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June 4, 2010
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http://beamreach.org/101

**Unraveling the Communicative Properties of Surface Active Behaviors in Southern Resident killer whales**

Benefits to living in social groupings include mutualistic foraging techniques, increased group care for infants, and protection from predators (Parsons *et al*., 2009). It has been shown that through communication, animals such as the Gunnison's prairie dog, honeybees, and several species of birds, perform alarm calls (Forrester, 2008). Animals react differently depending on the situation. For example, some animals signal a warning to other individuals of impending danger and act in a group to avoid potential hazards. Based on spontaneous situations, animals can change their vocalizations and call signals (Forrester, 2008). Other than sound, animals also use behavior as a form of communication (Bradbury, 1998).

In bottlenose dolphins, aerial displays, kelp tossing, and belly-ups were defined as acts of socializing; **other behaviors, such as tail slaps by bottlenose dolphins, are used as warning signs (Shane *et. al*, 1982). Research shows that humans** use a variety of verbal and nonverbal methods of communication, and sometimes use visual communication signals to supplement the message, such as body language (Forrester, 2008). Understanding and classifying animal behavior is a continuous and arduous process, as the direction of evolution is not fully understood (Martin *et. al*, 1993). However, measurements of animal behavior are small fundamental building blocks towards the comprehension of larger natural phenomena (Martin *et. al*, 1993).

The Southern Resident killer whales, identified as the J, K, and L pods, live in complex, long-term social groupings (Ford, 1987). The population consists of about 85 individuals, residing in the waters off of the southern half of Vancouver Island and in Puget Sound (Ford *et. al*, 2000). The pods contain a group of related matrilines, closely related whale descendants following one older female. Given their long life spans of about 60-80 years, up to four generations can be present in a family group (Ford *et. al*, 2000).

Southern Resident killer whales display a wide variety of complex behaviors in their daily lives: foraging, traveling, resting, and socializing (Ford *et. al*, 2000). Surface active behaviors (SABs), such as breaching, tail slaps, and spyhopping, generally signify group cohesion (Ford *et. al*, 2000). Socializing whales will group together, emitting a variety of vocalizations **(Ford *et. al,* 2000). Vocalization consists of echolocation and calls: echolocation as a series of fast clicks to help the killer whales find prey, and calls that include whistles, variable calls, and discrete calls (Bigg *et. al,* 1987). Discrete calls, otherwise known as call-types, vary between different pods, as each killer whale pod produces a different call repertoire. Recording and identifying specific calls help to link individuals back to their original pods (Bigg *et. al,* 1987).**

Since 1973, starting with the work of Michael Bigg, a variety of long-term behavioral studies on killer whales have been conducted, such as measuring general behavior and behavioral states being impacted (Osborne, 1986, Bain, 2006). One study by Morton (*et. al*, 1986) on the connection between killer whale surface behaviors with the sounds emitted has shown some categorical results. The study was done on two killer whales by the names of Corky and Orky at Marineland in Palos Verdes, CA. Recordings were made monthly with several breaks during theme park performances. Results showed that when an F1 call was made in captivity, it was recognized as indicating tranquility. In contrast, wild F1 calls were frequently used during behaviors such as directional course change, spyhopping, or blowing in unison (Morton *et. al*, 1986). The question of whether or not there would be specific behavioral responses to certain call types or sounds emitted was not thoroughly answered. Concerns over larger sample sizes and more analysis on frequent patterns of call occurrence at specific behaviors developed from the study (Morton et. al, 1986). Previous Beam Reach student Juliette Nash (2006) found that S10 calls were mainly heard when the Southern Resident killer whales were active in foraging behavior. Results showed no direct correlation between actual foraging and the S10 phonations to demonstrate the act of "foraging". Other calls, such as S42, occurred too randomly to be categorized with a behavior (Nash, 2006). Beam Reach student Heather Hooper (2007) measured call-types within two minutes of a behavioral event. Pectoral fin slaps, breaches, tail slaps, and changes in direction have statistically significant higher frequency in relation to one to three discrete call types (Hooper, 2007). Both Nash (2006) and Hooper (2007) had similar concerns over small sample sizes. It is highly important to continue to collect behavioral data to increase available quantity of behavioral data for better statistical analysis. The main goal of this study was to continue to search for a correlation between particular SABs and call-types created by the Southern Resident killer whales. In turn, this could help to discern the particular meanings of the call-types related to an SAB and to further comprehend the communication systems of these highly social animals.

