Examination of killer whale (*Orcinus orca*) call duration changes to boat noise and vessel presence

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Introduction:

Southern resident killer whales (SRKW) were listed as endangered, on November 18, 2005 under, the Endangered Species Act (NMFS, 2008). This animal has been an icon to many people, including scientists, whale watchers, Indian tribes, and others around the world, especially in the Pacific Northwest (NMFS, 2008). Many people around the world come to see these amazing creatures (Hoyt, 2003). Because of that the whale watching industry increased as a result of tourism demand, which lead to more companies sending their boats out to sea (Hoyt, 2003). Not only did the whale watching industry grow, but also in the past few decades' commercial ships, ferries, and recreational boating have increased as well, including in the Pacific Northwest region (NMFS, 2008).

There are more vessels out at sea, which increase the chance of harming the SRKW (NMFS, 2008). With an increase number of vessels out at sea, it creates additional noise for the SRKW to deal with. In an experiment done by Veirs & Veirs (2005) they calculated that average sound pressure level (SPL) in Haro Strait has a frequency band of 0.1 – 15-kilohertz (kHz) (Veirs & Veirs, 2005). Then another experiment done by Szymanski et al (1999) about killer whales hearing audibility, their hearing range is from 18 and 42 kHz, and then 20 kHz is the most sensitive frequency (Szymanski et al, 1999). If too much boat noise is being made, the SRKW will not be

able to detect any calls because they won't hear it.

The SRKW use sound as a primary source of communication with each other (Richardson et al, 1995). This extra human made noise has the potential to interrupt their normal activities, like foraging, resting, traveling, milling, and playing. These noises may also prevent the SRKW from the detection of important sounds (Richardson et al, 1995). In an experiment done by Ford (1989), he classified three different types of killer whale sounds: clicks, whistles, and pulsed calls (Ford, 1989). Clicks are a brief pulse of sound generally used during echolocation (Ford, 1989). Whistles are characterized as non-pulsed or a continuous waveform (Ford, 1989). Then a pulsed call is the most abundant and characterized class of vocalization used by the killer whales (Ford, 1989). This means that each call has different lengths and harmonics, making each pulsed call unique. If any of these sounds are masked by boat noise, then behavior shifts and communication is lost between each of the killer whales.

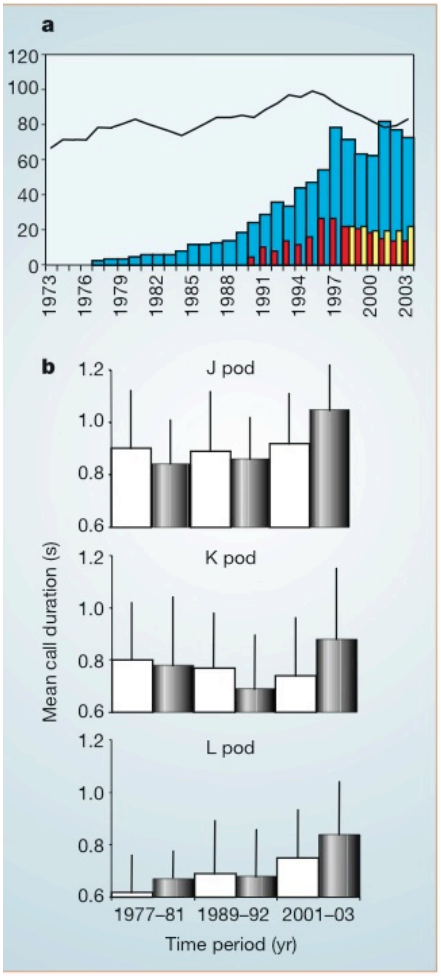


Figure 1: Andrew Foote historical analysis of the whale watching industry from 1973-2003 (a). Then the mean call duration versus time period for each pod (b).

