Can clicks tell us anything about the foraging behavior of the southern resident *Orcinus orca*?

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September 18, 2011

Abstract:

Foraging is of great importance in understanding the biology of killer whales. One of the three major threats to the southern resident killer whales (SRKW's) is limited prey availability. It is particularly hard to decipher when killer whales are engaged in foraging because this activity mainly takes place below the water's surface. It is believed that killer whales use pulsed calls and whistles to communicate, while echolocation clicks are thought to be associated more with foraging than communicating. The SRKW's are thought to be particularly vocal during foraging due to their preference in prey. To determine whether click rate (number of clicks per minute) may be a proxy for observing foraging behavior, acoustic data was collected from September thru October in 2011. A linear 4 hydrophone array was used to record clicks made by the SRKW's while observational data was collected. Behavior data and recordings from the 4 hydrophone array were synchronized in time. Click rate for foraging behavior was compared to click rate during other known behaviors. This data was then analyzed and compared to data collected from similar experiments using the same experimental set up.

Introduction

The Northeastern Pacific killer whales have been classified as three different ecotypes, which are the transients, the offshores, and the residents. In November of 2005, under the Endangered Species Act, NOAA (National Oceanic and Atmospheric Administration) Fisheries listed the southern resident killer whales as endangered (NOAA, 2011). Additionally, the Canadian federal government declared the southern resident orcas an endangered species. Three threats to the southern resident killer whales have been identified. These threats are exposure to toxic

pollutants, the presence and noise effluence created by vessels, and declining prey abundance (particularly Chinook salmon) (WDFW, 2011). Geographic locations, social differences, and feeding preferences differentiate the southern resident killer whales from other ecotypes (Ford, 1991).

Killer whales primarily depend on their advanced hearing ability and vocalizations to traverse through a varying environment, convey information to other members of their pod, and to forage (NFSC, 2011). Unlike the transients who feed upon marine mammals which have a well – developed sense of hearing, the southern residents are thought to be particularly vocal during foraging since they feed on salmon whose hearing is poor in the frequency range which killer whales use to produce clicks (Simon, 2007). Differences in the rate of sound production are believed to be influenced by prey preference (Simon, 2007).

Chinook salmon represent 65 % of the southern resident killer whales diet (Ford, 1998). The importance of Chinook salmon to the southern resident killer whales has been quantified in two ways. First, researchers have analyzed the stomach contents of beached resident killer whales and identified the remains of Chinook salmon (Ford, 1998). The second way of determining the importance of Chinook salmon in the southern resident killer whales diet is by carefully monitoring their foraging behaviors and subsequently collecting fish scales (Hanson, 2010) Within the home range of the southern resident killer whales Chinook are also listed as endangered (Hanson, 2010). Establishing the significance of Chinook in the southern resident killer whales diet is important to understanding factors limiting population recovery of these *orcas* (Hanson, 2010).

It is difficult to address selective foraging by echolocating killer whales in the wild due to limited visibility of underwater foraging. However, in several species of toothed whales,

studies found relationships between acoustics and foraging behaviors (Simon, 2007). This research focuses on the southern resident killer whales. Because the southern resident killer whales are known to vocalize frequently, this experiment is designed to test the hypothesis that if southern resident killer whales are foraging, then there will be a noticeable increase in their click rate.

Methods

Data was collected along the west side of the San Juan Islands, during September and October of 2011.

Mobile Hydrophone Array

A linear array of 4 Labcore hydrophones were pulled behind a 42 foot catamaran, named the Gato Verde. These hydrophones were spaced 10 m apart, with hydrophone 4 being the most distal hydrophone from the catamaran preceded by hydrophone 3, hydrophone 2, and hydrophone 1. Hydrophone 1 was the most proximal hydrophone to the catamaran in the linear array. A 1.5 kg weight was secured to the linear hydrophone array with a bungee cord. Another rope which was 1m long was attached to the same weight and secured around the stern port cleat on the catamaran. The mobile hydrophone array was deployed as the catamaran travelled at approximately 2 knots. The speed of 2 knots was enforced to minimize noise produced by water flowing over the hydrophones. Hydrophone 4 was the first hydrophone on the linear array lowered into the water, followed by hydrophone 3, hydrophone 2, and hydrophone1. Hydrophone 1 was deployed simultaneously with the attached weight to decrease tension on the array. The 1.5kg weight was used to insure the linear hydrophone array remained under water while the Gato Verde was in motion. The hydrophone array was connected to sound devices

solid state recorders which were used to make recordings. The recordings were broken up into one minute sound files, and used to determine click rate. The start and stop times for each recording were noted using the clock on a GPS.

