Sound transmission into large aquarium shark tank

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ABSTRACT

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This study examines how sound from public spaces transmits into a large shark tank at the Loveland Living Planet Aquarium (Utah). Sharks primarily hear frequencies between 100 and 400 Hz and in the tank they are exposed to noise from filtration systems and sounds originating in nearby visitor. Ambient tank noise was compared with signals played in adjacent public areas. Recordings were made with hydrophones inside the tank while white noise, simulated crowd noise, and logarithmic chirps (100–2000 Hz and 500–4000 Hz) were played from loudspeakers in the guest viewing room, banquet hall, and tunnel. White and crowd noise never exceeded ambient levels. Chirps exceeded ambient levels only when played in the guest viewing room or banquet hall; no transmission was detected from the tunnel. Transmission strength depended on both frequency and source location, with the clearest signals from the guest viewing room. These findings provide baseline data for managing sound exposure in aquarium tanks.

Keywords: Underwater acoustics, Acoustical measurements, Aquarium system, Aquarium sound, Sound Transmission

1. INTRODUCTION

This study investigates how sound from surrounding public spaces transmits into a large aquarium tank, adding to the noise already present from internal filtration system. While sound levels in public spaces are easy to measure, less has been reported regarding sound levels in tanks. To better understand the relationship between sound levels in public areas and aquarium tanks, acoustical measurements were taken at the Loveland Living Planet Aquarium (LLPA) in Draper, Utah. An understanding of the correlation between these levels can inform setting noise level guidelines in viewing areas.

A. SHARK HEARING

At the LLPA, the largest tank is home to many species including sharks, rays and fish. This project focuses on the hearing range of sharks and rays, refered to as cartilaginous fish. Cartilaginous fish have skeletons made of cartilage, unlike mammals, which have bones. Hearing is crucial for these animals, as they rely on sound to navigate, avoid obstacles, orient themselves to the current, track, localize, and capture prey.[1]

These animals rely on two main structures for sensing sound: their inner ear and a lateral line that runs along their entire body. Through these structures, cartilaginous fish can detect noise not only through fluctuations in sound pressure but also through particle motion. In this study, we used hydrophones to detect pressure changes, but subsequent studies with particle motion sensors will be also beneficial.

Sharks are most sensitive to low-frequency sounds $(< 1500\mathrm{Hz})$, with peak sensitivities between 200 and 400 Hz.[2] As a result, we focused on looking at these bands to evaluate how they are transmitted into the tank.

B. NORMAL NOISE EXPOSURE IN SHARK ENVIRONMENT

The sharks that inhabit the tank at the LLPA are naturally found in tropical reefs and shallow waters. These animals are regularly exposed to a variety of noises generated by various natural and human-made sources. Such noises can result from physical processes such as wind, waves, rain, or seismic activity, as well as from anthropogenic sources like commercial fishing boats, sonar, and oil and gas exploration.[3]

Ambient noise in the Pacific Ocean, where some of the shark species in the tank originate, is shaped by both environmental conditions and biological activity. Studies have shown that an increase in wind speed raises overall ambient noise levels for frequencies below 4 kHz in the water,[4] and that acoustic levels fluctuate based on the time of day and the lunar phase.[5] A group of scientists from the Scripps Institution of Oceanography and the National Oceanic and Atmospheric Administration found that in the tropical and subtropical Pacific Ocean, sound levels ranged between 67 and 76 dB reference to 1 $\mu\mathrm{Pa}^2/\mathrm{Hz}$ at 50 Hz. This unit describes how much sound energy is present per unit of frequency. They also reported that frequencies less than 100 Hz corresponded to higher sound levels, while frequencies higher than 100 Hz generally corresponded to lower levels—except in cases where biological noises, such as whale calls, caused elevated values.[3]

Since the tank at the LLPA is enclosed, the overall noise levels are not influenced by environmental variables in the same way as in nature. However, it remains important to compare noise levels in the tank to those in the wild, even though the sources of noise differ.

C. ACOUSTICS OF LARGE TANKS IN AQUARIUMS

A project similar to our experiment took place at the Georgia Aquarium in a Beluga whale exhibit. The researchers studied the transmission of music in an event space into the tank. They played music at specified levels outside the tank and recorded the transmitted sound on a hydrophone inside the tank. They concluded that noise levels in the room of 90 and 95 dBA were sufficiently attenuated that the sound transmitted into the tank through the viewing window did not have an adverse effect on the animals in the tank.[6] This study highlights the importance of understanding how external noise sources interact with aquarium tanks. While this study took place in a Beluga whale tank and focused on the whale's response, our current study involves sharks, which have distinctly different hearing abilities.

Multiple studies have shown that the life support system (LSS) of and aquarium is a major source of noise in large aquarium tanks. The LSS includes all the pumps and filtration equipment used to keep the water clean and healthy. A study on aquaculture systems found that frequencies below 400 Hz were commonly detected, with sound pressure levels ranging between 125 and 135 dB.[7] Similarly, research at the Georgia Aquarium reported that the loudest frequencies ranged from 0 to 200 Hz, attributing them to the LSS of the tank.[8] Another study further supports these findings about low frequencies in aquarium tanks, indicating that aquarium environments tend to have elevated low-frequency sound levels due to water filtration systems.[9] These consistent observations suggest that low-frequency noise is a defining characteristic of captive aquatic environments. At the LLPA, the LSS is located about 5 to 10 feet (1.5 to 3 meters) from the tank, so its noise is especially important to consider. While this project mainly focuses on sound coming from the viewing areas, we also measured the LSS noise.

D. OVERVIEW OF PAPER

The purpose of this paper is to report and analyze the results of measurements conducted at the LLPA. Specifically, sound transmission into a large shark tank is investigated through analysis and comparison of sound levels inside the tank under ambient conditions and when sound was generated in three adjoining public spaces. Section 2 explains the methods behind the experiment, detailing the equipment, setup, and types of signal processing used to analyze the recorded signals. Section 3 shares the results of the experiment and shows how different types of signals transmit into the tank. Section 4 discusses the conclusions from the measurements of sound transmission into the shark tank.

