gain a better understanding of noise levels of the Haro Strait. This study aims to determine received noise levels for ships and to correlate that noise to ship size, speed and distance. The findings will then be related to past studies to address the affect on

Orcas by the other Haro Strait residents, the ships. This study will also provide a stepping stone for future research in the area.

II. Methods

The methods of this research project break down into several subcategories. First, prior to recording, all equipment must be calibrated to produce consistent data. Then, once equipment was fully organized and calibrated, recordings were made. While recording, distance to and speed of source boat were tracked using a NobelTec Radar, and AIS (http://www.nobeltec.com). Finally, recordings were transferred to computer for data analysis.

II. A. Equipment and Calibration

This study used one hydrophone made by InterOcean Systems, Inc., Model 902 Acoustic Listening and Calibration System (http://www.interoceansystems.com). This is an omnidirectional hydrophone with frequency range of 20-10,000Hz and sensitivity of 100dB re 1 micro Pascal RMS pressure yields 0dB output on the most sensitive setting. On the least sensitive setting it yields 0dB output for 170dB re 1 micro Pascal pressure. An output of 0dB then corresponds to a 1 volt RMS output at 600 ohms across the recorder jack. This hydrophone was used to make all recordings for this project. Due to amplification of the recording device and conditions when data was transferred to the computer, the calibrated output was not in any known units on the computer.

To solve the above problem a 1 volt RMS oscillator was built. The output from the oscillator was used as a standard of comparison for the output from the hydrophone.

The idea being since the computer units were of an unknown scale, the computer units of the oscillator could be used to scale the computer units of the hydrophone output. For example the computer units of the hydrophone divided by the computer units of the oscillator equals output voltage RMS from the hydrophone recorder jack. Then using the specifications of the hydrophone described above and the setting at the time of the recording the received decibel level was calculated. This whole calculation was condensed into the following equation:

$$\boxed{\text{Received dB re 1microPascal} = 20\text{Log}(\text{RMS}_{\text{Hydrophone Computer units}} / \text{RMS}_{\text{oscillator computer units}}) + \text{dB Setting of hydrophone}}$$

The oscillator was built with a 7555 chip and a low pass filter after the output from the oscillator to clean up the signal. The oscillator was designed with a frequency of 800 Hz in order to be within the range of all recording instrumentation and to be on the same order of frequencies expected from boat noise or orca calls. Fig. 2 shows a circuit diagram and picture of the oscillator.

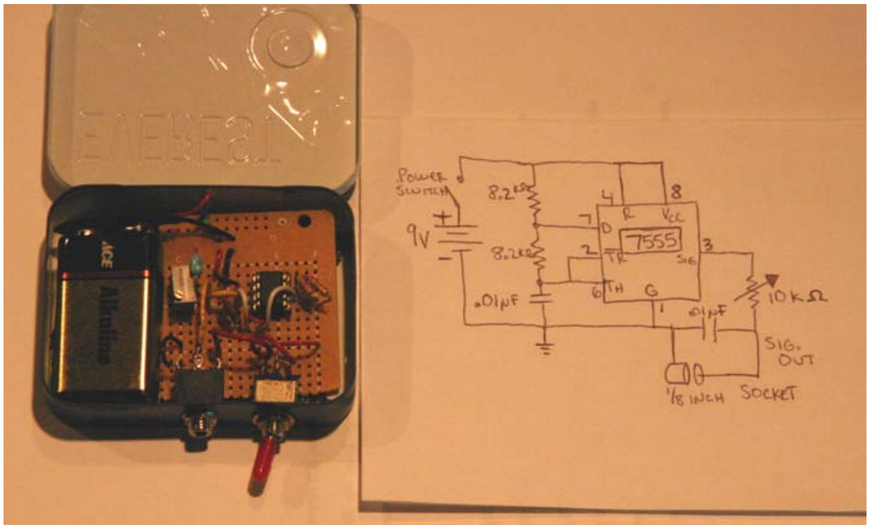


Fig. 2. Oscillator and circuit diagram

The hydrophone and oscillator were plugged into a portable solid-state recorder; model PMD660, produced by Marantz (http://www.marantz.com). The PMD660 is a digital audio recorder with a sampling rate of 48 kHz. It has 2 channels when on stereo mode; the right was used to record the oscillator and the left to record the hydrophone. The recorder has an input sensitivity of 300mV RMS at a resistance of 20kohms. Recordings are saved onto a CF memory card as wav. files at a rate of 1536kbps. Finally, recordings are transferred to computer via USB cable for analysis.

II. B. Recording Methods

All recordings were made from the comfortable cabin within the 33' catamaran, Cat's Cradle, owned and operated by Dr. Val Veirs, see Fig. 3 for photo.

While recording, the boat drifted with the sail down, the engine off, and the center boards up, when necessary, to reduce any excess noise from the listening location. The boat sat in the open waters of the Haro Strait in depths of over 700 feet. Recordings were made with the hydrophone approximately 7m below the aft starboard corner of the boat.

