Preferential habitat use in the San Juan Islands by Killer Whales based on call rate and bathymetry

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Introduction

Animals use communication to convey many signals such as alarm, individual identification or territorial defense (Magrath and Bennet 2012; Bradbury and Vehrencamp 1998; Sogge et al. 2003; Beletsky et al. 1980; and Nakahari and Miyazaki 2011). Their brains are constantly receiving and interpreting sounds to create the world they perceive around them. That is why so much research focuses on acoustics, and how it affects animals' success. Similar to other animals mentioned above like the scrub wren and bottlenose dolphin, killer whales, Orcinus Orca, are very acoustic animals. They rely on communication to maintain cohesion in their highly social pods (Au et al. 2004). These whales also hunt cooperatively in their pods and matrilines and must be able to communicate in order to be successful. Excessive amounts of background noise can easily disrupt communication. The Southern Resident killer whales of the Salish Sea in particular are threatened due to increasing noise pollution from boat traffic and other anthropogenic sources. Therefore, it is important to understand how these whales use their environment. Specifically, which areas are most critical for their ability to communicate if their population is to increase. This distinct population of killer whales is the focus of this paper due to their listing status of endangered in 2005, which was determined after a 17% decline in population size. (NOAA-NMFS 2008) In the recovery plan NOAA identified critical habitat that the Orcas use most often. In order to protect their habitat, more critical areas need to be identified and understood. (NOAA-NMFS 2008) Analyzing bathymetry and transmission loss and their affects on orca communication will help identify these critical areas.

Given its importance in aquatic environments it is important to understand how sound travels. Sound is attenuated much faster in air than it is in water. In the water, waves can spread in a spherical or cylindrical model (Jensen and Kuperman 193). Spherical spreading occurs in deep water and causes a wave to propagate out evenly in all directions like a sphere. Cylindrical spreading occurs in shallow waters where the wave bounces off the surface and the bottom of the ocean, which disrupts continuous propagation and creates a cylindrical shape (Jensen and Kuperman 1983). Spreading is often more complex and can result in a combination of spherical and cylindrical spreading (Erbe and Court 2011).

The type of spreading can also affect the amount of transmission loss. As a sound spreads out there is transmission loss between the source and the received sound levels. Since spherical spreading continues evenly in all directions, more sound energy is lost, whereas in cylindrical spreading sound is contained by the bottom or surface of the ocean and there is lower transmission loss (Erbe and Court 2011). To measure transmission loss (Erbe and Court 2011) use the sonar equation RL (received level)=SL (source level)-TL (transmission loss). This equation can be impacted by depth, bottom type, and speed of sound. All of these aspects are important when looking at animal communication because they all have the ability to affect the degree to which animals are able to communicate.

The landscape of an environment can really affect the way sound propagates, especially in the ocean. Transmission can vary greatly between locations especially in the San Juan Islands located in the Salish Sea. These islands are acoustically different due to the contrast between shallow muddy environments alongside deep fractured bedrock bottoms. The shallow water assumes cylindrical spreading, while deep water takes on spherical spreading, which makes for an acoustically interesting area for the Orcas. The areas of lower transmission loss could be beneficial to orca communication and in turn might be why the southern residents prefer the Salish Sea.

While the southern residents occupy the San Juan Islands, killer whales as a species, do occupy more regions in the world than any other dolphin species (Leatherwood and Dahlheim 1978). While there is only one recognized species of killer whale there are several ecotypes. (Ford et al. 1999) have identified three types, resident, transient, and offshore. They can be distinguished by both physical and behavioral characteristics such as foraging patterns, spatial distribution, saddle patch shape, and dorsal fin shape. However different individual populations may be, all killer whales communicate with unique pod-specific calls. Within each pod there are even distinct dialects shared among matrilines. There are 22 calls for the southern residents in general, with more calls identifying each individual pod and matriline (Ford 1987).