2. METHODS

A. AQUARIUM TANK LAYOUT

The tank at the LLPA includes three main viewing areas, a tunnel, a guest view room, and a banquet hall. The life support system (LSS) is located next to the tank behind the scenes as depicted in Fig. 1. Hydrophones were placed at each numbered blue dot shown in Fig. 1. The

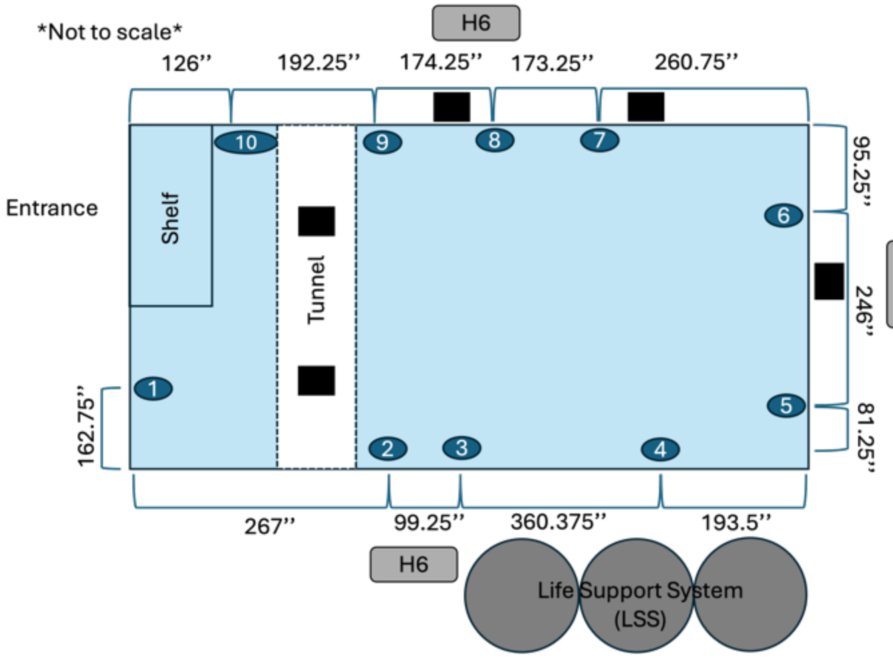

Figure 1: Layout of aquarium tank from above.

tunnel runs underneath a portion of the tank, as indicated. The guest view room is located on the top of Fig. 1, and the banquet hall to the left.

B. EQUIPMENT

A key goal of this project involved creating a simple recording method for conducting tests in a large aquarium tank. The equipment needed to be financially friendly, good quality, and portable. We found that using Zoom H6 Handy Recorders (Zoom Recorders), Aquarian AS-1 Hydrophone, and Aquarian PA6 Phantom-Powered Hydrophone Preamps fulfilled all of these goals.

i. Zoom H6 Handy Recorders

Zoom H6 Handy Recorders feature four XLR inputs and an X/Y microphone on top, totaling five recording channels. Each input has a gain control knob, allowing individual signal amplification. It can supply multiple voltage levels of phantom power to its inputs. Phantom power is a way to provide power to microphones or hydrophones power without using an external power supply.[10]

One of our first tasks in preparing for the aquarium measurements was to determine the gain in decibels corresponding to each notch on the gain control knobs. Understanding and quantifying this effect is crucial because it influences our data analysis: To find the sound levels in the tank, we need to remove the gains added by the recorder, hydrophone sensitivity, and the preamplifier.

To calculate the corresponding decibel gain to each notch of the control knobs, we connected the Zoom Recorder to a signal generator. Initially, the signal generator produced a 250 Hz sine wave. The amplitude of the sine wave was selected to be the highest possible value for a specific gain setting (notch) without introducing peak clipping, based on the level indicator as described in the instruction manual for the Zoom Recorder. The notches on the knobs range from 0 to 10;

however, we only conducted this test for notches 2 through 7. A good input voltage was not found for the remaining notches: 0 and 1 were too quiet, and 8, 9, and 10 were too loud to yield useful results. To find the gain associated with each notch, we used the ratio of the measured peak amplitude A_{meas} to the input amplitude A_{in} and converted to decibels:

$$\text{setting\_gain\_dB} = 20 \log_{10} \left(\frac{A_{\text{meas}}}{A_{\text{in}}} \right) \tag{1}$$

Several repetitions were conducted for both the 250 Hz and 1000 Hz sine waves. The results were averaged from both frequency tests to create Table 1, which lists the setting_gain_dB values. We estimate the uncertainty in these gains to be approximately less than 1 dB, primarily because the setting notches are not discrete, i.e., the control knob turns smoothly and does not click into place for each notch.

Table 1: Gain control knob settings and corresponding gain in decibels.

Gain Setting	setting_gain_dB
2	20
3	33
4	39
5	46
6	58
7	70

ii. Hydrophones

When selecting a hydrophone, we prioritized finding one with a frequency range aligned with the sharks' sensitive hearing range which was affordable and compatible with the Zoom H6 recorders. The hydrophone needed to provide high fidelity recorded signals while remaining affordable, as we required at least 10 for our tests in the aquarium tank. For these reasons, we chose the Aquarian AS-1 hydrophone. The Aquarian AS-1 has a frequency response of 1 Hz to 100 kHz. The hydrophone has a receiving sensitivity of $-208\,\text{dB re }1V/\,\mu\text{Pa}$, equivalent to $40\,\mu\text{V}/\text{Pa}$. In other words, it produces a $40\,\mu\text{V}$ signal in response to a sound pressure of $1\,\text{Pa}$.

We chose the Aquarian PA6 preamplifiers for these hydrophones, which provide a gain of 26 dB. These preamps require phantom power to function properly, which is compatible with the Zoom H6 Recorder.