Fig. 3: From left: Scott Yee, Kari Sherman, Michael Grabstein and Jon Will. Hard at work, making recordings, in the cabin of the Cat's Cradle

The aft starboard corner of Cat's Cradle was chosen because the Nobeltec AIS (http://www.nobeltec.com), automatic identification system, for tracking vessels is located on this corner. This system receives radio information from large boats in the area relating some of their travel information. Large vessels are required to transmit their ship name, speed and direction; the system also gives a very accurate distance separation between its antenna and the target boat. This system was the primary means for collecting speed and distance data. However, many boats do not transmit a strong enough signal for the AIS to receive data at long distances. In addition, small personal crafts and whale watching boats are not required to transmit the above information at all. When this was the case distance measurements were made using a Nobeltec InSight Radar 2 (http://www.nobeltec.com). The radar was a good system for distance measurements but due to the software available it was insufficient for providing boat speeds.

When a target boat was in sight the researchers on board the Cat's Cradle would use the afore mentioned distance and speed measuring instruments, that were available, to collect target information while a simultaneous recording was made of the target and of the oscillator. Durations of recordings were between 30 seconds and 3 minutes, with distance updates logged as often as feasible. For any given target vessel, a series of recording were made from the first feasible instant that reasonable listening and measurement conditions were available until the vessel was out of range. For loud, slow moving, tankers more recordings were taken, but for small, fast moving, personal crafts and whale watching boats fewer recordings were made. Before and after recordings were made of the target, a recording was taken of the ambient noise or background noise. Background recordings help to see what noise is representative of the target vessel compared to the noise of the ocean or the research vessel.

II. C. Data Analysis

Once back on sold ground, recordings were transferred from the Marantz digital recorder to computer via USB connection. Then using Orca Sound, a sound analysis program, written by Dr. Val Veirs, recordings were evaluated. This program displays recordings in a visual form, with a plot of amplitude versus time. Then using a zoom function, sections of the recording were chosen for measurement. Sections were chosen, for measurement, based on a visual appearance that they were consentient with the entirety of the recording and contained less extraneous background noise, which often appeared in the form of low frequency high amplitude noise. This type of background sound was often created by a wake hitting the side of the Cat's Cradle.

Once sections were chosen, RMS values were measured from recordings of both the oscillator and the corresponding oceanic recordings. Then using the calibration equation discussed previously computer RMS values were converted to a calibrated received dB re 1microPascal level. With all data available, comparisons were then made and relationships ascertained.

Power as a function of frequency is a critical aspect in understanding the acoustic environment. It will also aid in relating boat noise to Orca vocalizations. Using the same sound analysis program, received power spectra were analyzed. Power spectra also needed to be converted from computer units to dB re 1microPascal^2/Hz, this is a decibel expression of power at a given frequency level. The equation used for this conversion appears below:

$$\boxed{\text{Received dB re 1microPascal}^2\text{/Hz} = 10\text{Log}(\text{Power}_{\text{per band}} \times \text{Frequency}_{\text{Bandwidth}}/\text{Total Power}) + \text{Received dB re 1microPascal}}$$

Power spectra were analyzed to determine at what frequency sound from different boat types have the most power. Power spectra, from the same boat, were also looked at to see how power at differing frequency levels were absorbed at different distances. Absorption of noise at different frequencies is an interesting and important aspect of underwater sound propagation that there is still more to be learned about. In both *Principles of Underwater Sound*, by Robert Urick, and in Marine Mammals and Noise, by John Richardson, disproportionate absorption of high frequency noise as a function of distance is mentioned. However no one has ever found circumstances that lead to disproportionate absorption of low frequency noise.