Based on the significant role communication plays in orca success it is important to understand how killer whales utilize their habitat as well as what might affect their ability to communicate and maintain pod cohesion. From what is known about the way sound travels and the bathymetry of the Salish Sea in conjunction with killer whale communication, Orcas will communicate with a higher call rate in locations with a lower transmission loss. Alternatively, Orcas may be communicating less frequently in areas with low transmission loss since they do not need to repeat their calls in order to be heard to compensate for a higher transmission loss. The goal of this paper is to measure sound speed profiles and characterize bathymetric types of the Southern Resident Killer Whales' most frequented locations based on (Hauser et al. 2007) and inversely locations they rarely frequent in order to understand if they are preferentially using specific locations based on ease of communication.

Methods

Data were collected from the 42' catamaran the Gato Verde and the dinghy the Ratoncito from late April to late May, 2012. Critical habitat areas have been identified from sightings maps by (Hauser et al. 2007) based on frequency of sightings and are as follows: salmon bank, west side of San Juan Island, and north of San Juan Island near Boundary Pass. For comparison, data was collected at sites less frequented by Orcas.

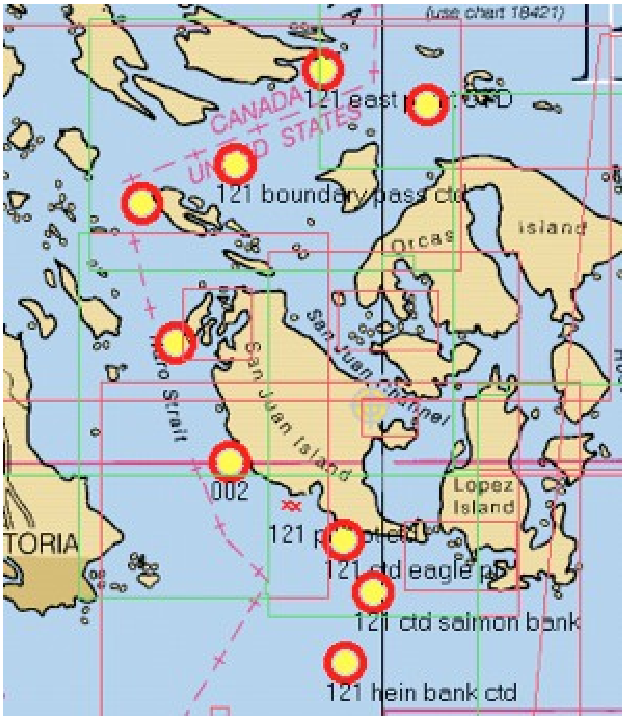

Figure 1: Chart of the San Juan Islands with labeled waypoints.

Acoustic Recordings

Acoustic data were recorded using dual time-synchronized recorders (Sound Devices 702 model). Sound was detected by a 4 hydrophone array to calculate call rate and an Interoceans System calibrated listening hydrophone (model 902). When whales were present the 4-hydrophone array was deployed behind the Gato while traveling at a speed no more than 2.4 knots to avoid flow noise from the boat throughout the encounter. Observations were recorded on both surface behavior and vocal behavior. The data was recorded on phonation sheets including the number of calls, the type of calls, number of clicks, and any additional comments regarding the recording. Once the sighting ended the hydrophone was stored away. The recordings from the encounters were listened to again later to ensure no vocalizations were missed.

Spreading Experiments

To analyze transmission loss variance between habitats, experiments were conducted to measure sound spreading. The calibrated hydrophone deployed from the Gato was used as a receiver and the speaker deployed from the Ratoncito as a sound source at distances of 1m, 10m, 50m, 100m, and 200m away from the single calibrated hydrophone. Distances were determined with a rangefinder from the Ratoncito. These distances were subject to change dependent on sea state and boat traffic.

The experiments were conducted using a Lubell underwater projector connected to an ipod playing tones of frequencies at 1000Hz, 3600 Hz, 5000 Hz, and 10,000 Hz. Once the hydrophone was deployed off the side of the boat, the speaker was also deployed, both at a depth of 5m as can be seen in figure 2. Using radios to communicate range and coordinate sound projection, the experiment was conducted for duration of 2 minutes, 30 seconds per tone.