Using the Zoom H6 Recorder, Aquarian AS-1 Hydrophones, and PA6 preamplifiers, we successfully developed a simple affordable recording method for conducting tests in a large aquarium tank. The next step was to design a system to stabilize the hydrophones in the water.

iii. Hydrophone Stabilizer Rods

The shark tank at the LLPA has a walkway around the edges, as shown in Fig. 2(B). The railing around the walkway provided a stable place to attach the hydrophones. The aquarium

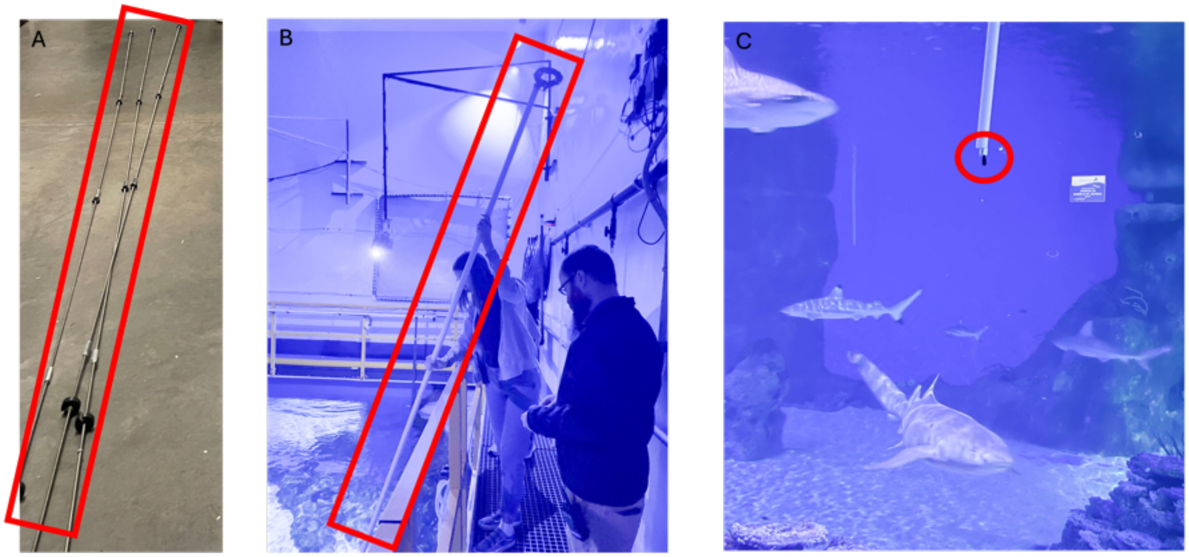

Figure 2: A) Threaded Rods, B) PVC Pipe with Hydrophone placed in water, C) View of hydrophone in tank.

installed PVC pipe mounts on the railing, and we built hydrophone mounts that were enclosed in PVC pipe. The distance from the water's surface to the top of the handrail is 5 feet (1.5 m), so the PVC pipes needed to be long enough to position the hydrophone at a reasonable water depth while incorporating equipment to keep it stable.

The hydrophone holders were created using threaded metal rods, 3D-printed stabilizers and lock nuts. A schematic of the complete set up is shown in Figure 3. The hydrophone cable was loosely wrapped around threaded rods; each rod was 3 ft (0.9 m) long, and four rods were connected connected metal couplers, as shown in Fig. 2(A). The threaded rods were fed into a PVC pipe with a diameter of 1 inch (2.5 cm) and a length of 10 feet (3 m). The BYU Physics and Astronomy Machine Shop 3D printed custom-designed stabilizers to hold the rod in the center of the PVC pipe as well as caps for the end of the PVC pipe. They also machined custom stainless steel hydrophone holders that securely held the backside of the hydrophones. Lock nuts were used throughout the entire setup to ensure that pieces did not slip apart. Once assembled, the poles were ready for placement in the water, depicted in Fig. 2(B). The orientation of the hydrophone at the end of the pipe is shown in Fig. 2(C).

C. MEASUREMENTS

As shown in Fig. 1, we positioned hydrophones (dark blue ovals) along all sides of the tank to record underwater sound levels. Loudspeakers (black squares) were placed in the adjacent public spaces and used to transmit signals, which were simultaneously recorded by sound level meters (SLMs) in the rooms and the hydrophones in the tank. The hydrophones captured three types of signals: ambient noise, white and crowd noise, and logarithmic chirps. Ambient recordings captured the tank's baseline soundscape, allowing us to assess whether sound levels were elevated near the life support system (LSS) compared to more distant locations. The white noise and chirp signals—played in public spaces—allowed us to analyze how external noise transmitted into the tank. The loudspeaker locations are illustrated in Fig. 1 as black squares, but the loudspeakers

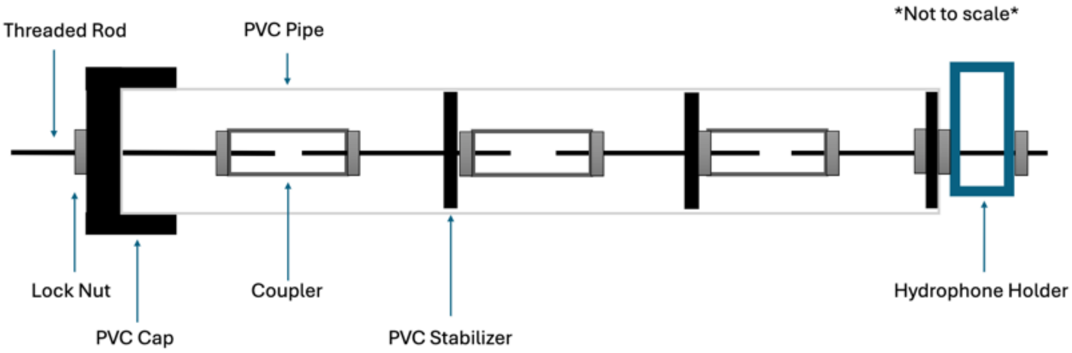

Figure 3: Schematic of hydrophone holder in the PVC pipe.

were positioned 9 ft 7 in (2.92 m) from the tank's acrylic wall in the guest view room and 11 ft 6 in (3.53 m) in the banquet hall. They were connected to a Crown XLS 1000 amplifier that received the signals from a laptop-based software program called Room EQ Wizard. (For additional details on the room setup, see the companion paper on room measurements.[?])

We conducted measurements during two trips. During the first trip (21 August 2024), hydrophones were placed at all ten positions as seen in Fig. 1. Hydrophones 1, 2, and 3 were connected to the Zoom H6 recorder closest to the LSS; hydrophones 4, 5, and 6 were connected to the Zoom H6 recorder above the wall of the banquet hall; and hydrophones 7, 8, 9, and 10 were connected to the recorder above the wall of guest view. All recorders operated at a sampling frequency of 48 kHz with the gain set to 5. This gain setting provided sufficient amplification without causing peak clipping from the acoustic signal. Signals were produced by two Mackie MR824 loudspeakers in the guest view room and the tunnel. Two types of signals were generated. First, we played white noise from the guest view room at nine different amplitudes, with signal durations ranging from 30 to 60 seconds. Next, we played logarithmic chirps covering 100–2000 Hz, a frequency range that includes and extends beyond the sharks' sensitive hearing range. Each chirp was repeated eight times at the same amplification level during a 45 seconds interval before the amplification was increased until reaching the aquarium's set sound level maximum (of 70 dBA measured on sound level meters near the acrylic). We increased the volume of the amplifier five times for the chirps produced in the guest view. In the tunnel, chirps were played at eight different amplitudes with fixed 30-second durations. Fewer trials were conducted in the tunnel due to time constraints.