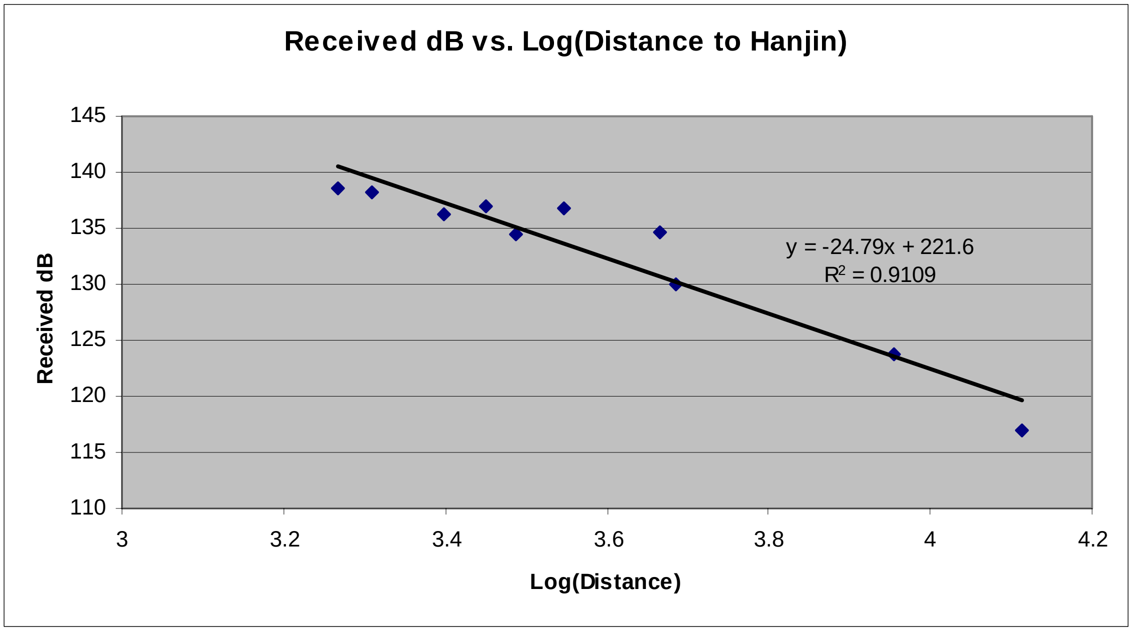
III. Results

Data collected during this experiment reveals many interesting concepts of sound propagation of boat noise in the Haro Strait. Comparison of different sources also shows how received noise levels relate to source type, size and speed.

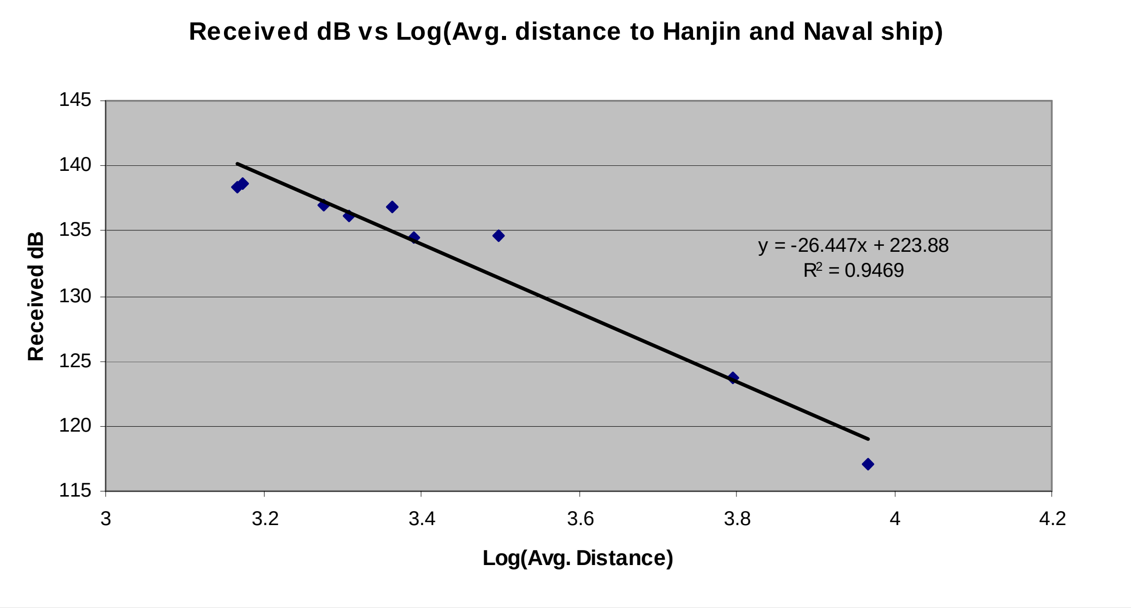
The first set of graphs shown below demonstrate how sound from the Hanjin, a tanker that was recorded on 5/9/06, was absorbed more rapidly than even a spherical spreading model would predict. While the Hanjin was being recorded a Canadian Navy ship, #702, was also in the area. Both ships, photographed in fig.#4, were traveling towards the recording location at similar speeds, the Hanjin at 11.6 meters per second and the Navy ship at approximately 10 meters per second, but Hanjin was slightly farther away than the Naval ship. The Hanjin, which was fully loaded, dominated the received

Fig.4 The Hanjin is seen on the left and the Canadian Naval Ship on the right.

sound levels but two graphs are presented below; in Fig.5, a graph of received dB re 1microPascal vs the distance to the Hanjin is shown, and in Fig. 6 a graph of received dB re 1microPascal vs the average of the distance to the Hanjin and the Canadian Naval ship is shown. The same type graph is shown for Go Faith, another tanker recorded on 5/9/06, in Fig.7. During the time of recording the Go Faith was going 6.64 meters per second, traveling light and spilling ballast water. The same type of graph is presented, for a Canadian Zodiac traveling at full throttle, in Fig.8.



Fig#5. This graph shows the received dB level of the Hanjin as a function of the log of its distance (in meters) from the recording location. The slope of the trendline represents how power is related to distance. As mentioned in the introduction, a slope of -10 implies cylindrical spreading and a slope of -20 implies spherical spreading. The slope of -24.79, seen here, implies that transmission loss is occurring faster than that of a spherical spreading model.



Fig#6. Here the even larger negative slope of the trendline implies a transmission loss that is proportional to distance$^{2.6}$, rather than the being proportional to distance^{2} as in a spherical spreading model.