Click Rate Analysis

The click rate (# of clicks/ minute) was obtained by counting the number of clicks in one minute sound files corresponding to both foraging and non-foraging (control group) behaviors using Audacity. To determine whether click rate (# of clicks/minute) increases during foraging, the average number of foraging clicks in a given hour was compared to the average number of non-foraging clicks during the same hour. This analysis was repeated by day.

The average number of foraging clicks on a given day was compared to the average number of non – foraging clicks on the same day. Analyzing the data by day compares a broader range of click rate data.

The collective click rates (the mean click rate of all foraging behaviors and the mean click rate of all non – foraging behaviors for all five days) were also compared to determine if there is a noticeable increase in click rate when the southern resident killer whales are foraging. Analyzing the data this way, allows for comparison of a broader range of click rate data.

Behavioral Data

Observational data was collected from September thru October on the Gato Verde. For the purpose of this experiment, behaviors were classified as foraging and non-foraging. Foraging was defined as dispersed travel involving changes in direction, lunging, and/or visual pursuit of prey (Lusseau, D., et. al. 2009). Non-foraging behaviors were considered anything that was not

defined above as foraging. The behavioral data was recorded on a spreadsheet which consisted of time, orientation of the Gato Verde to the killer whales, focal group size, and range (distance from Gato Verde to the killer whales in meters). The time of each behavior recorded was synchronized with a clock on a GPS. The recording start and stop times on the sound devices solid state recorders were also synchronized with the GPS to maintain consistency in times throughout the experiment.

Audacity

One minute sound files corresponding to the behavioral data were located for foraging and non-foraging behaviors. Approximately 30 minutes of recordings corresponding to observed foraging behaviors, and 30 minutes of recordings corresponding to observed non-foraging behaviors were analyzed for September 27, 2011; October 2, 2011; October 4, 2011; and October 8, 2011. About 60 minutes of recordings corresponding to observed foraging behaviors, and 60 minutes of recordings corresponding to observed non-foraging behaviors were analyzed for September 28, 2011, which was the longest day the killer whales were observed. The recordings were listened to in Audacity and the total number of clicks were hand counted for each of the one minute sound files. Clicks were only counted if they were twice the background noise in the one minute recording, if they were audible, and if they were evenly spaced. The spacing between qualifying clicks was used to rule out any echoes from the original clicks as seen in Figure 1.

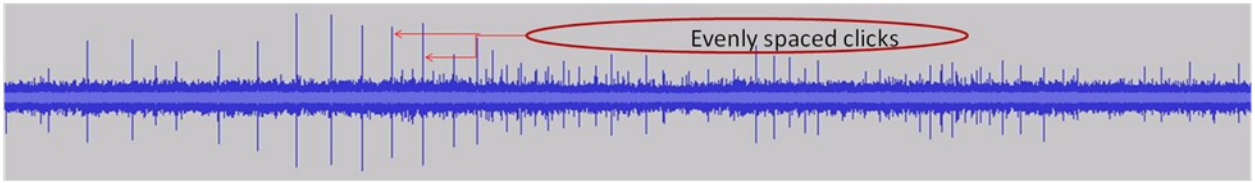


Figure1. Screen shot of a segment of qualifying clicks which were listened to and counted in Audacity. The thick blue line in the center is background noise.

Statistics

Statistical significance, indicated by P – values, for all of the data was obtained by running a Wilcox test in R. The box plots seen in Figure 3 and Figure 4 were also created using R. The error bars seen in Figure 2 and Figure 6 show the respective standard deviations. Standard deviations were calculated in Microsoft Office Excel 2007.

Results

A total of 278 minutes of acoustic recordings correlating with observational data were analyzed for five separate days. Recordings corresponding with foraging and non – foraging behaviors were chosen based on clarity. Click rates were analyzed in the following ways: by the hour of each day, and by the day to determine changes in click rates over time; also the collective mean click rate (mean of the total click counted for all 5 days during defined foraging behaviors, and the mean of the total clicks counted for all 5 days during behaviors defined as non – foraging) was analyzed to determine differences in click rates during observed foraging and non – foraging behaviors. Statistical significance of this data was obtained by running a Wilcox test in R.

Mean Click Rate by Hour

. The P-values seen in Figure 2 indicate the statistical significance of the analyzed data when foraging click rates and non-foraging click rates were examined by the hour of each day. No consistent pattern was found showing that click rate increases significantly when foraging behavior occurs, as illustrated in Figure 2.