On the second trip (7 April 2025), hydrophones were placed at positions 3–10 as seen in Fig. 1, omitting the tunnel side due to limited transmission observed in the first visit. With fewer hydrophones, we used only two Zoom H6 recorders, one above the guest view area and one above the banquet hall. We also increased the sampling frequency to 96 kHz. Sounds were produced by a single Mackie MR824 loudspeaker in the guest view room (at the same locations as the first trip) and the banquet hall. We introduced crowd noise, in place of white noise, to simulate typical visitor activity and repeated the chirp signal experiments using two frequency bands: 100–2000 Hz (as before) and an extended range of 500–4000 Hz. The same procedure of repeated chirps with incremental volume increases was followed, though the starting amplitudes were higher due to the use of a single speaker and the limited transmission noted previously.

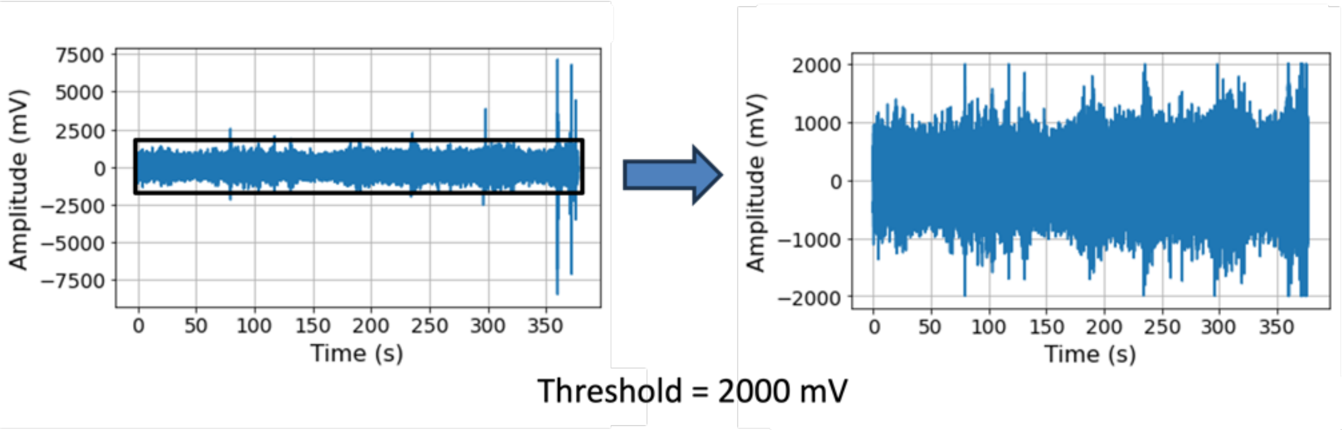

Figure 4: (Left) Example of an original waveform and (right) the clipped version using a threshold of 2000 mV.

D. SIGNAL PROCESSING

An initial quality check of the hydrophone signals revealed the need to apply peak clipping. Plots of the time waveforms contain some strong spikes caused from a hydrophone being hit by a shark or turtle. By examining the waveforms, we determined a threshold for clipping the signals and applied the `np.clip()` command in Python. An example of an original and clipped signal are shown in Fig. 4. The clipped waveforms were used for the one-third octave band processing, the calculation of overall sound pressure levels and spectrograms.

The overall sound pressure level (OAL) is calculated from the clipped signals after accounting for all portions of the measurement chain. First, the overall voltage level is calculated:

$$L_V = 20\log_{10}(|x(t)|/1\mathrm{V}) \tag{2}$$

The levels L_V in dB re 1 V are changed to units of dB re 1 μPa using the sensitivity of the the AS-1 hydrophone: sensitivity_dB $= -208$ dB re 1V/ μPa. The gains from the PA6 amplifier (preamp_gain_dB = 26 dB) and the added gain from the Zoom recorder, (setting_gain_dB = 46 dB from Table 1), are both removed. Thus, the overal sound pressure level (OAL) is calculated as

$$\mathrm{OAL} = L_V - \text{sensitivity\_dB} - \text{preamp\_gain\_dB} - \text{setting\_gain\_dB} \tag{3}$$

The one-third octave (OTO) band spectra for each clipped signal was computed. The OTO band processing was done using `PyOctaveBand`, a Python package available on GitHub[11] developed by Jose M. Requena Plens. While his original code returns OTO spectral levels re 20 μPa, we modified the code slightly to accept the reference as an input. Thus, our version returns the OTO spectral (voltage) levels L_V in dB re 1 V. The measurement chain components are accounted for to obtain the OTO sound pressure levels (SPL) in dB re 1 μPa:

$$\mathrm{SPL} = L_V - \text{sensitivity\_dB} - \text{preamp\_gain\_dB} - \text{setting\_gain\_dB} \tag{4}$$

Examples of SPL and OAL for the different types of signals at different locations around the tank are now presented. The variability in the corresponding spectrograms is also examined.