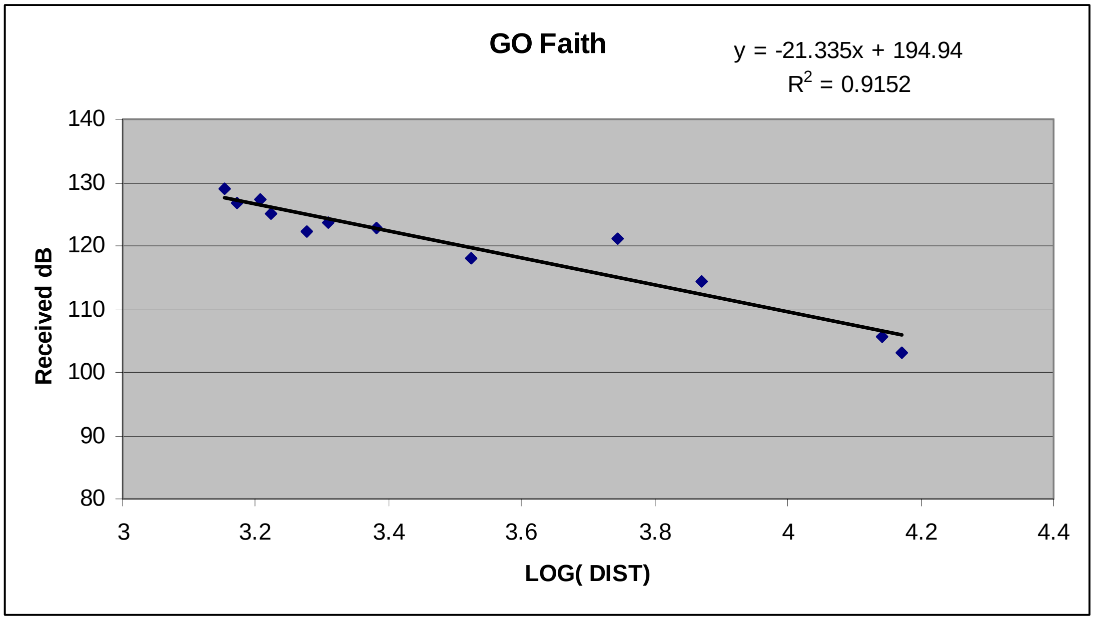


Fig.#7. Here the received dB level of the Go Faith is plotted verse the log of its distance from the Cat's cradle. Here the slope of -21 implies a spreading model much closer to spherical than that seen from the Hanjin.

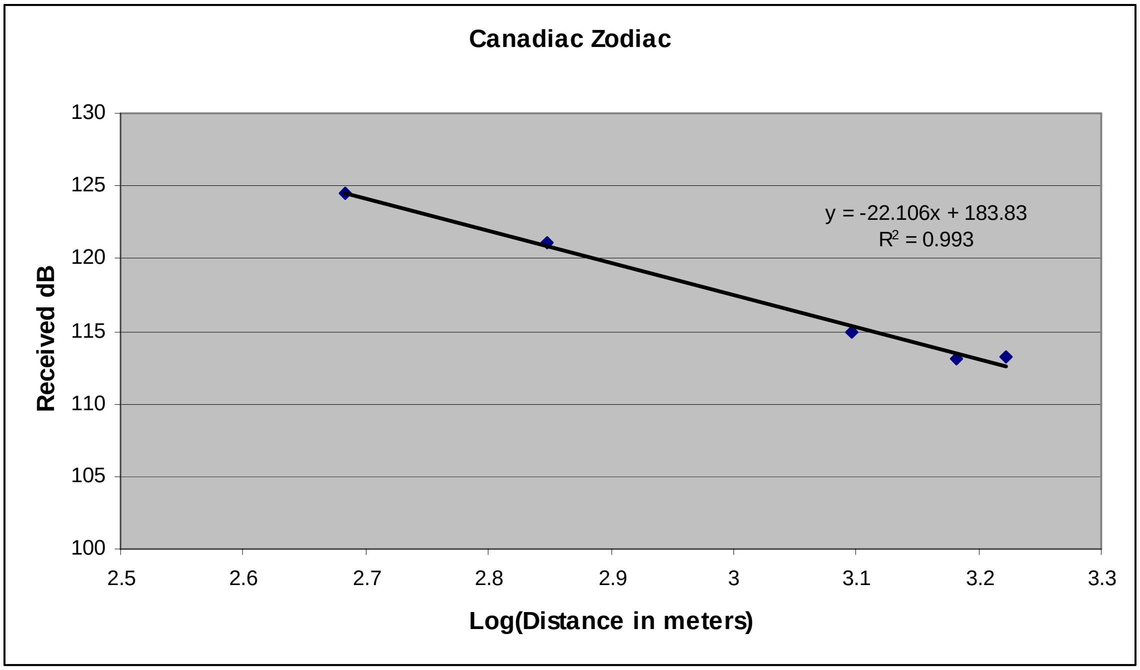


Fig.8 Here once again the slope of -22 implies a propagation model that is hypershierical in nature.