An analysis of historical data done by Foote et al (2004) compared recordings in the presence and absence of boat noise during the time period of 1977-1981, 1989-1992, and 2001-2003 (Foote et al, 2004). They found out that there was a small but significant increase in call duration that correlates with the

increasing size of the whale watching industry over these years (Foote et al, 2004). Figure 1 shows the whale and boat numbers in part A (Foote et al, 2004). The solid line is the whale population, the blue bar is the number of active boats per year, red is the average number of boats following the whales per year, and the yellow is the average number of vessels following the whales per year (Foote et al, 2004). Then part B is the call duration of the three pods that are separated by each time period of study and the presence of boats in black and without the presence of boats in white (Foote et al, 2004).

In another study done by Holt et al measured call amplitude in response to vessel noise (Holt et al, 2008). They learned while doing their experiment that there is a positive correlation between call source level and background noise (Holt et al, 2008). As well as killer whales increasing their call source level by one decibel (dB) as the background noise levels increase by one dB (Holt et al, 2008). Another thing that they observed was that whales did not significantly adjust their call duration as background noise increases (Holt et al, 2008). Their results were the exact opposite as Foote et al (2004) experiment. Holt et al (2008) mentions that their different results could have come from difference in methods and the data collection (Holt et al, 2008). They measured the background noise while Foote et al (2004) counted boats.

Many people go to great lengths to view these amazing creatures. A method of continuously viewing killer whales up close is called leapfrogging (Williams et al, 2002). Leapfrogging is when a vessel speeds parallel to the orcas and cuts them off to view them directly in their path and the killer whales have to go around them, then this process gets repeated several times (Williams et al, 2002). Williams et al (2002) conducted a controlled experiment to test the responses of male killer whales to leapfrogging vessels

(Williams et al, 2002). They set up land base stations to view the orcas without any disturbances and recorded their behaviors (Williams et al, 2002). Once that step was done, they called in a vessel to 'leapfrog' the orcas and kept on repeating the process three more times (Williams et al, 2002). After all the data was collected they found out that with the vessels around, the orcas would avoid the vessels and created a new path (Williams et al, 2002). This then affected the direction they were going which interrupts the killer whales behaviors like foraging (Williams et al, 2002).

Another study, done by Erbe (2002), tested the underwater noise produced by whale-watching boats conducted in the Haro Strait, first in Victoria from June1-4, 1999 and then in the San Juan Islands from June 8-10 and August 30,1999 (Erbe, 2002). She recorded the first tour operation at 8:30 am and all the rest that follows until 6pm outside of Victoria Harbor (Erbe, 2002). Then binoculars and photographs identified each whale watching boat and a radar gun measured the speed of each boat (Erbe, 2002). Then the same was done at San Juan Islands (Erbe, 2002). At each location four different noises were recorded: single whale watching boat, the whale watching boats around the whales, the sounds from the killer whales, and ambient noise (Erbe, 2002). What this study found out is that the whale watching industry are aware of the guidelines when around the whales, it is the private owners that make the most noise because they are unaware of the guidelines (Erbe, 2002).

The more vessels appear in the waters the more killer whales tend to move towards open water (Jelinski et al, 2002). In an experiment done by Jelinski et al (2002), analyzing the interactions between killer whales and recreational whale-watching boats using geostatistics discovered that most vessels except for kayaks and small pleasure sails

demonstrated that they were intentionally tracking the orcas and where they were going (Jelinski et al, 2002). The area of study was a reserve created by Sir John Henry Creek in Johnston Strait in coastal British Columbia, Canada, which is 1248 hectare (ha) (Jelinski et al, 2002). This includes a marine and land reserve (Jelinski et al, 2002). The boundary extended 1km offshore on each side, and the researchers created a 200 m buffer zone incase people did not see the signs which were only posted on land (Jelinski et al, 2002). They discovered that more people did not care about the boundaries or guidelines. The vessels dominated both sides of the shore just so the people can get a great view of the killer whales (Jelinski et al, 2002). The killer whales tend to use tactics to escape the mass number of vessels, like maneuvering the boats to avoid contact (Williams et al, 2007). If too many vessels are around, they stop and just rest in one location (Williams et al, 2007). The rules need to be learned and understood by private boaters before they go on the water and view the SRKW. If not too much noise will be made, behaviors will be interrupted, and the call duration will be extended. All of these factors add stress to the SRKW.