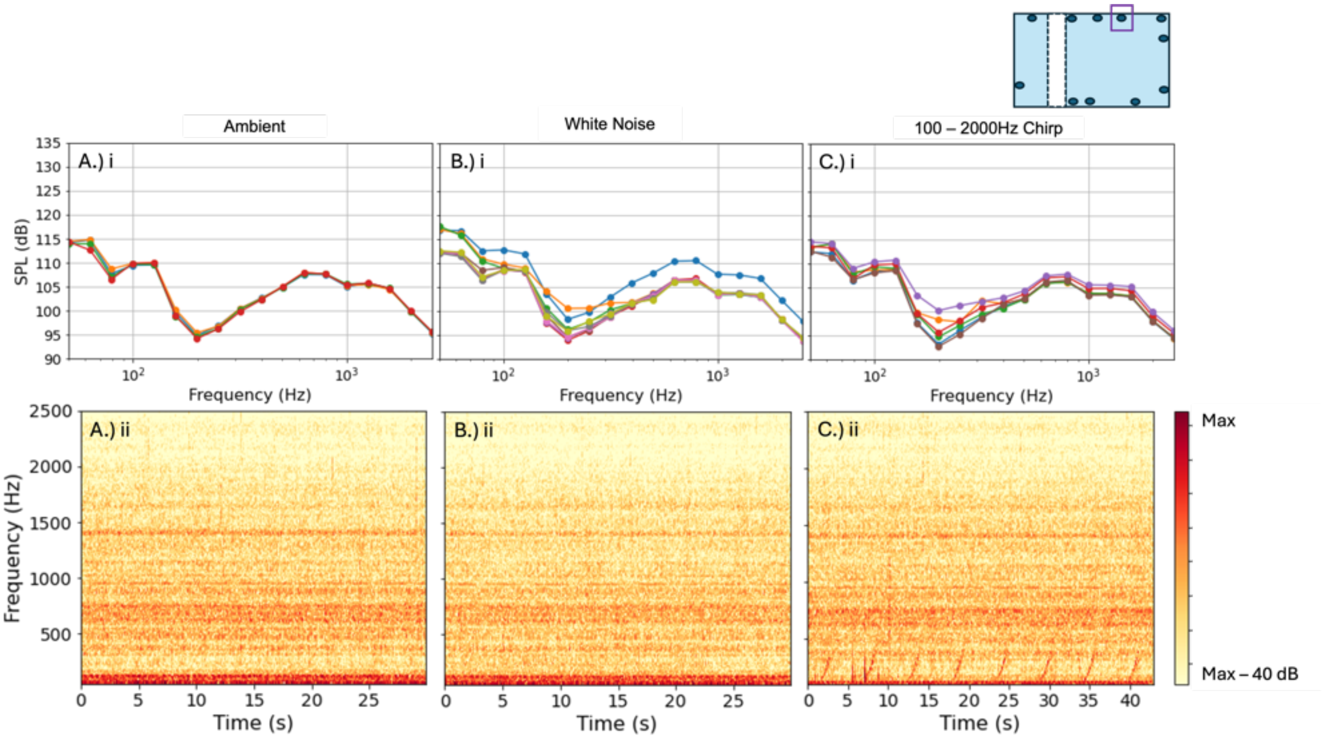

Figure 5: One-third octave band sound pressure levels and spectrograms of ambient, white noise, and chirps on hydrophone number 7 from day 1.

3. RESULTS

We recorded three types of signals: (1) ambient noise, (2) white noise or crowd noise, and (3) chirps. The levels at the different hydrophone locations are compared in this section.

As an example of the recordings, we plotted the OTO band SPL for ambient noise, white noise, and chirp signals. The first observation is that white noise signals, regardless of volume, did not exceed the ambient noise of the tank. In contrast, the chirps rose above the ambient noise, but only within certain frequency bands, such as 100–400 Hz. These are illustrated in Fig. 5 for the hydrophone at position 7 showing OTO band SPL (top) and spectrograms (bottom). Plots (A.i) and (A.ii) show the ambient noise in the tank. When compared to plots (B.i) and (B.ii), which represent the white noise transmission, there is only a slight difference in the OTO band SPL plots, and the spectrograms appear nearly identical. Additionally, there was no audible change in sound. In contrast, plots (C.i) and (C.ii), which represent the chirp transmission, show a clear difference: the OTO band SPL plots look similar, but the spectrogram displays distinct chirps in the 100 to 400 Hz band. These chirps were also clearly audible in this recording.

A. AMBIENT NOISE

We recorded the ambient noise on all ten hydrophones in the tank on day 1. The OTO band SPL plots are shown in Fig. 6. To help evaluate the spatial context for the distribution of the ambient noise, the SPL plots are positioned around a schematic of the tank.

As seen in Fig. 6, ambient noise levels increased as the hydrophone moved closer to the LSS. In

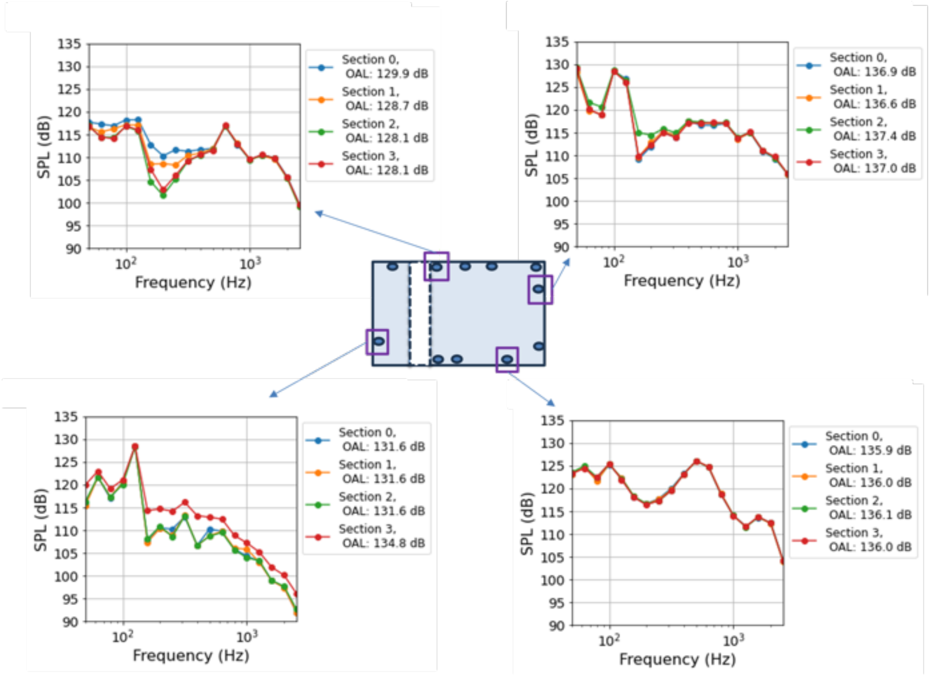

Figure 6: One-third octave band sound pressure levels of four recordings (or sections) of ambient noise at four different locations around the tank from day 1.

other words, overall noise became higher near the LSS. Since the LSS generates significant noise, we expected a result like the one observed.