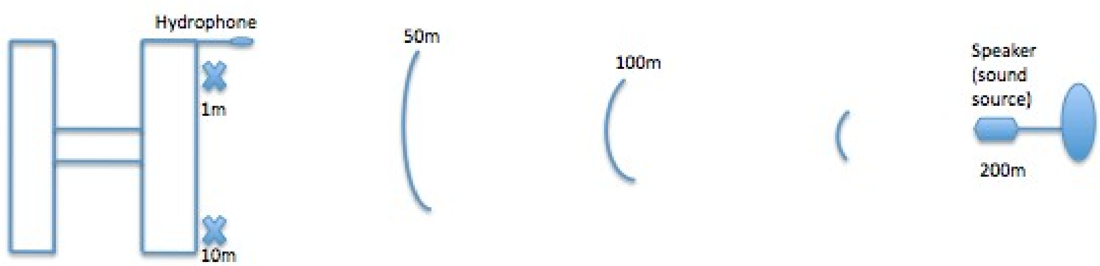

Figure 2: Diagram of spreading experiment set up. The hydrophone is deployed off of the starboard bow of the Gato Verde and the speaker is deployed off of the port side of the Ratoncito.

The frequencies were chosen because they represent the average peak intensity of most Southern Resident calls. The 1m trial was used to set the sound levels of both the ipod and the Lubell amplifier to ensure maximum volume without saturating the recording system. During recordings, gain settings were also changed to prevent saturation and optimize tone volume against background noise. After each gain setting change a calibrated tone was played for comparison in later analysis. Recordings were monitored on a MacBook Pro in Audacity. Watching the recording in a spectrogram form aided in correcting for saturation during a recording. Post recording analysis was also done in audacity by comparing the calibrated tone and the experimental tone to measure the contrast. Contrast was used to calculate the received level when subtracted from the gain setting on the interoceans system hydrophone.