Other research has shown how SABs in Southern Residents may also be affected by vessel noise. David E. Bain (*et. al*, 2006) discussed how whales at a greater distance from vessels will perform fewer surface active behaviors to lessen detection. Vessels within the proximity of about 100-400m of the whales can cause potential stress and the whales would find ways to avoid vessel traffic altogether (Bain *et. al*, 2006). Bottlenose dolphins demonstrate similar behavior: if vessel traffic continually increased, the energetic cost of boat avoidance becomes too great for the dolphins to remain in the area. Therefore, the areas with high vessel traffic are completely avoided (**Lusseau, 2005). Noren (*et. al,* 2009) studied how vessels at different distances influenced the rates of SABs in the Southern Residents. About 70% of SABs occurred when the closest vessel was 224 meters or closer to the whales (Noren *et. al,* 2009). While Bain (*et. al,* 2006) focused on vessel distance effects and Noren (*et. al,* 2009) on presence of vessels, these studies did not look into acoustical components.**

Whale watching has become hugely popular in Haro Strait and the waters near British Columbia, and currently, there is a regulation stating that boats have to distance themselves away from the whales at least 100 yards (Koski *et. al*, 2005). Increasing numbers of visitors and whale watching boats congregate in places such as Lime Kiln National Park, especially during the summer months (Koski *et. al*, 2005). The results from whale behavior and human impact research can help lead to better better whale watching vessel regulations to reduce potential stress and disruptions for the Southern Residents (Bain, 2002).

**This study has two objectives. First, I will investigate the sound that motorized vessels produce which can influence a killer whale's behavior. In general, every time background noise increases by 1 dB re 1 μPascal, the killer whale call source levels increase by 1 dB re 1 μPascal, as found in a study by Holt (*et. al,* 2009).** This leads to my second objective, which is to search for how presence and/or sound of motorized vessels will affect the rate of SABs from the Southern Residents.

To be able to answer my various questions and objectives, I will test the following hypothesis: Specific calls types from the Southern Resident killer whales will occur during a certain time interval of predefined SABs. My second hypothesis is that in the presence of vessels, the Southern Residents will have more frequent occurrences of SABs. Testing these hypotheses is important, because continuation of these studies will increase the bank of behavioral data; this will that allow for more valid research analysis and conclusions.

Methods:

The observation period lasted for five weeks in the spring of 2010. Data was recorded while on a 42-ft quiet electric-biodiesel catamaran, the *Gato Verde*. The study area was located around the San Juan Islands, WA. Be Whale Wise guidelines were observed at all times (NOAA Fisheries). Whales were observed with 7X50 Bushnell binoculars. SABs were recorded on pre-made data sheets from Excel, along with the time of occurrence, pod identification, and surface active behavior performed. A chart describing wild killer whale behavior was formulated referencing Table 1 of Noren's (*et. al*, 2009) study on SABs (Table 1). All occurrence behavior sampling was used during data collection periods (Altmann, 1974). Any missed behaviors were pinpointed with help of others aboard the *Gato Verde*. Vessel numbers within sight were documented, including the *Gato Verde,* whenever an SAB occurred. Distance between the closest vessel and the whale performing the SAB was documented. This distance was identified in two categories: near, 0m≤150m and far, 150m<more.

**Table 1.** Noren's (et. al, 2009) surface active behavior definitions

| *Surface Active Behavior* | *Description* |
|---|---|
| Breach | The body of the whale clears the water completely and then lands on the lateral or ventral side, generating a large splash. |
| Cartwheel | The whale performs an exaggerated tail slap by hurling the posterior portion of |

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| | the body, from the dorsal fin to the tail, out of the water and over its head. The entire posterior end of the whale (dorsal, lateral or ventral side up) lands, generating a large splash. |
| Dorsal Slap | The whale slaps the water with its dorsal fin by rolling onto its side with force, generating a splash. |
| Half Breach | One half to two-thirds of the anterior portion of the whale clears the water and then lands on the lateral or ventral side, generating a large splash. |
| Pectoral Fin Slap | The whale slaps one or both pectoral fins (ventral or lateral side up), generating a splash. |
| Spyhop | The whale rises vertically out of the water so that both eyes are exposed. The pectoral fins can either be in or out of the water. |
| Tail Slap | The whale slaps its tail (dorsal or ventral side up) on the surface of the water, generating a splash. |