Four samples of the ambient noise are shown at each location in Fig. 6 to evaluated the temporal variability of the ambient noise. Overall the ambient noise levels are steady in time, except along the front of the tank where the fish and sharks are more likely to swim and bump the hydrophones. The clipping decribed in Sec. 2.4 helps reduce some but not all of this effect, which leads to a few sections having higher levels than others.

B. WHITE NOISE

On day 1, a series of white noise signals with increasing levels as described in Sec. 2.3. Sound level meters in the rooms monitored the levels; the loudest sounds were approximately 70 dBA, which is the level advised by the aquarium.[?]

The hydrophone recordings while white noise is played show that the transfer of white noise signals into the shark tank do not exceed the ambient levels, as in the example in Fig. 5(A and B). Plots of the ambient noise in the tank and the plot of the white noise playing look almost identical. Careful listening of the hydrophone signals also confirmed the lack of any audible change when the white noise signals were played. Similarly, crowd noise played on day 2 did not exceed the ambient noise level and was not audibly detectable in the hydrophone recordings.

C. CHIRPS

We generated chirps as the second type of signal in the guest view room, banquet hall and tunnel. On both days, a set of logarithmic chirps at different levels were played for the 100 to 2000

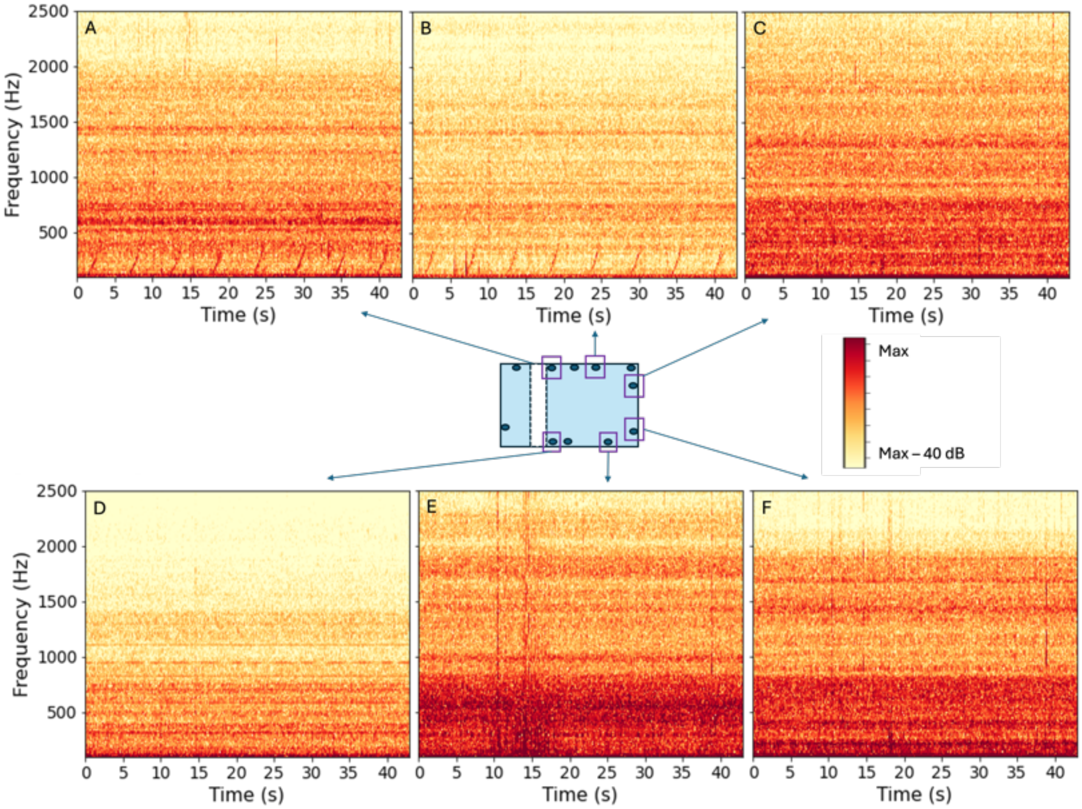

Figure 7: Spectrograms of the 100-2000 Hz chirp signal played in guest view room as indicated by the tank diagram, day 1 - highest level chirp.

Hz band, and on day 2, a second set of chirps was played that covered the 500 to 4000 Hz band. As described in Sec. 2.3, each recording consisted of 8 chirps, each lasting a total of 30 seconds. We played chirps at 5 different amplitudes, increasing the amplitude sequentially until the sound level meters read 70 dBA. Careful listening to the hydrophone recordings revealed that chirps were detectable at locations closest to the signal source. This is also shown in Figs. 7, 8, 9, and 10.

For the guest view room, the effectiveness of sound transmission through the acrylic wall varied depended on frequency. The spectrograms recorded when the sound source was placed in the guest viewing room can be seen in Figs. 7 and 8. In both figures, hydrophones near the guest view room (plots (A) and (B)) indicate that some of the signal transmitted through the acrylic and into the water. Interestingly, for the low-frequency chirp ranging from 100–2000 Hz, only the lower portion of the band (approximately 100–400 Hz) transmitted effectively through the acrylic. In contrast, the entire frequency range of the 500–4000 Hz chirp is visible in plots (A) and (B) of Fig. 8.

The spectrograms recorded when the sound source was positioned in the banquet hall showed similar results. Specifically signal transmission was primarily detected at the hydrophone positioned closest to the acrylic. In Figs. 9 and 10, the signal is visible only in plots (C) and (F). An important observation when comparing the banquet room signals to those from the guest viewing room is that the transmitted signals are less noticeable in the spectrograms from the banquet room. This difference may be due to the use of only one speaker in the banquet hall, as opposed to two