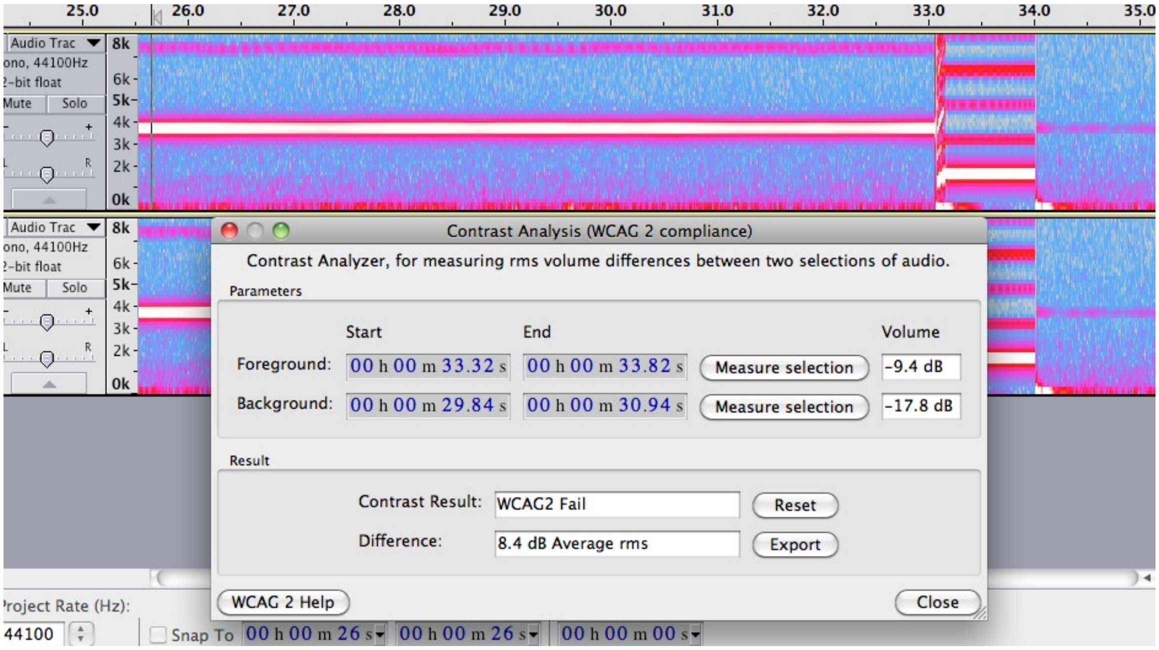

Figure 3: Screen shot of measuring contrast for calculating received level in Audacity.

CTD: Sound Speed Profiles

To measure the sound speed profile the SeaBird 9+/17+ CTD was deployed to understand the structure of the water. The CTD is a device that when deployed measures depth, conductivity, temperature, transmissivity, fluorescence levels, oxygen and a computed value for sound speed. Each cast when possible was deployed at 60m to compare to previous casts from archived data also deployed at 60m. The sound speed profile was used to average the speed that sound travels throughout the available depths in chosen locations.

Archived Data/ GPS Tracks

Actively collected data was not the sole focus of this study. In order to use archived data, all useful hydrophone recordings were correlated with GPS tracks of the boats movement using recorded times and coordinates in the science log. Useful hydrophone recordings are identified by location and amount of background noise. In order to understand and categorize the bathymetry type of each location where recordings were taken and analyzed GPS tracks were correlated with hydrophone recordings.

Bathmetry Category	Description
1	shallow and wide
2	shallow and narrow
3	deep and wide
4	deep and narrow

Table 1: Description of categories given to varying bathymetry types selected because of affect on sound spreading in the water

Archived data was collected from previous Beam Reach classes that did research similar to this. All recordings of whale encounters from 2011 were from archived data. These data were incorporated into the current data set to achieve more complete and accurate results.

This study analyzed the rate of all Southern Resident calls. Rate of calls will be determined by counting number of calls per minute and then averaging over the whole encounter. Time permitting, individual call use proportions will be calculated for all calls used during that encounter as well as general call rate for all calls together.

Results

From 990 minutes of hydrophone recordings calls were counted and compared to bathymetry, sound speed, site, and transmission loss resulting in a few significant relationships.

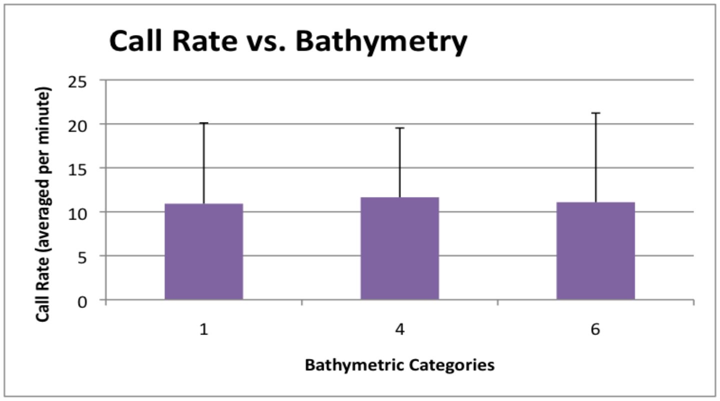

Figure 4: Call rate plotted against bathymetry type showing no significant difference in call rate between bathymetric types.

Call rate against bathymetry type in figure 4 shows no clear difference between bathymetry types and call rate. Statistical testing using a kruskal test a p-value of .3491 supports that there is no statistically significant difference between bathymetric types based on call rate. No literature supports these results, on the contrary (Erbe and Farmer 2000a) thought bathymetry affected communication enough to include it in their model on the effects of masking on orca communication. The model mentioned above comes from a paper by (Jensen et al. 1994). That study looked at how rays travel through the aquatic environment and found that they are shaped by bathymetry and sound speed.