To document vocal behavior, a Lab Core four hydrophone array was trailed behind the port aft stern. The hydrophones were connected to Sound Devices 702 as the recording medium. An eight pound weight was attached ten meters before the first element of the hydrophone array by a bungee cord, to deploy the array to a depth of about 5 m. The time of the start of each recording session was noted. For precision, my watch was synced with the GPS, and a waypoint was taken for metadata. Start of recording was determined when there were Southern Residents in sight. Headphones and speakers were used throughout the majority of the time of observation and behavioral data collection.

All recordings and data obtained were downloaded to a Windows XP Dell Vostro 1500 for reference and analysis. All written behavioral data was transferred into Microsoft Excel spreadsheets. Behavioral events were counted and graphed on bar graphs, displaying rates of each surface active behavior performed. Call-types 60 seconds before and 60 seconds after the behavioral event were defined as part of that SAB. A one minute recording right before the SAB time increment was used as the control period for each SAB. All hydrophone data was analyzed using Audacity 1.3.12-beta. Previous recordings of categorized call-types and sound spectrograms in Ford's (1987) catalog of underwater calls were used to help determine call-types.

The summer of 2007 Lime Kiln data from June 23 – August 3 was used, with the same methods specified in Wieland's thesis on Repertoire Usage of the Southern Residents (2007). Her study area was located at Lime Kiln lighthouse, where she used two Cetacean Research Technology C340 hydrophones connected to a Sony Sound Forge, a digital audio software program (Wieland, 2007). She used a Navy Sonobuoy hydrophone, and recordings were saved using Light House Vocal Observer (Wieland, 2007). Sampling rate was set to 44.1 kHz (Wieland, 2007). Recordings were made whenever whales entered a hydrophone vicinity of 1 mile and stopped when whales were at least 1.5 miles away from the hydrophones (Wieland, 2007). All behavioral data and pod identification notations included the time of occurrence recorded by Wieland and other personal at the lighthouse (Wieland, 2007).

Audacity's Analyze Contrast option was used to find the background noise RMS of the selection. The average dB of the selection was in Audacity values, which was then added by the calibration factor calculated from our hydrophone array calibration. To calibrate the hydrophone array, we used the Interoceans Blue Box which contained a calibrated hydrophone that sent a 130 dB re 1 μ Pascal tone. The RMS value of the Blue Box hydrophone was determined using MatLab. The log was taken and multiplied by 20 (equation to get dB) and was subtracted from the received level in the hydrophone array to get the calibration factor. The end goal was to get dB re 1 μ Pascal.

For boat data, a timeline divided into 5 minute increments from recording start time was used. All 5 minute increments without an SAB were ignored. Each time increment was defined as vessels being in one of the two distance categories. In cases where the 5 minute time increment contained both 'near' and 'far' vessel data, whichever category was greater in number was used to define that five minute time interval. Rates of an SAB performed by a Southern Resident killer whale were calculated by dividing the total number of SAB occurrences by 5 minutes. An average dB re 1 μ Pascal of the five minute interval was calculated from our calibration factor to use for statistical tests.

Call rates with an SAB were calculated by taking the number of total calls and dividing by a time increment (2 minutes). The rate of calls during the control period was calculated by dividing the total call-types by a control time increment (1 minute) (Figure 1).