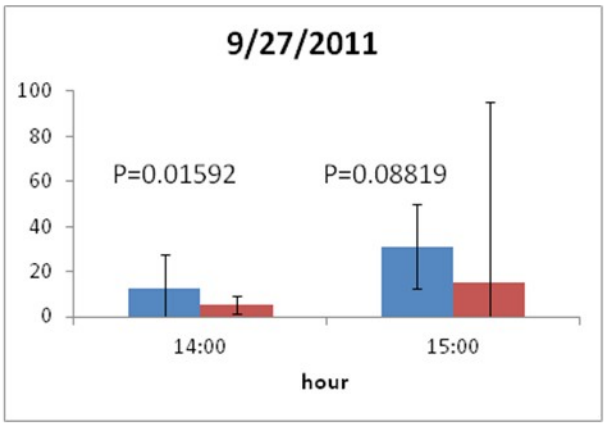
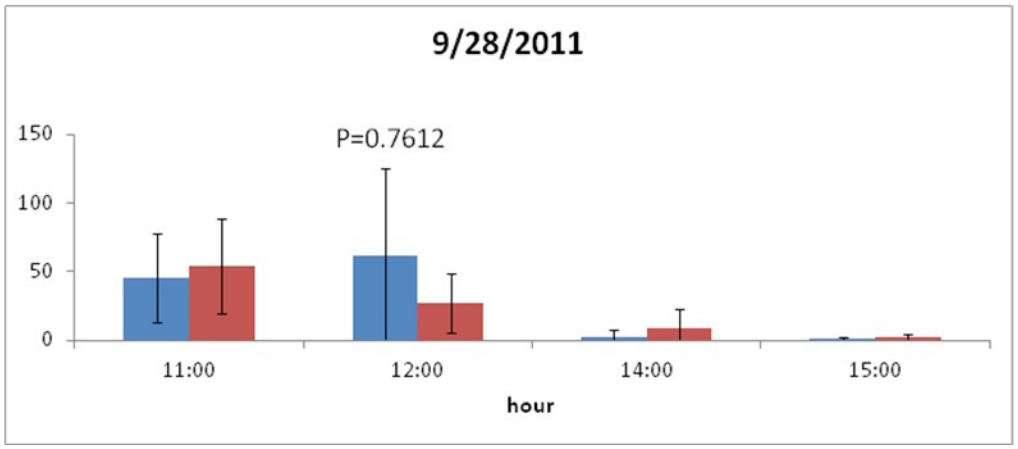
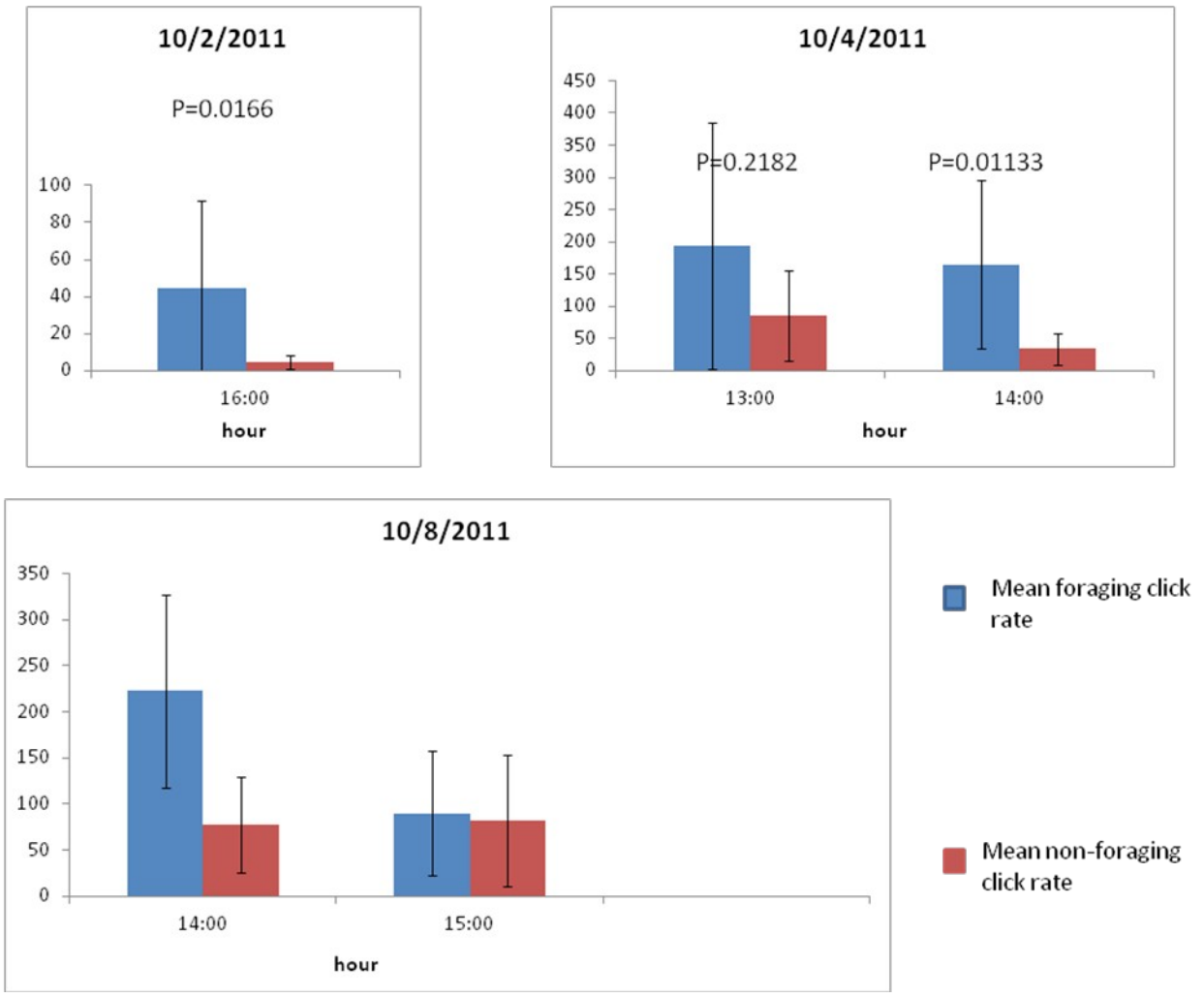