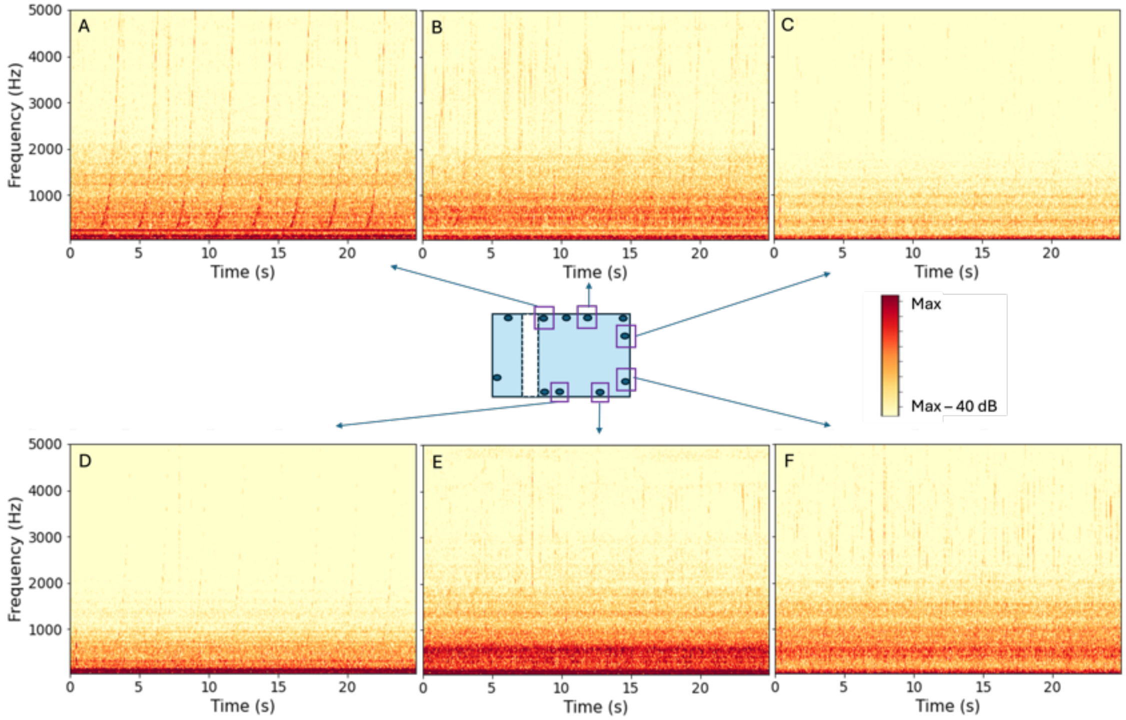

Figure 8: Spectrograms of the 500-4000 Hz chirp signal played in guest view room as indicated by the tank diagram, day 2 - highest level chirp.

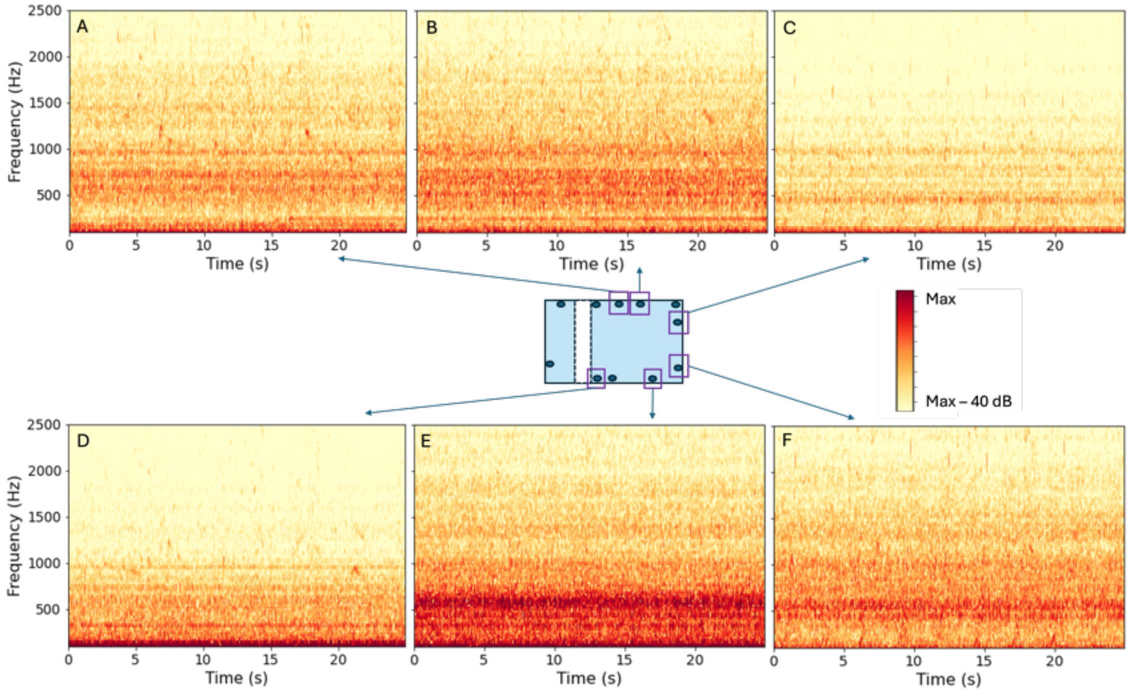

Figure 9: Spectrograms of the 100-2000 Hz chirp signal played in banquet hall as indicated by the tank diagram, day 2 - highest level chirp.