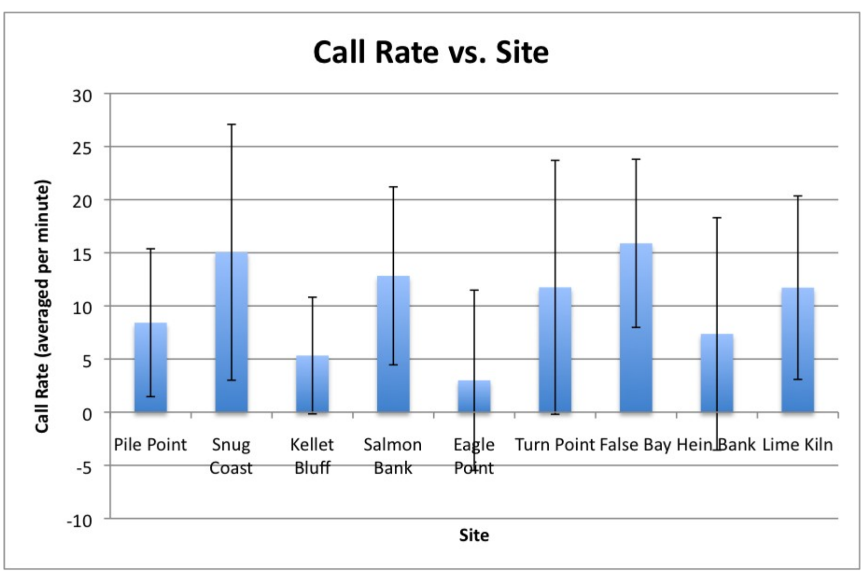

Figure 5: Call rate plotted against site to look at preferential habitat use by Orcas. No significant differences among sites.

Comparing call rate and site also illustrates the lack of significance of call rate and locality. The graph alone shows there are several sites indicating potential significance. False Bay, Kellet Bluff, and Eagle Point were statistically tested using a Kruskal test. Test results supported insignificance. False Bay and Kellet Bluff yielded a p-value of .4335 and Eagle Point and False Bay resulted in a .3173 p-value. Both values are not significant and cannot imply a difference between the sites.

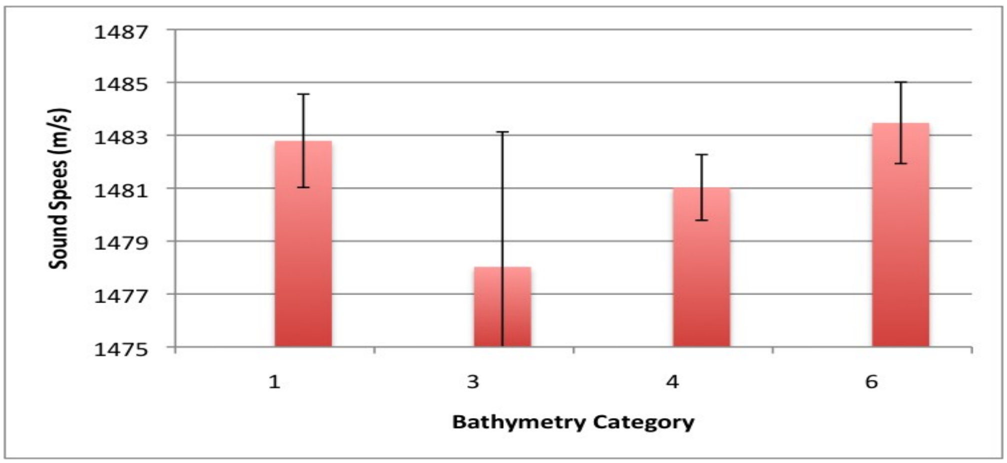

Figure 6: Plot of sound speed averaged per cast against bathymetric type. No visual evidence of statistical significance.