Figure 2 Comparison of mean foraging click rate to mean non-foraging click rate by hour of each day. The error bars represent the standard deviation for each hour.

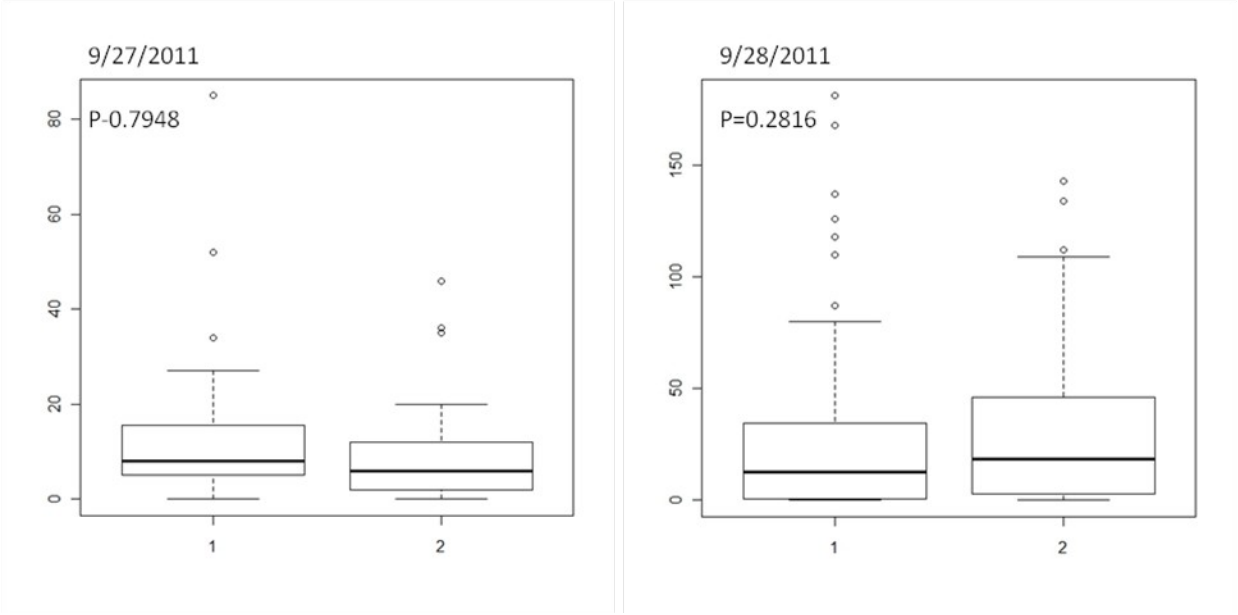


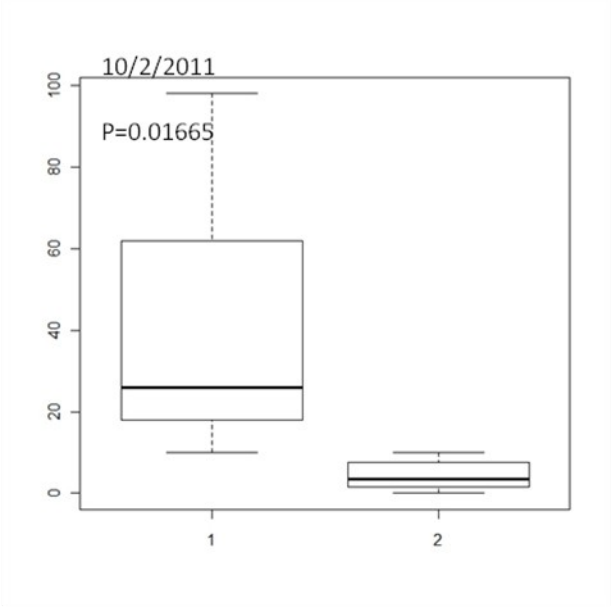


Mean Click Rate by Day

The P-values in Figure 3 show statistical significance between the mean click rate and behaviors defined as foraging and non – foraging during each day. No strong correlations indicating that mean click rates increase when the southern