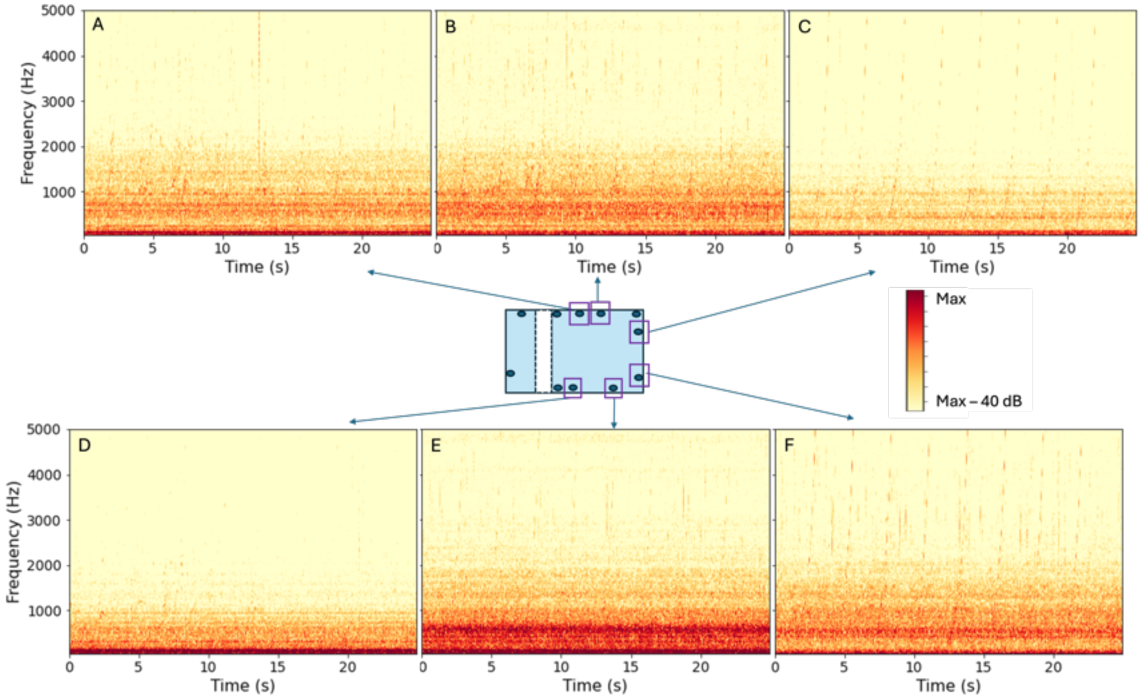

Figure 10: Spectrograms of the 500-4000 Hz chirp signal played in banquet hall as indicated by the tank diagram, day 2 - highest level chirp.

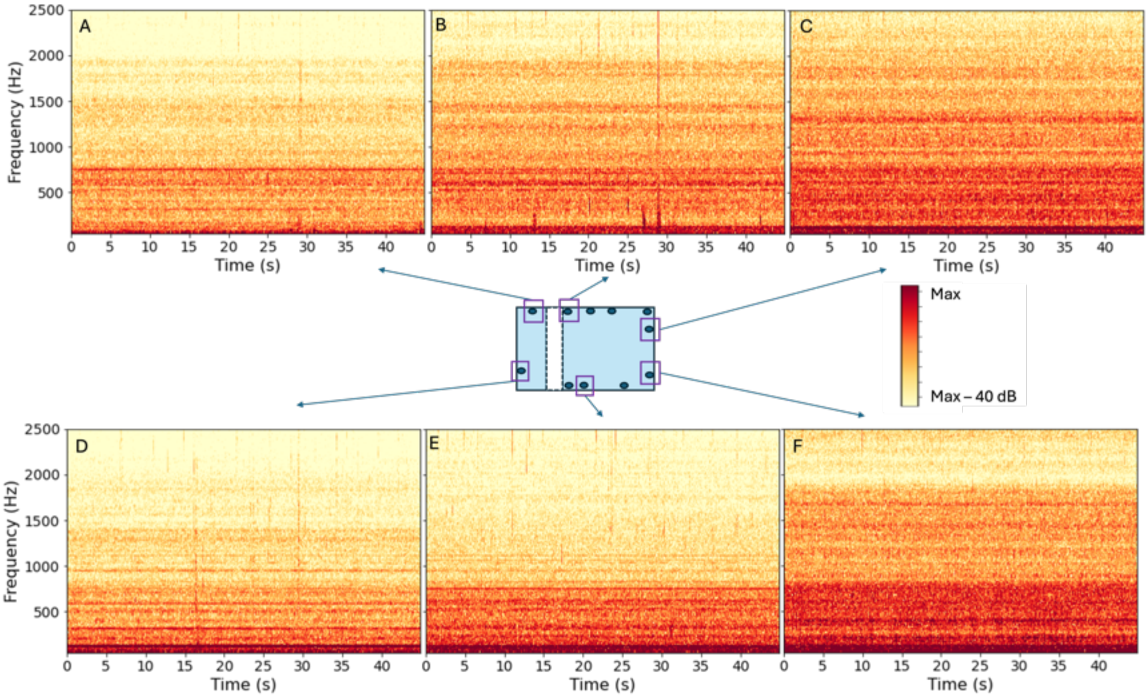

Figure 11: Spectrograms of the 100-2000 Hz chirp signal played in tunnel as indicated by the tank diagram, day 1 - highest level chirp.

in the guest viewing room, or it could indicate inherently weaker transmission from that location.

The pattern of detectable transmission to the nearest hydrophones did not hold when the signal originated in the tunnel. These recordings contained no audible chirps, and the spectrograms in Fig. 11 show no signs of signal transmission at any hydrophone position. This lack of transmission could be due to the shape of the tunnel, which may have caused increased reflections and reduced transmission through the acrylic into the water. The acrylic tunnel wall likely caused additional attenuation because it is thicker and varies in thickness compared to the flat walls in the other rooms.

4. CONCLUSION

This project has investigated how sound transmits into a large aquarium shark tank. We now have a better understanding of sound levels within the tank and the areas that are louder than others. All recordings showed that the ambient noise is loudest near the back wall, where the life support system (LSS) is located. Our findings indicate that white noise and crowd noise signals played in public spaces do not differ significantly from the ambient noise levels in the tank. This lack of transmission results from a combination of absorption by the tank's thick acrylic walls and masking by the overall ambient noise.

Recordings of chirps differed from white noise by exceeding the ambient noise levels in certain areas of the tank. We detected chirps only when the source played in the guest viewing room or the banquet hall; none of the hydrophones recorded chirps when the signal originated in the tunnel. Additionally, hydrophones positioned along the wall of the room where the sound was played detected the chirps, while those at other locations did not. This pattern suggests that the sound attenuated before reaching these locations, becoming masked by the ambient noise.

Two logarithmic chirps for different frequency bands produced different transmission results. For the lower frequency band (100–2000 Hz), the hydrophones recorded only the lowest frequencies (100-400 Hz) when played in the guest viewing room as seen in Fig. 7. In contrast, when played in the banquet hall, nearly the entire frequency range appeared in the spectrogram (see Fig.9(C)), although the signal was much fainter and appeared as dashed rather than solid lines.

For the higher frequency band (500–4000 Hz), the entire range appeared clearly in the guest viewing room spectrograms (Fig.8(A), and partially in plot (B)). When played in the banquet hall, the signal remained visible but followed a similar faint, dashed pattern as the lower frequency band (compare Fig. 9(C) with Fig. 10(C)). Both signals were noticeably weaker and more fragmented in the banquet hall compared to the clearer transmission in the guest viewing room.

This study demonstrates that sound transmission into the shark tank varies significantly depending on the type of signal, its frequency, and the source location. These results give us a better foundation to explore more about sound transmission into aquarium tanks.

5. ACKNOWLEDGMENTS

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