To demonstrate that sound is absorbed differently at different frequencies the following graphs display the percentage of power above the corresponding frequency, of the Hanjin, Fig.9, the Go Faith, Fig.10, and a Canadian Zodiac, Fig.11, at a few distances.

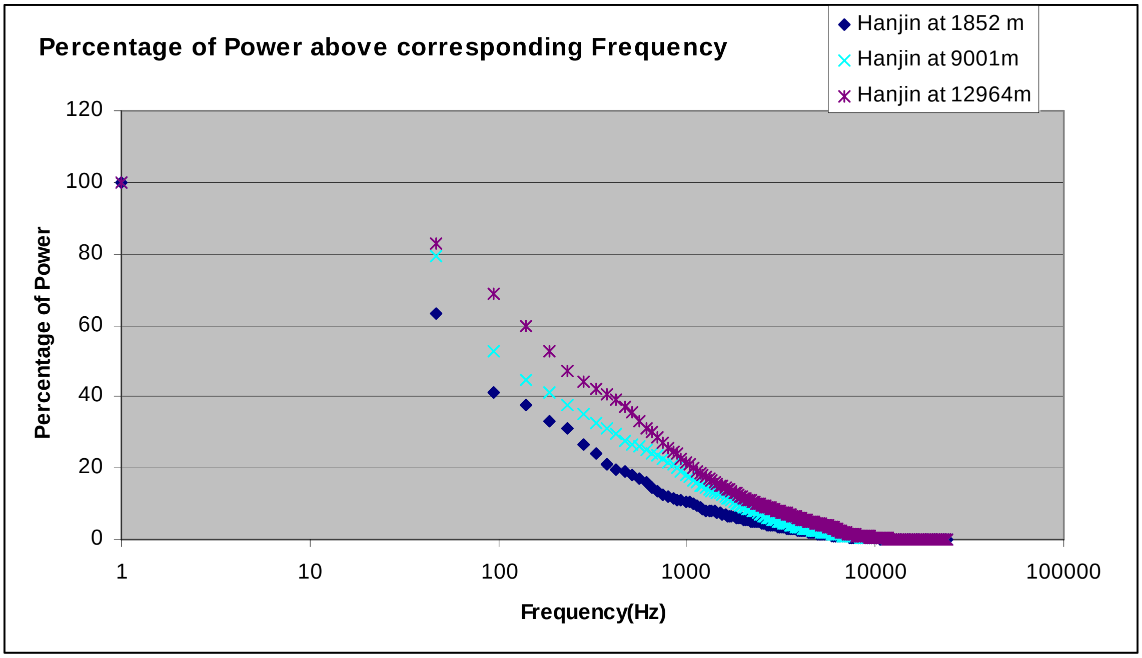


Fig.9. This graph shows that there is a higher percentage of total power retained at higher frequencies at farther distances. At 1.8km there is only 40% of total power above 100Hz. At 9km there is 40% of total power above 200 Hz, and at 13km there is 40% of total power above 400 Hz.

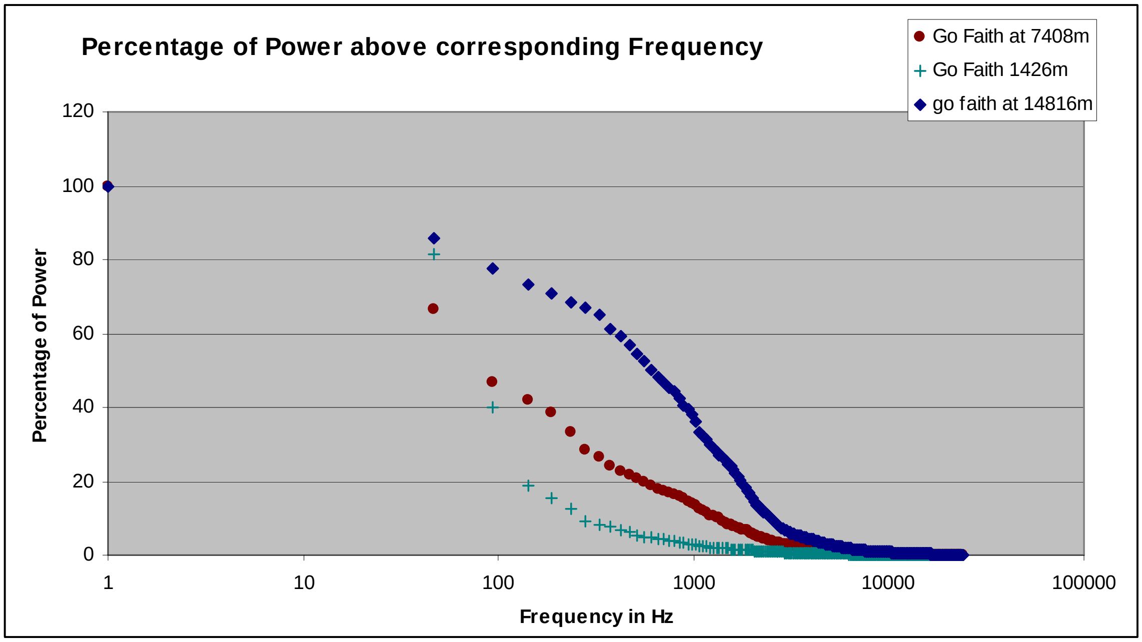


Fig.10. This graph demonstrates the same phenomena, as seen in the previous graph of the Hanjin, to an even greater degree. Here the Go faith has only 40% of its power above 100Hz at 1.4km, but it has 40% of it power above 150Hz at 7.4km. At 14.8km the Go Faith has 40% of its power above 900Hz.