resident killer whales are foraging were found when the data was analyzed by day. However, it should be noted that some P-values in Figure 3 suggest the southern resident killer whales increase their click rate when foraging.

Figure 3 Compares the mean foraging click rate to the mean non – foraging click rate each day.

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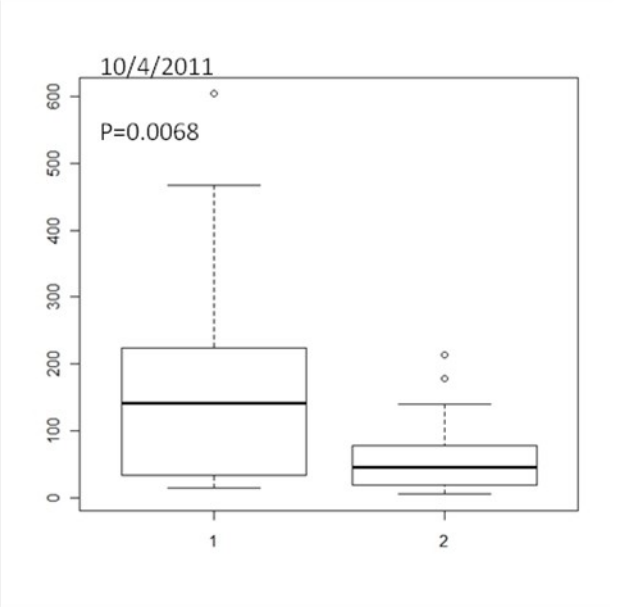
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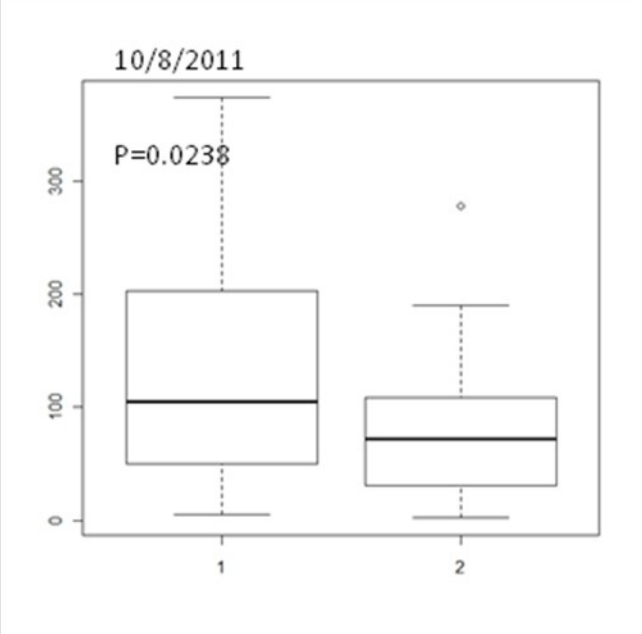