Problem Statement:

Many people do not realize that different vessels that try to view the icon of the Pacific Northwest may hurt and endanger the lives of the Southern Resident Killer Whales (SRKW) by not following the guidelines and coming too close. It is mainly private boats that do not realize that they damage the SRKW the most with the noise of their engines and the fact that they do not know or follow the rules and regulations about observing the whales (Erbe, 2002). As summer gets closer, more vessels come to view the orcas and it makes it harder for the orcas to function because it affects the orcas call

duration. If too many boats are around it is going to take more effort for them to communicate with each other. Most of their behaviors involve them working together. We need to see how many boats it does take to affect their behavior and what behavior it does effect. Even though Holt et all (2008) and Foote at al (2004) searched for a call duration affect, it is beneficial for me to repeat it because these two studies found different results and it is worthwhile repeating the study so it can determine which one is correct. By the fact that I am counting boats, measuring the SRKW call duration, and measuring boat noise this makes my study a combination of Foote et al (2004) and Holt et al (2008). More behavioral information is needed in order to understand the SRKW. Once we understand these amazing animals, then it will be our job to pass on the information to the general public informing the private boaters of the risk. I want to help improve the guidelines to help preserve these creatures so many more generations can witness these amazing marine mammals.

Methods:

For this research project the data was collected on the Gato Verde, a 42-foot long catamaran sailboat, from April 19, 2009 through May 3, 2009 and then from May 10, 2009 through May 31, 2009. A linear Lab Core Array with 10 meters seperating each hydrophone with four in total was used to listen to the SRKW. Then a Sound Device 702 was used to record the Southern Resident killer whales. A 4.5-kilogram weight was used to stabilize and keep the hydrophone under the water.

I analyzed call duration with these recording from the Sound Device 702 and used the computer program audacity to analyze them. When I analyzed the calls I was looking for the S1 call because each call type will vary in duration. I was only looking at the most

commonly heard call. Then I was using the sound analysis software, Audacity to view the call by making it fit vertically to fill the screen in order to see each call better. Then I turned the sound file into a spectrogram format to improve my view of each call. In order to reduce the masking effects or boats noise from each call I used the hydrophone furthest away from our boat to analyze the call duration. Then if I still had problems I had a trial and error process to view each of the calls when they were masked. I first listened to the call to hear and get a good sense of it. Secondly I highlight the section of the spectrogram where I believed the entire call is. Third I listened to the highlighted area and make sure I heard the entire call. Fourth, I adjust the length of the highlighted section to make it either longer or shorter in order to just get the call. Lastly, I cut out the call and listened to what was left to make sure I did not have any part of the call. Then I just altered the cut, checked my work, and then recorded the duration of the call.

With each of the recordings I also measured the background noise. After I measured the duration of the S1 call, I took a second long clip right before the call and exported it. This was done in order to create a sound file of the background noise by its self. Sometimes the calls were so frequent I only took a second in one minute to measure the background noise. Dr. Jason Wood has created a function for me to use in Matlab to calculate the broadband dBrms re 1μPa. This function needs the channel, the sensitivity, the start time, and the duration along with the sound files and the function properties in order for it to calculate the broadband dBrms re 1μPa.

Besides the recordings I also created a data sheet in Excel to record the vessel count and the behaviors of the SRKW. As a group we collected the data together by having three different data sheets that consisted of: boat count, clicks and calls, and behavior. A

vessel count was recorded every five minutes and every time the behavior changes I will recorded the change and the current elapsed time. I recorded the behavior change every time it changes because I correlated the behavior change with the call. I am using the behavior characteristics that were decided at the Southern Resident Killer Whale Behavioral Workshop in 2004 sponsored by National Oceanic and Atmospheric Administration (NOAA). The behavioral states that were defined during this workshop are: resting, traveling, foraging, play, and milling (NOAA, 2004). Resting is when the SRKW are in a flank or non-linear formation, directional, a tight distance between each other, and at a slow speed (NOAA, 2004). Traveling is when the SRKS are directional and moving at any speed (NOAA, 2004). Foraging was difficult to define by just looking at the surface, so it could be many things like flank or nonlinear, directional or non-directional, tight or spread out distance between each other, and any speed (NOAA, 2004). Play is another behavior with any combination of the different categories that SRKW can do, but there are different specific types of play: objects, interaction, and solitary (NOAA, 2004). Finally, the last characteristic is milling and it s a repeated, non-linear, non-directional and any speed (NOAA, 2004).