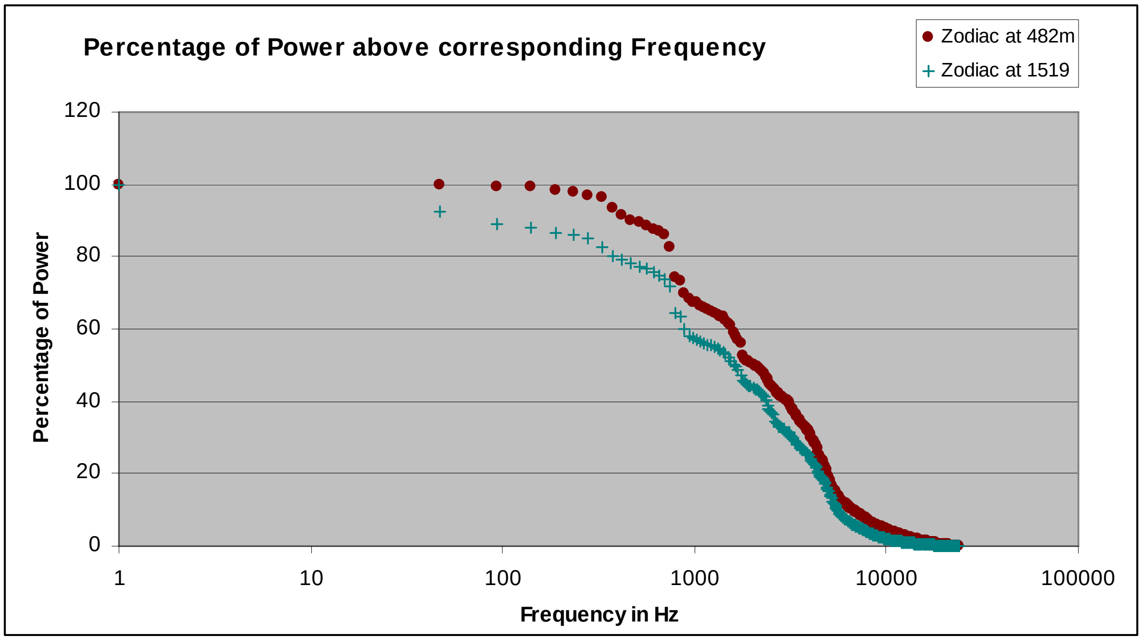
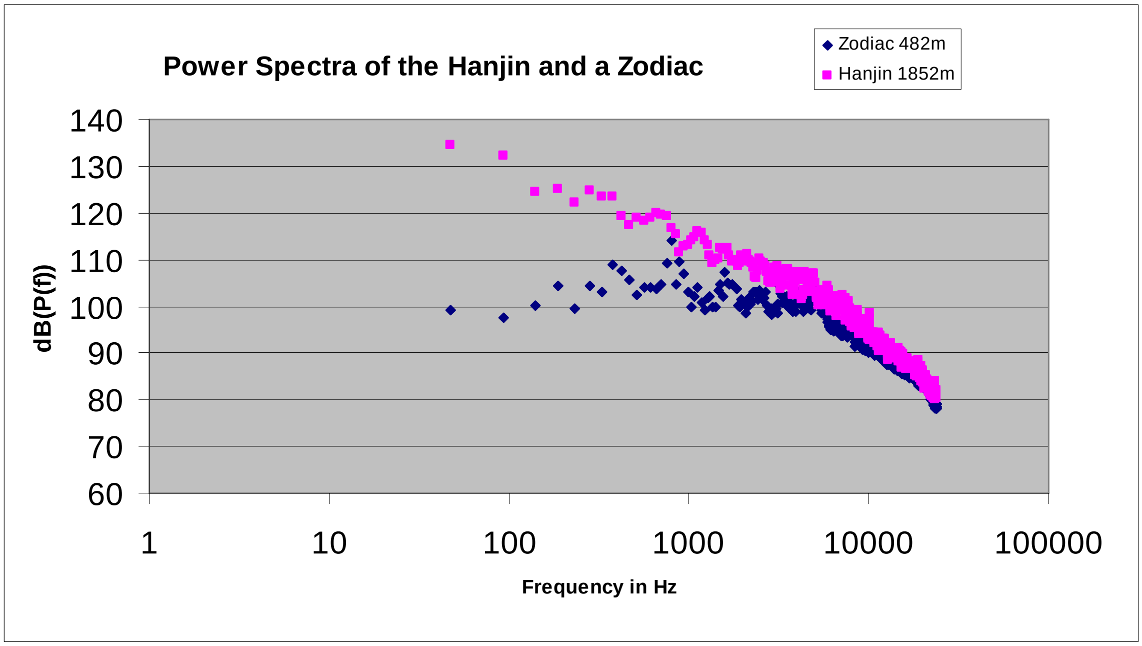


Fig.11 Here the Zodiac demonstrates the exact opposite phenomena as seen from the large commercial vessels. The Zodiac, at 1.5km, has 50% of its power above 1600Hz, however, at .5km it has 50% of its power above 2000Hz. This relationship is the inverse of that seen from the larger Vessels.