Collective Mean Click Rate

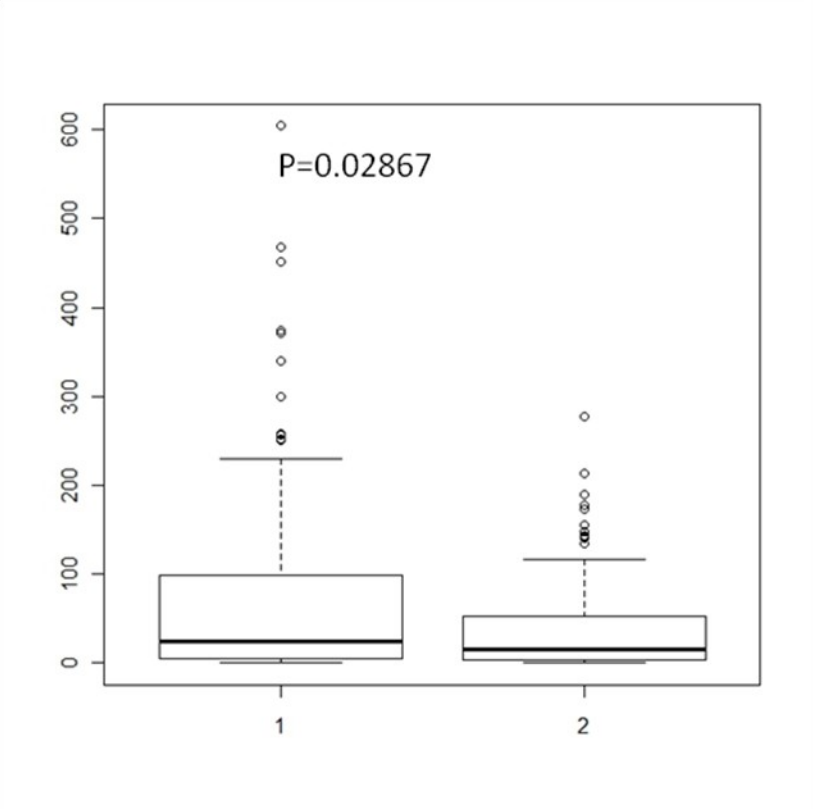
When the collective mean click rates (the mean click rate of all foraging behaviors and the mean click rate of all non – foraging behaviors for all five days) were compared, statistical significance was reported in the P – value (Figure 4). Figure 4 suggests that click rates are greater when the southern resident killer whales are foraging. This data implies that click rate may be a proxy for observing foraging behavior. A larger sample of data is need in order to accurately determine if

there is a direct correlation between the mean click rate and observed foraging behaviors.

Figure 4 Collective Mean Click Rate: Comparison of all foraging mean click rates (1) and all non – foraging mean click rates (2).

#1 is foraging mean click rate

#2 is non - foraging mean click rate



Discussion

The data analyzed did not fully support the hypothesis that there is a noticible increase in the southern resident killer whales click rate when behaviors defined as foraging were observed. While some results indicate significant differences in click rate during behaviors recorded as foraging, the variation in these results must be considered.

Mean Click Rate by Hour

The mean click rate for foraging and non – foraging behaviors were analyzed by hour on five separate days (Figure 2). The data was analyzed in this way to determine if the mean click rate for each behavior changes over time. The P – values in Figure 2 show no correlation between the time of day and the average number of clicks produced. These results suggests that the time of day does not effect the southern resident killer whales click rate when foraging and non – foraging behaviors were documented. Variability in mean click rates are seen (Figure 2) in four of the five days (9/27/2011, 9/28/2011, 10/4/2011, and 10/8/2011) in hour 14:00; and in three of the five days (9/27/2011, 9/28/11, and 10/8/2011) in hour 15:00. These results also suggest that the southern resident killer whales may not be foraging at the same time every day. Furthermore, Figure 2 implies that there is no noticible increase in click rate when the southern resident killer whales are foraging.

The variability among P – values in Figure 2 do not fully support the hypothesis that there is a noticible increase in the mean click rate when the southern resident killer whales are foraging. While some P – values in Figure 2 suggest that there may be a relationship between the mean click rate and behaviors defined as foraging or non – foraging, small sample sizes of click rate

data should be considered when reviewing these results. Additionally, it is hard to determine when the southern resident killer whales are foraging, since most of this behavior takes place under water where visability is limited. It is possible that some behaviors documented as foraging, were non – foraging behaviors.

Mean Click Rate by Day

The mean click rates for foraging and non – foraging behaviors were analyzed by day in Figure 3. This analysis was completed to determine wether the mean click rates during a given day could be used as a proxy for observing foraging behavior. Examining click rate data for foraging and non – foraging behaviors by day allowed for comparison of a larger sample size. As seen in Figure 3, the P – values in three of the five boxplots (10/2/2011, 10/4/2011, 10/8/2011) suggest there is an increase in mean click rates when foraging behaviors are observed. On each of the days listed above, the mean click rate during observed foraging behavior was greater than the mean click rate during non – foraging behavior. While these results do not fully support the hypothesis that the southern resident killer whales increase their click rate during foraging behaviors, most of the P – values in Figure 3 suggest a relationship between increased click rates and foraging behavior.

Figure 3 also shows an interesting correlation between the mean click rate during foraging and non – foraging behaviors and the months in which these behaviors were observed. Figure 3 indicates the greatest differences in mean click rates corresponding to observed foraging and non – foraging behaviors were during the month of October. Figure 3 also indicates that click rates increased when the southern resident killer whales were documented as foraging during the

month of October. These results are attributed to a more refined approach at documenting foraging and non – foraging behaviors.

To obtain more accurate data, the points of observation on the Gato Verde were sectioned off into three parts. Observer 1 was responsible for observing behaviors on the starboard side of the Gato Verde, observer 2 was responsible for port side, and observer 3 was responsible for the stern. Each observer used the same definition described previously to determine foraging and non – foraging behaviors.