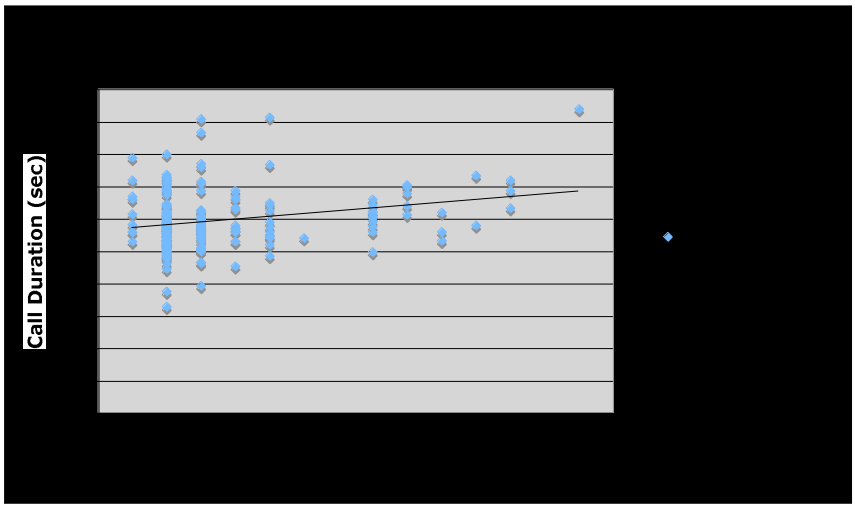
When the research was completed I compared the duration of the S1 call with each of the behavior to see if calls need to be longer when doing different activities. Then I am going to analyzed the number of vessels with call duration as well as see if there are longer calls with more vessels in the water. In addition, I compared the call duration to the boat noise. I also compared the vessel count to the boat noise to see if there was a correlation between the two. All of these comparisons were analyzed through a linear regression and reported the following: the r-squared, the equation, the p-value, the mean,

the standard error, and the 95% confidence level. All of these comparisons were analyzed by each behavior and as a whole. I also ran a non-parametric test called the Mann Whitney U test because that is the same statistical analysis Foote et al (2004) ran during their study. Foote et al (2004), found out that all the calls of these pods were found to be longer with the increasing presence of boats (Foote et al, 2004). Those findings contradicted those of Holt et al (2008) who found out that the SRKW did not increase the duration with the increasing number of boats (Holt et al, 2008). My experiment consisted of a combination of both experiments. We also had the chance to be the only boat out in the water and got recordings of S1 calls during that time. Even though we were on the water, the Gato Verde is so quiet, we assumed that Foote et al (2004) would not hear us while listening to his historical recordings. Assuming that the longer calls add more stress to the SRKW, with this data I wanted to see if more vessels around the SRKW adds more stress to them. With the number of vessels around and boat noise the SRKW it will increase their stress by different behavior changes and longer calls.