As demonstrated by figure 6 there is no significant difference due to overlapping standard deviation error bars between different bathymetry categories, but statistical testing found significance. The Kruskal-Wallis test yielded a p-value of .01029 indicating a significant difference among the bathymetric categories. Looking broadly at averaged sound speed per site against bathymetry type a Kruskal test also revealed a significant difference between sites with a p-value of .003604. In literature searches, no studies were found to support these results, which may be due to inconsistent sampling. CTD casts were not taken at the same time at each site. Since temperature and salinity change throughout the day these discrepancies may alter the results seen in this study, explaining the lack of literature support. Another Kruskal test was run to identify a relationship between time of day and speed of sound from CTD cast. The test showed no significant difference between times with a p-value of .419.

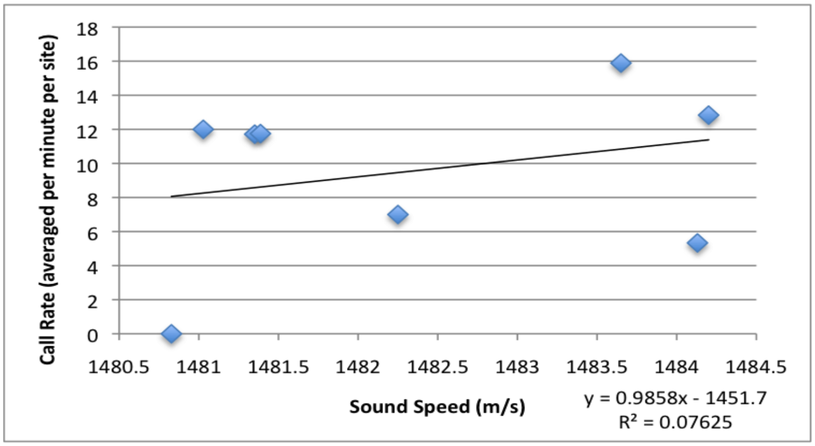

Figure 7: Linear regression of sound speed per site and average call rate per site.

The relationship between call rate and average cast sound speed was examined using a Kruskal test, which yielded a p-value of .4232 showing that there was no difference in call rates between different sound speeds. Looking at figure 7 it is also evident from the linear regression that there is no significant relationship between sound speed and call rate.

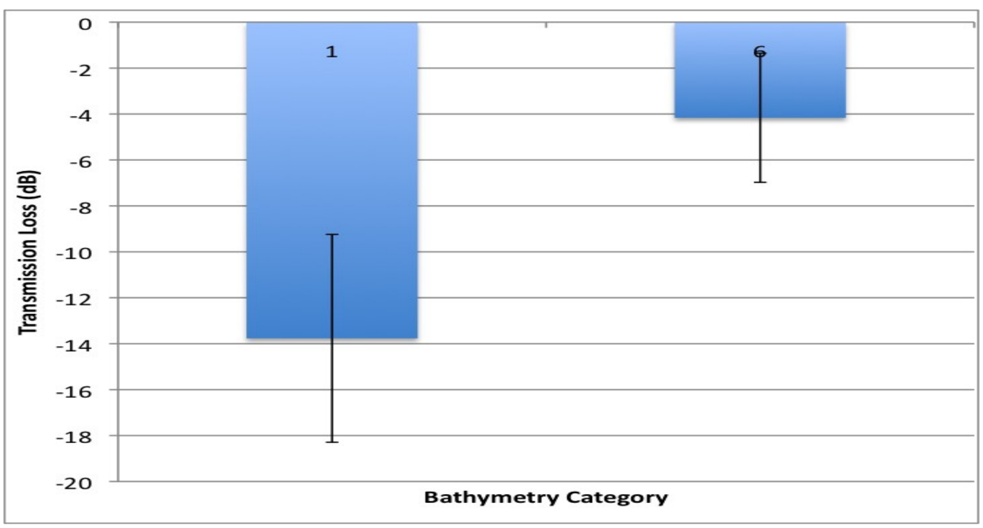

Figure 8: Transmission loss plotted against bathymetry. Significant difference between bathymetric types.