These results are also attributed to the clarity and the amount of available recordings during the month of October. Both the refined method of collecting data and the amount of data available during October are factors that should be considered when viewing these results.

Collective Mean Click Rate

The collective mean click rates (the mean click rate of foraging and non – foraging behaviors for all five days) were compared to determine differences during foraging and non – foraging behaviors. The P – value seen in Figure 4 shows that the collective mean click rate is greater during foraging behaviors than the collective mean click rate during non – fraging behaviors. The notable difference in the collective mean click rate between foraging and non – foraging behaviors indicates that click rates can potentially signify wether the southern resident killer whales are foraging when their behaviors can not be seen. These results are credited to the broader sample of analyzed click rate data.

The variations in P – values between Figures 2, 3, and 4 show a trend. As mean click rate for foraging and non – foraging behaviors are analyzed on a broader scale, mean click rates during foraging behavior are determined to be greater than mean click rates during non – foraging

behavior. Collectively the results seen in Figures 2, 3, and 4 do not fully support the hypothesis that there is a noticible increase in click rates when the southern resident killer whales are foraging. This trend suggests that a larger sample size of data would indicate that the southern resident killer whales produce more clicks when they are engaged in foraging.

Future Research

Mean Click Rate and Fish Finder Data

Two fish finders were located on the Gato Verde. The images seen on the fish finders were captured in a photo every minute. Fish finder photos were taken when the southern resident killer whales were present. The depth and relative size of the targets seen on the fish finders were also captured in these images. The number of large targets captured by the fish finders were counted. The methods for determining large targets seen on the fish finders are found in the paper Correlating Southern Resident Orca Sightings with Pacific Salmon Densities: A Three Part Analysis (Basran, 2011).

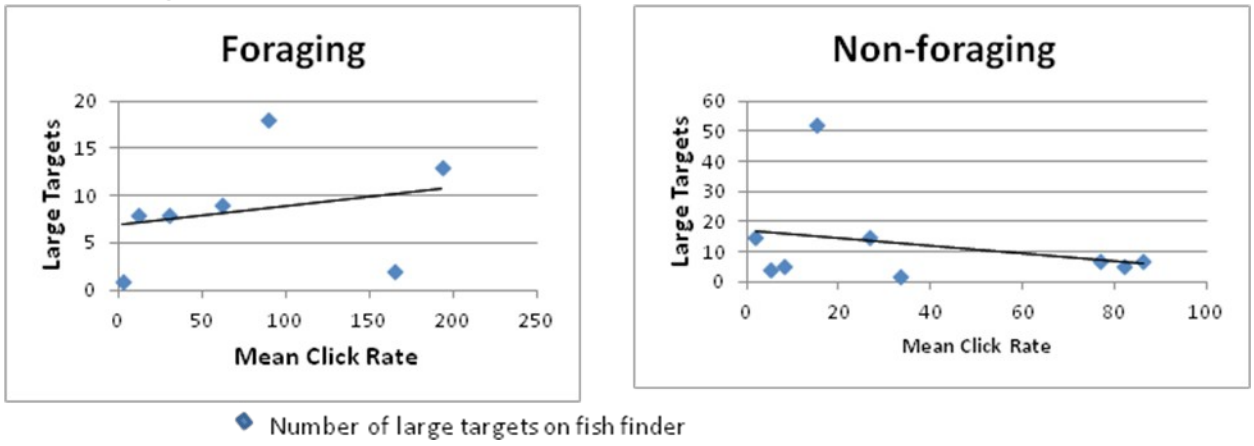
Scientsts recognize that echolocation target strenght is influenced by the animals orientation, feeding state, reproductive state, and length (Henderson, 2008). Southern resident killer whales are believed to selectively hunt chinok salmon because of their seasonal distribution, high fat content,and their large size (Ford, 1998).

The number of large targets counted during foraging behaviors were ploted against the corresponding mean click rates during foraging behaviors for all five days (Figure 5). As seen in Figure 5, this same procedure was used to compare the number of large targets counted during non – foraging behaviors. The data was analyzed this way to determine if the southern resident

killer whales increase their click rate when the number of large targets seen on a fish finder increases.

Figure 5 shows verry weak correlation between mean click rates and the number of large targets recorded. The small sample of data analyzed renders these results inconclusive. Further studies involving click rates and the number of large targets captured by a fish finder are potential markers for determining when the sothern resident killer whales are foraging.

Figure 5 Compares the number of large targets seen on a fish finder to the mean click rates during foraging and non – foraging behaviors. Fish finder data provided by Basran, C.