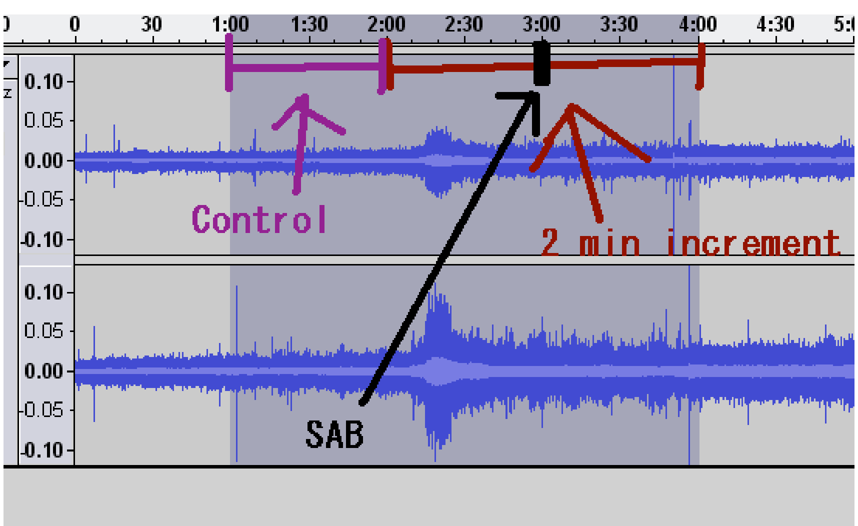


**Figure 1.** Time increments used in measurements in Audacity. The experimental period was 2 minutes, with the SAB occurrence in the very middle. One minute right before the experimental period was used as control, with no SAB occurrences.

Statistical analysis was done by using paired t-tests for call-types for total SABs, call-types during every SAB, popular calls used during each individual SAB, and rare calls used during individual SAB. Popular call-types were defined as the two most used calls for each Southern Resident pod: J pod – S1 and S4, K pod – S16 and S17, and L pod – S2 and S19 (Wieland *et. al*, 2009). All other call-types were categorized as rare call-types. The SAB call rates were analyzed in pairs with the control periods with known non-SAB occurrences. Two ANOVA (Analysis of Variance) tests were used to test the rate of SAB occurrences for both close and far vessels and the calculated received levels in dB re 1 μ Pascal of the background noise in relation to the close and far vessels. A linear regression statistical test was used to compare the calculated received levels with the rate of SABs.

Results:

We had three days with the whales out of the five weeks that we were out at sea. Two days were with L pod and one day was with J pod. 43 minutes of recording were analyzed for J pod while 3 hours and 14 minutes of recording were analyzed for L pod. The whales were not around the first four weeks, which brought to our attention that we needed old data. Wieland's (2007) data produced 11 hours and 21 minutes of J pod recordings, 2 hours and 52 minutes of K pod recordings, and 50 minutes of L pod recordings. Instances where at least two Southern Resident pods were present were analyzed as well. Wieland's (2007) data contained 1 hour and 57 minutes of JK recordings, 1 hour and 59 minutes of JL, and 4 hours and 19 minutes of JKL recordings. A total of 26 hours and 25 minutes of recordings of calls were analyzed. There were 1127 call-types that were heard and 209 surface active behaviors (Figure 2). Boat data collected by Wieland did not have similar distance categorizations, and therefore, her boat data was excluded from the study.

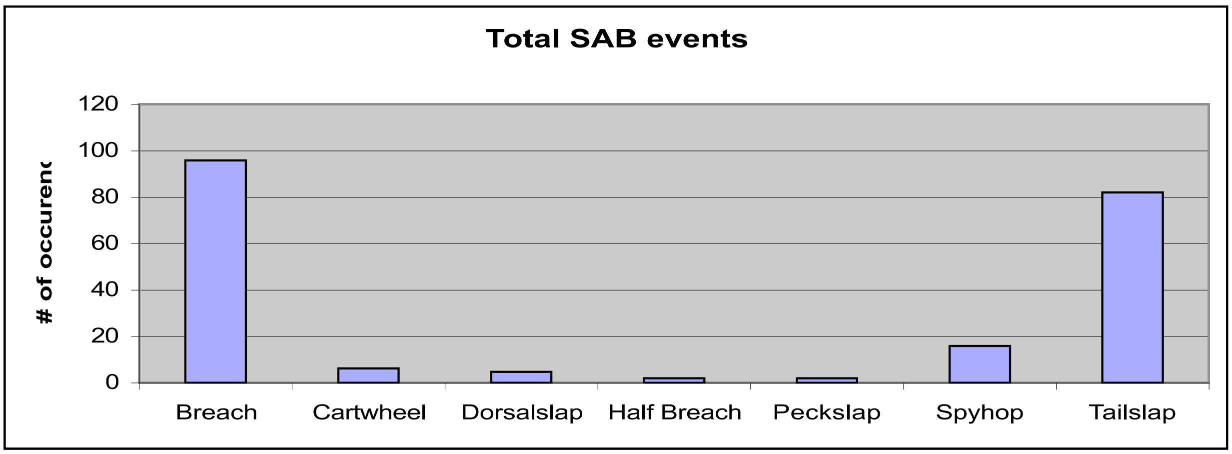


**Figure 2.** 209 total behavioral events analyzed: 96 Breaches, 6 Cartwheels, 5 Dorsalslaps, 2 Half Breaches, 2 Peckslaps, 16 Spyhops, and 82 Tailslaps.