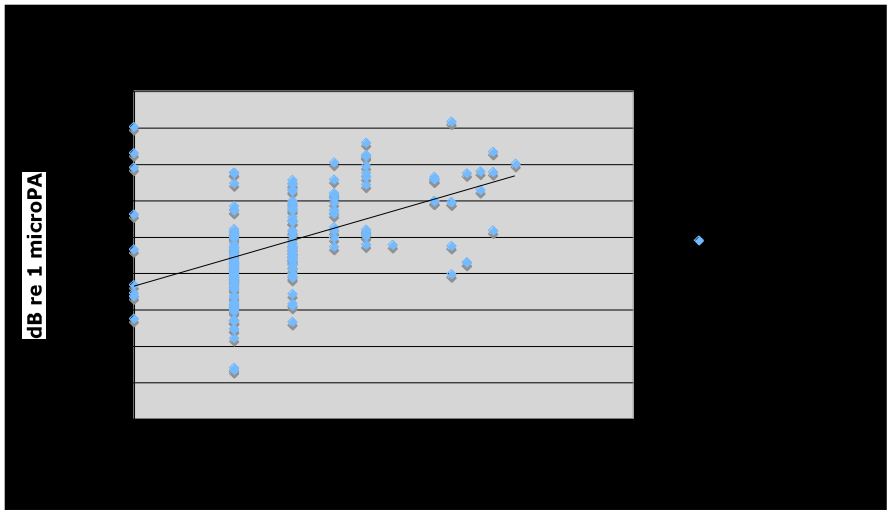
Results

After all the S1 calls were analyzed I had a total sample size of 181 with a mean of call duration of 1.18 seconds with a standard error of 0.0138 and a 95% confidence interval of 0.0268. I compiled all my information in to a spreadsheet and ran a Linear Regression. I found out that there was significance between call duration versus vessel count and vessel count versus boat noise, but found no significance in call duration versus boat noise.

Graph 1: Linear Regression for Call Duration VS Vessel Count. Includes all behaviors with a sample size of 181 and a p-value of 0.000718.



Graph 1 shows the comparison between call duration versus vessel count for all of the behaviors. When I ran the linear regression test I discovered that there is a positive correlation between the two, but the r-squared was only six percent. This means that the line only explains 6% of variance in the data. Then I calculated a p-value to show any significance between call duration versus vessel count and I got 0.000718. This number shows great significance because in order for a p-value to show any significance it has to be lower than 0.05.



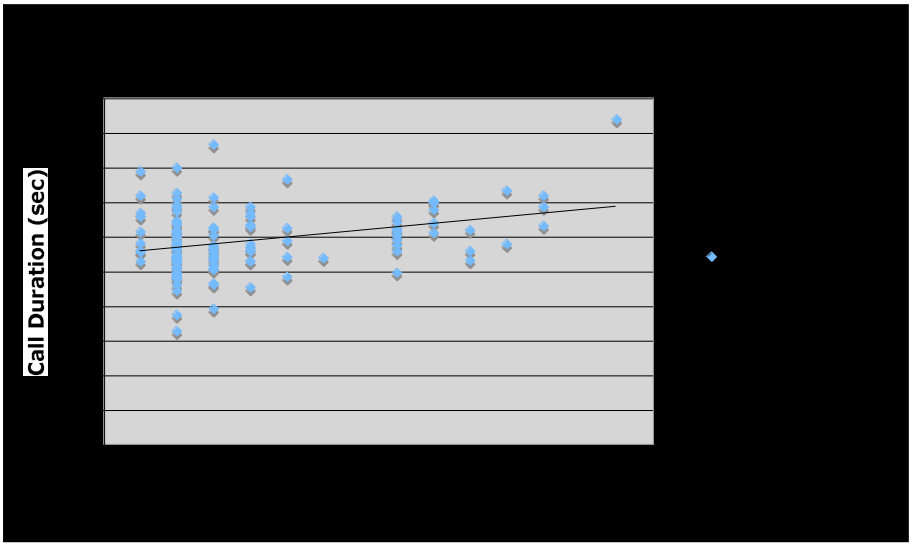
Graph 2: A linear regression for all the behaviors with a sample size of 181 and a p-vallue < 0,001

Graph 2 shows the comparison between vessel count and boat noise. Before I did

the linear regression I log transformed the vessel count because the boat noise is already in a log transform by transforming the vessel count it makes it easier to compare. This was also beneficial because it was what Marla Holt did to her vessel count in her study. This linear regression shows a positive correlation between the vessel count and boat noise with an r-squared of 24%. The p-value was less than 0.001 which turned out to be a very low number showing a great significance between vessel count and boat noise.

After having all the behaviors together I split them up by individual behavior and did the linear regression for call duration versus boat noise and call duration versus vessel count. I only got three different behaviors out of the five with S1 calls during my analysis and they were: traveling, foraging, and play. I discovered that there was significance for both call duration versus vessel count and call duration versus boat noise in traveling, but neither in foraging nor play.