Another important part of understanding the noise levels in the Haro Strait is understanding how the sound levels of tankers, like the Hanjin, compare to that of small craft. This next graph, Fig.#12, compares the power spectra of the Hanjin to that of a Canadian Zodiac, at their respective points closest approach to the Cat’s Cradle. The Hanjin was traveling at 11.6 meters per second; the speed of the zodiac is not known but it was at or near full throttle.



Fig# 12 During these recordings Hanjin and the Zodiac produced a received sound level of 138.61 and 124.54 dB re 1 microPascal respectively. This graph shows that despite the much higher received sound level from the Hanjin the noise from the Zodiac has nearly the same power at high frequencies.

It is clear that from the above graph that different types of boats produce significantly different power spectra. The next graph, Fig13, compares the power spectra of the Hanjin to that of the Go Faith, both from recordings at approximately 1 nautical mile or 1852 meters.

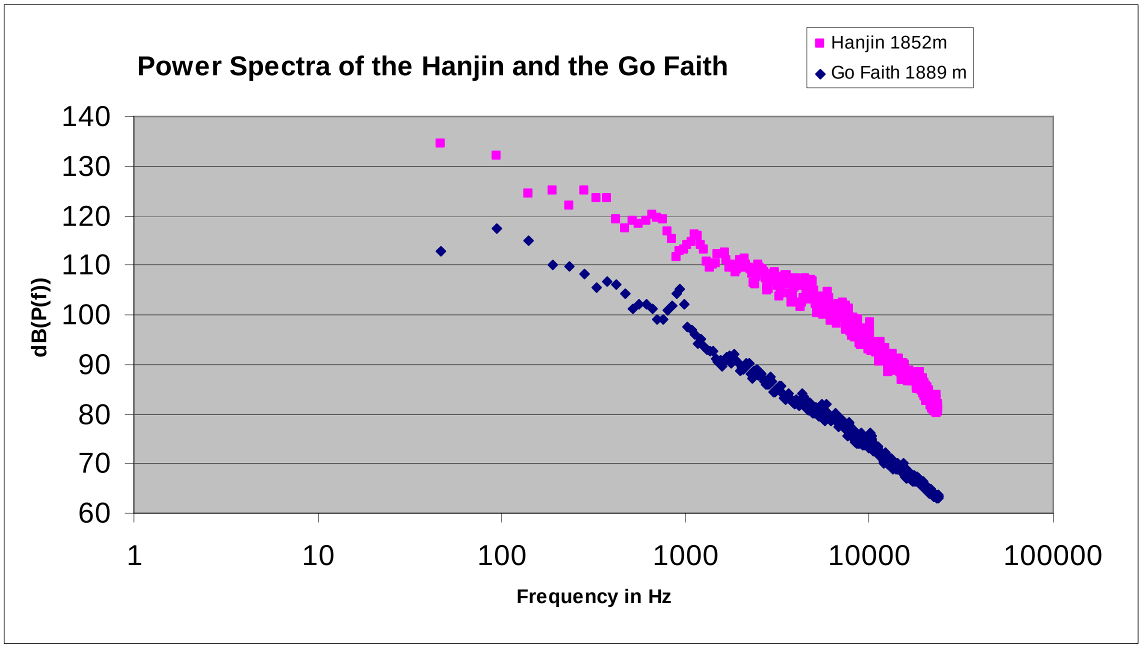


Fig.13. This graph shows the power spectrum of the Hanjin recorded while fully loaded traveling at 11.6 meters per second above the power spectrum of the Go Faith traveling light at 6.6 meters per second. The received noise levels from these recordings were 138.6 and 122.3 dB re 1microPascal, respectively. This clearly demonstrates how a similar sized boat traveling loaded at nearly double the speed of another produces much louder noise level, but very similar power distribution.

IV. Discussion and Conclusion

This project set out with the goal of better determining the acoustic environment in which the Southern Resident Killer Whales live. The study focused on assessing sound propagation, and comparing noise levels of different classes of boats. The data found in this study implies a sound propagation model in the Haro Strait that is hyperspherical. Data also shows that the power in low frequency noise, from large vessels, is disproportionately lost as distance increases. The opposite was found with regard to noise generated from small vessels. Results also show that large vessels produce a significantly smaller fraction of their acoustic power at high frequencies than small craft, and that the shape of a vessel’s spectrum level (power vs frequency) is more closely related to vessel type rather than weight or speed.