Another Kruskal test was run on transmission loss and bathymetry in an attempt to understand the driving factor between differences in sound speed. The test resulted in a p-value of 8.05e-16, which shows a significant difference between bathymetry types. Received level and bathymetry had a similar result when tested. The Kruskal test resulted in a p-value of 6.097e-8. Findings from this study are consistent with results from (Jensen et al. 1994) The result was called the Ray Theory and was also used in a study by (Erbe and Farmer 2000a) to model sound propagation in Haro Strait. (Erbe and Farmer 2000a) calculated transmission loss on the assumption that is was impacted by bathymetry. This study found significant results to support the comparison between bathymetry and transmission loss.

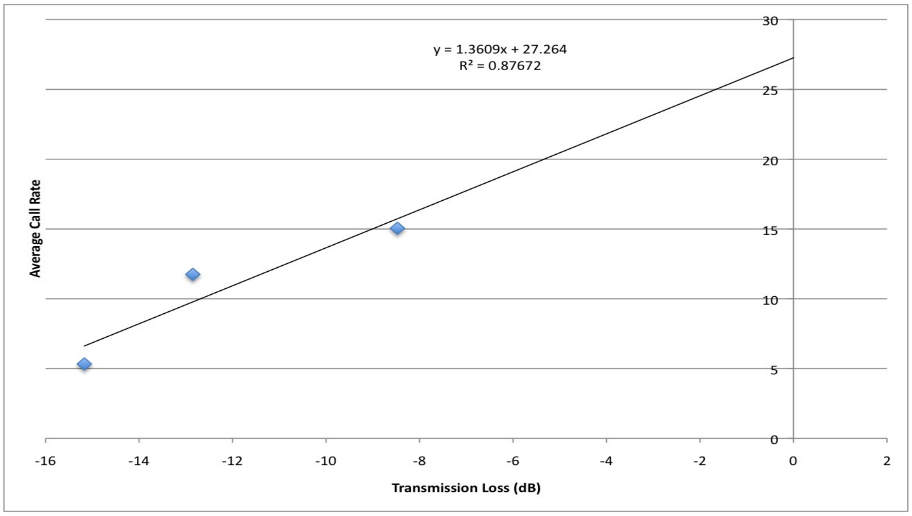

Figure 9: Regression of transmission loss against averaged call rate resulting in an R^2 of .876.

The plot of average call rate against transmission loss illustrates a potential linear relationship based on the .876 R^2 value from the linear regression. No statistical testing was done to verify relationship due to insufficient number of data points.

Discussion

From the data it is evident that there is no significant connection between call rate and bathymetry, sound speed or site. Looking at call rate and bathymetry it is clear from both the plot and statistical testing that there is no difference in call rate between bathymetric types. With more time data would be collected uniformly across the Salish Sea. Hydrophone recordings would also be analyzed from each bathymetric category for a more complete analysis and comparison. There is no significant difference in call rate between sites, but, since there were so few recordings analyzed, this data may not be painting the whole picture. There may in fact be a significant difference that is just not evident in this data.

Also, when analyzing the relationship between sound speed, averaged per cast, and bathymetry there seemed to be a difference. Statistical testing confirmed that there is a significant difference between sound speed and bathymetry. Sound speed, averaged per site, was statistically compared to bathymetry and also yielded significant results. So it can be inferred from these result that while bathymetry does not seem to factor into call rate, it does play a part in altering sound speed. Again, it would be preferable to have more data and in the future more data would be collected to strengthen the results. However, when sound speed averaged per cast was compared to time in an attempt to make a connection between the speed of sound and time of day, the results were insignificant. The reasoning behind that comparison was that maybe the aspects of the water column that changed from night to day could influence the sound speed profile, and therefore affect Orcas' use of the Salish Sea temporally as opposed to spatially. From the insignificant results it seems unlikely that this is the case. Since there was a significant result from the comparison of sound speed to bathymetry, sound speed was also tested against call rate using a linear regression and a kruskal test, Both tests yielded insignificant results meaning that sound speed does not have a measureable affect on the rate at which Orcas communicate.