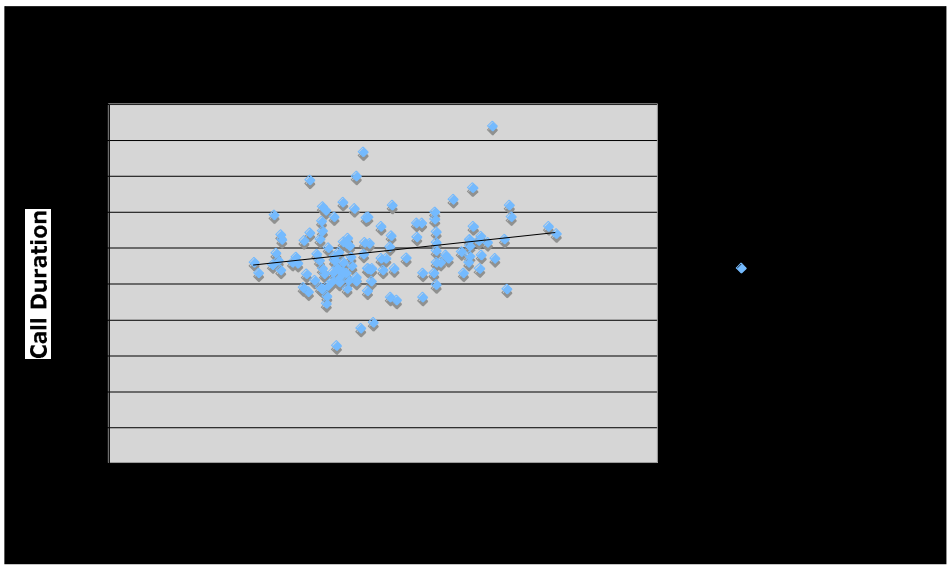
For traveling I got a sample size of 127 with my mean call duration to be 1.17, my standard error to be 0.016, and my 95% confidence interval to be 0.0317. Graph 3 shows the linear regression for



Graph 3: Linear regression for Call Duration VS Vessel Count in traveling with a sample size of 127 and a p-value < 0.001.

traveling. The graph shows the linear regression for call duration versus vessel count, and it has a positive correlation with an r-squared for about 11 %. Then the p-value was less than 0.001, which shows that it has great significance between call duration and vessel count.

Graph 4 shows the linear regression between call duration and boat noise with a positive correlation and an r-squared with 5%. Then the p-value was 0.0153, which shows a good significance between call duration and boat noise. It was not as high of a significance as call duration and vessel count, but it still shows significance.



Graph 4: Linear Regression for Call duration VS Boat Noise for traveling with a sample size of 127 and p-vaue of 0.0153.

When I ran my linear regression for foraging I only had a sample size of 31. I got a neutral correlation between call duration and vessel count with an r-squared value that was not even one percent. The p-value showed no significance because it was above 0.05. Then when I ran the linear regression for call duration versus boat noise I got a negative correlation with an r-squared value of two percent. After I ran my p-value for this comparison and found no significance between the call duration and boat noise.

Then I ran my linear regression for my last behavior; play with a sample size of only 23. I got a positive correlation between call duration and vessel count with an r-squared of 11%. Yet when I found my p-value I got no significance between call duration and vessel count. Then I ran the linear regression between call duration and boat noise and negative correlation with an r-squared of 5%. Then I got my p-value still found no significance between call duration and boat noise.

Like Andrew Foote I ran a non-parametric test called Mann Whitney U with my results. I first ran the test with one boat compared to more than one boat and I found no significance in the results. I ran the test one more time with our boat and one other compared to three or more boats. I still found no significance in my results.