Hyperspherical propagation means that sound intensity is dissipated more quickly than a spherical spreading model would suggest. Spreading here refers to loss of power due to power being spread over a larger area as sound propagates and absorption refers to loss of power due to other phenomena. There are a few reasons that that could explain why this hyperspherical model was found, one being disproportionate absorption of low frequency noise at long distances leading to an overall power loss, this is demonstrated in figures 9 and 10. But the zodiac also demonstrates hyperspherical propagation despite more anticipated power absorption. I believe a likely cause, for the hyperspherical propagation seen in the Hanjin, is poor distance modeling in the case of the recordings of the Hanjin and the Canadian Naval Ship. The Go Faith and the Canadian Zodiac do not demonstrate nearly as extreme properties of hyperspherical propagation. Another possible explanation for the apparent hyperspherical spreading is local bathymetry. Despite the fact that the Cat's Cradle sat in deep open water the bathymetry between it and the target boats was not taken in to consideration during data analysis; unknown bathymetry, between the target and the recording location, could have caused significant reflection resulting in an indirect path of travel for sound from target to the hydrophone. This may help to explain the apparent non-spherical spreading. Erbe, in her 2002 paper, used a much more comprehensive sound propagation modeling system that took into account many of the factors that were not considered for this research. The propagation model found in this research is important to consider because it shows much faster sound dissipation than past research, but to what extent it is correct is hard to quantify. However, the fact that sound was found to be absorbed in a hyperspherical fashion is a good sign for the orcas because it implies that they may be able to avoid a larger amount of sound, by increasing the distance between themselves and a source, than previous thought.

Far and away the most surprising results from this study and those that require further investigation are shown in figures 9 and 10. These figures show, for the first time ever recorded, that low frequency noise, from large vessels, is disproportionately absorbed as distance increases. At this point I have only been able to devise one possible explanation for this occurrence. It is possible that the long wavelengths, of low frequency sound, are actually being destructively interfered with due to bathymetry. This seems unlikely since absorption occurs over a very broad band of frequencies.

This study also reveals some very interesting relationships between received sound levels and source types. From data collected in this project it is clear that even at very large distance noise produced by tankers is a dominant source in the Haro Strait. During recordings, large commercial vessel noise was not only recordable at long distances but it often drowned out noise from other much closer boats. Despite the higher received sound levels from large commercial vessels, the power they produce at high frequencies was found to be disproportionately lower than that of smaller vessels. For instance at approximately 1.5km the Zodiac produced over 50% of its power above 1600Hz as opposed to the Hanjin at 1.8km that produced only 40% of its power above 100Hz.

It is also clear that a full tanker a traveling at high speed produces a huge amount of noise at all frequencies compared to a light tanker at low speeds. Figure 13 shows the power spectra of Hanjin and the Go Faith at appoximatly 1.8km to be nearly parallel, which implies similar power per Hz. This shows the percentage of power per Hz is not dependent on speed or weight, since the Hanjin was traveling at 11.6 m/s, loaded, and the Go Faith was traveling at 6.6 m/s, light. This graph shows that total power will increase as speed and weight increase but the power distribution will not.

This research will hopefully provide a good launching pad for future projects related to the impact of large commercial vessels on the acoustic environment of the Haro Strait. With more research it may be found that some sort of speed regulations on tankers is a necessary set in dropping the ambient noise levels in the waters in and around the Haro Strait. Future research on the subject should be sure to record vessels at a larger variety of speeds, both loaded and unloaded, to better quantify how the power spectra are correlated to size and speed. I also hope that future research will aim to discover what could possibly explain the disproportionate absorption of low frequency noise as a function of distance first seen in this study.

V. Acknowledgements

I would like to thank Dr. Val Veirs my professor and mentor throughout the course of this research. I would also like to thank Jon Will and Scott Yee, for their aid in the data collection and recording process, Scott Veirs, for his guidance in the early stages of this research. My biggest thanks go out to Leslie Veirs for her motivational talks and cookies that keep us going to the very end.

VI. Bibliography

Erbe, Christine. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Science, 18 (2): 394-418

Griffin, Rachael M. and David E. Bain. 2005. Sound Exposure of Southern Resident Killer Whales in the Southern Strait of Georgia. Unpublished Report for the National Marine Conservation Area Feasibility Study.

National Marine Fisheries Service. 2005. Proposed Conservation Plan for Southern Resident Killer Whales (Orcinus Orca). National Marine Fisheries Service, Northwest Region, Seattle, Washington.

Richardson, W.J., C.R. Greene Jr., C.I. Malme and D.H. Thomson.1995. Marine Mammals and Noise. Academic Press, San Francisco.

Urick, Robert J. 1983. Principles of Underwater Sound. Peninsula Publishing, Los Altos, California

Wursig, B. and C.R. Greene Jr. 2001. Underwater sounds near a fuel receiving facility in Western Hong Kong: relevance to dolphins. Marine Environmental Research 54: 129-145

Equipment Producer Websites
InterOcean Systems, http://www.interoceansystems.com

Marantz, http://www.marantz.com

NobelTec, http://www.nobeltec.com