In order to understand what was driving transmission loss, the averaged transmission loss per site was compared to bathymetry in a plot and a kruskal test and both resulted in a significant difference in transmission loss between bathymetry types. This suggests that bathymetry type greatly influences how sound is lost in an environment, both depth and bottom type could be factors since the two were not differentiated in this project. Given more time, depth and bottom type would be treated as two separate variables in order to understand which has a greater effect on transmission loss. As a means of double-checking results, received level was also compared to bathymetric type and that test also resulted in a significant difference.

After organizing data into tables, a trend was identified in one of the summary tables.

Site	**Bathymetry**	**Avg TL**	**Avg Sound**	**Avg Call**

			Speed	Rate
Kellet Bluff	1	-15.17	1484.14	5.33
Turn Point	1	-12.85	1481.39	11.75
Snug Harbor	6	-8.473	-	15.05

Table 1: Summary of averaged transmission loss, sound speed and call rate at sites where all 4 data were collected.

It is difficult to draw inferences from the low amount of data, but it can be seen in this table that average transmission loss decreased from deep/fractured bedrock bottom to a shallow/muddy bottom. Spherical spreading (-20TL) was observed at Kellett Bluff and a mixture of both spherical and cylindrical (-10TL) was observed at Turn Point, while cylindrical spreading was observed at Snug Harbor. It can be assumed from this trend that depth and physical shape of the ocean bottom play more of a factor that the bottom type. Spherical spreading occurs in deep water environments such as Kellett Bluff and Turn Point while cylindrical spreading occurs in shallow water environments like Snug Harbor. So when a shallow muddy bottom site, with lower transmission loss, experiences cylindrical spreading despite the fact that sound would lose more energy to the muddy bottom, it can be inferred that depth is the more influential factor. Also from this table it can be seen that call rate increased as transmission loss decreased which, supports the previously stated hypothesis that Orcas' may be using areas of lower transmission loss to communicate more frequently. It would make sense if this were true, because in areas of lower transmission loss the sound attenuates through the water more efficiently and it may be easier for the whales to communicate and hear each other.

Alternatively, killer whales may be communicating at the same rate but due to the higher transmission loss the hydrophone may not be picking up all of the calls made. This would make the data appear to have the trend mentioned above, but in actuality the whales are not changing their call rate in areas of different bathymetries. For a future study it would be interesting to look at Orca sightings and how those have changed over the past decade. Have killer whales been seeking out areas of lower transmission loss more commonly as background noise increases? However, in order to compare sightings to call rate hydrophone recordings would be needed from each location of low transmission loss and high transmission loss where there have been sightings. Ideally this would then be compared to data from 10 years ago to identify any outstanding trends. However, even with more data there may not be an actual trend. The small data set may be giving the illusion of a trend when there isn' t one, although there is one between the sound speed profiles. This trend could be attributed to inconsistent sampling. All of the CTD casts were not taken at the same time. As mentioned before the sound speed calculation relies on temperature and salinity, which do change throughout the day and may be affecting the data in a way that creates a trend. Either way more data is needed to come to a decisive conclusion.

Conclusion

Significant results were observed between sound speed and bathymetry, and potentially call rate and transmission loss. The equation for sound speed is derived from temperature and salinity readings from the CTD measurements. Temperature and salinity both vary with depth, but the casts taken in this project were only down to 60m. The sound speed profile was compared to the profiles of both salinity and temperature, and within the top 60m more often than not the profiles did not vary much. Due to the lack of direct correlation with bathymetry these results could lead one to believe that there is more influencing sound speed in this data which could create a significant difference between the sound speed readings at different bathymetric types.

With more data, there is a potential for a linear relationship between call rate and transmission loss as can be seen in figure 6. If more data does support the trend that killer whales are utilizing areas of lower transmission loss to call more frequently, it would be important to understand where these areas are and to keep these areas involved in discussion of killer whale critical habitat. Since these whales are such acoustic animals maintaining the sites they use for communication is of the utmost importance.

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