Discussion

I got very different, interesting, and varied results while doing my analysis. When I compared call duration vs. vessel count for all the behavior combined I got significance but it does not occur often. Then I did the same thing for call duration versus boat noise and found no significance and the r-squared was so low it was not even one percent. I thought it was the noise that would have bothered the SRKW and not the vessel because they do spend a lot of time under water. When they are underwater they are consistently hearing those engines around them. According to this data it is the presence of the boats that affect the SRKW more then the boat noise. Yet statistically since the r-squared is so low with only a six percent chance of that happening. It is not very high, but there is still a small chance of that vessel number could affect their call duration.

Like Holt et al (2008) I measured boat noise, and my results is what I thought it would be, their being a strong correlation between vessel count and back ground noise

with a r-squared value of 24%. To make the comparison easier I log transformed my vessel count, because boat noise already on a log scale. My range for the log of vessel count is from 0 to 1.5. Then Holt et al (2008) range of log and vessel count is from 0 to 1.8. Holt et al (2008) range of background noise is also greater than mine. Holt et al (2008) background noise range is from 95 to 125 dB re 1 μPa and my range of back background noise is from 110 to 128 dB re 1 μPa. Holt et al (2008) r-squared for background noise is 45%. Their higher background noise makes sense because they did their studies during the summer when I did mine during the spring. There is a dramatic difference in boats between each season because summer is the peak season for the San Juan Islands. Naturally it makes sense that their boat noise is greater than mine. What still puzzles me is the fact that they didn't find any significance between boat noise and call duration since I found some significance.

What made my experiment unique from Foote et al (2008) and Holt et al (2008) is my separation of call duration into the five behavior states that was classified by the NOAA Behavioral Workshop in 2004. I found significance in both vessel count and boat noise versus call duration during traveling. It could have been the sample size difference traveling had a sample size of 127 when Holt et al (2008) had a sample size of 104. By increase the sample size and splitting things into behavior there could be more significance between boat noise and vessel count versus call duration. If people in the future were to increase the sample size I think we could find more information and understand how and what it affects. I believe the only reason why I didn't find significance in foraging and playing was because the sample size was so small. I got a sample size of 31 for foraging and a sample size of 27 for playing. I believe if we found

more S1 calls during those behaviors and find S1 calls for milling and resting. It was a struggle this year just to encounter them when they were actually calling. From what I heard they were extra silent this year than of past years.

Another factor that could contribute to the difference of significance during each of the behaviors is what the whales are doing during each of the behaviors. When the whales are traveling they are heading in a general direction and their surfacing is timed. If boats are in the way it could disrupt their communication and they are going to have to try and avoid boats that are right in front of them. Then when killer whales are foraging they are so focused on hunting fish, they could not care about what is around them. I believe the only way to prove this is by increasing the sample size and running the same statistics I did and comparing the results. It also depends on how much information and calls they receive. It may also help to increase the objects of study from just J pod to studying all three pods.

Foote et al (2004) was on the right path when he was trying to discover if the presence of boats affected the call duration of killer whales. I just took his experiment to the next level and was out on the water counting for boats instead of just listening for them. He started the bases for continuing this experiment. The only thing is along with the rest of my experiment I also copied his experiment and ran the Mann Whitney U test and found no significance. I think he was heading in the right direction by having a larger sample size, but I think it was the lack of physically being there that could have caused some disbelief. The only way to see who is truly correct is to continue my experiment and hope to increase the sample size in all the behaviors. I believe that the information I have discovered does not say if Foote et al (2004) or Holt et al (2008) is

correct. I do think that killer whales call duration does have an effect due to boat noise and call duration just because of the significance I found in traveling and call duration versus vessel count when all the behaviors were combined.

What my study has shown is there is a correlation between call duration and vessel count, but may only occur during certain behaviors. I believe that SRKW call duration is being effected in some way with the presence of boats. I also think that my experiment needs to be repeated in order to know for sure. It is important to know this information because the SRKW are endangered and we want to prevent any potential harm that maybe inflicted upon them. With my results there is not enough concrete evidence to make any reforms, but I do encourage people to watch and report others that are not being whale wise. It is also important to realize that killer whales are not the only marine mammals out there that could be affected by boat presence. Many other marine mammals get hit by boats and die. I do think once more information is found to reform the current regulations and protect not only killer whales, but also the other marine mammals that in habit the ocean with them.

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