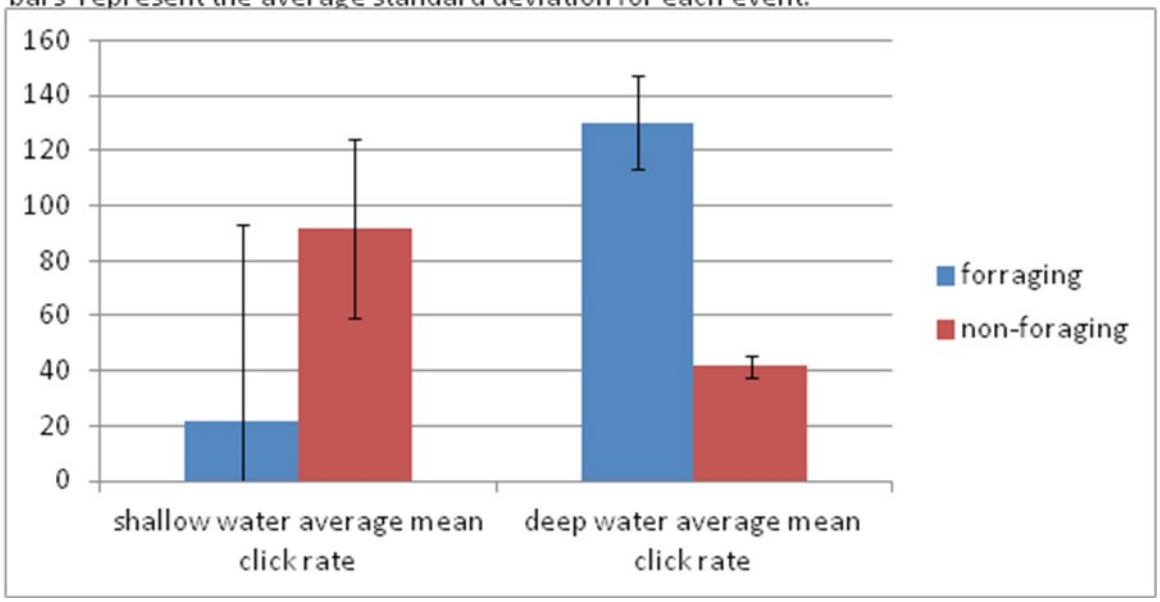
Bathymetry and Mean Click Rates

Studies found that high frequency sounds, like clicks used by the southern resident killer whales, experience more attenuation in shallow water (Bailey, 2011). Shallow waters host parameters that influence sound propogation (Holt, 2008). Sound is reflected off parameters like the sea surface and floor which have less distance between them in shallow waters. This creates more sound interfereance. Because the southern resident killer whales frequent many shallow water environments (Holt, 2008), bathyometry is a factor that should not be overlooked when studying acoustics. As seen in Figure 6, the mean click rates for foraging and non – foraging behaviors

were compared at different depths. The data was analyzed in this way to determine how click rates are affected by bathymetry.

When similar studies were conducted using bats, researchers found that bats can change echolocation pulse under certain conditions (Pye, 1980). It was also suggested that the structure of echolocation signals produced by different species of bats are adapted to the different environments in which they catch, and pursue prey (Schumm, A, 1990). This is similar to the southern resident killer whales and the transient killer whales, which are believed to use vocalizations differently due to their prey preferences (Simon, 2007).

Figure 6 Compares the average mean click rate during foraging and non – foraging events to shallow water and deep water environments. Shallow water was considered 80m or less, and deep water was considered 150m or more (Bailey, M., 2008). The error bars represent the average standard deviation for each event.



The error bars seen in Figure 6 show the mean click rate during documented foraging behaviors is significantly greater than the mean click rated during documented non – foraging behaviors

when bathymetry is considered. This data suggests that the click rates of the southern resident killer whales may be a proxy for observed foraging behaviors when less sound attenuation is experienced in deep waters. Further research incorporating bathometry may determine if click rates can be used as acoustic markers for identifying foraging behaviors.

In addition to investigating how bathymetry affects click rates, comparing these results in the spring and fall months would be useful, since the speed of sound in water decreases as temperature decreases, and increases as pressure increases (D'Spain, G. L., 2006).

Conclusion

While the aim of this study was to determine if click rates could be used as acoustic markers for foraging behavior, other factors that could effect or correlate with click rates were also investigated. These factors include the number of large targets seen on a fish finder when foraging and non – foraging behaviors were observed, and the bathometry of the location where data was collected.

While past studies have found relationships between acoustics and foraging behaviors in several species of toothed whales (Simon, 2007), the results above show much variation. As discussed previously, there are factors which may effect these results.

Due to the varriation in results, the hypothesis that there is a noticible increase in click rates when the southern resident killer whales are foraging was not fully supported. Further studies are needed before this hypothesis should be rejected.

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