All surface active behavior call rates for paired t-tests were log transformed whenever the variance of the call rate data was more than 0.5 apart. This study found no significant change in calling rate for all call-types when comparing SAB and non-SAB control periods (p=0.82286, n=209, t=0.22415). However, this study found that Southern Residents tend to use their more common calls when performing SABs (p=0.0093, n=209, t=2.63164) (Figure 3).

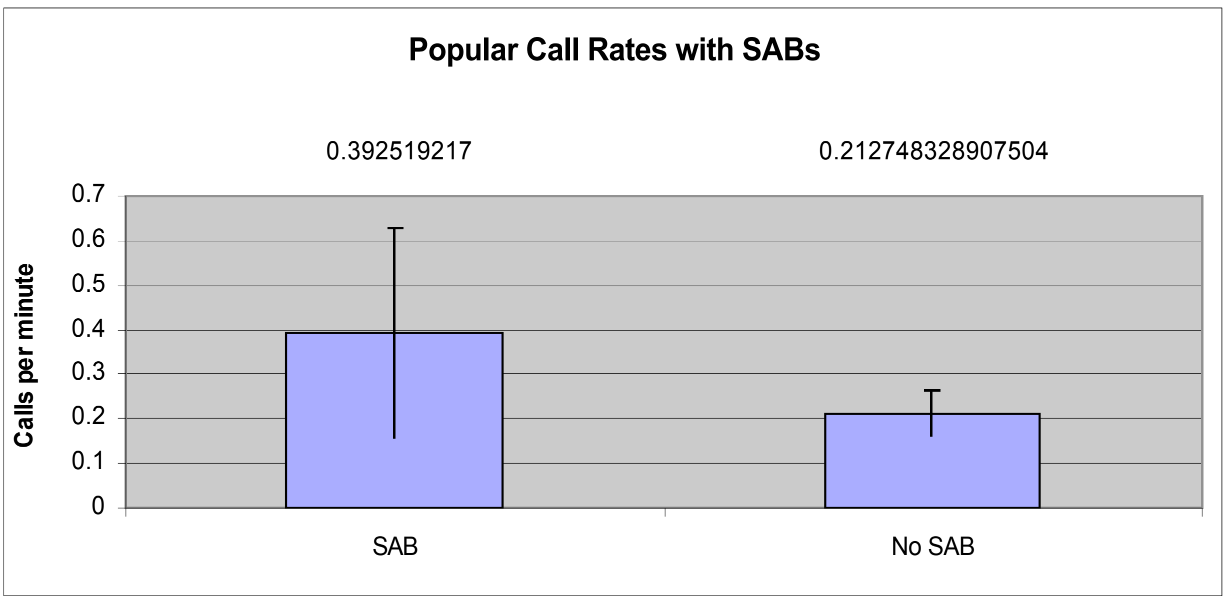


**Figure 3.** Call rates per minute of common call-types during surface active behaviors. Common call-types are discrete calls that JKL pod used most often. J – S1 and S4; K – S16 and S17; L – S2 and S19. A sum of all common call rates for each SAB was totaled and divided by 2 minutes, the SAB experimental period. No SAB control period was 1 minute instead of 2. p=0.0093, n=209, t=0.64102, SEM=0.235176, 0.049037

The study did not find any significance in change of calling rate for all call-types for each SAB (Tail slaps – p=0.17078, n=82, t=1.38198; Breaches – p=0.54716, n=96, t=0.60418; Spyhops – p=0.79931, n=16, t=0.2588; Cartwheels – p=0.13721, n=6, t=1.76851). The only

SAB that showed significance was the dorsal slap, suggesting that Southern Residents use less common call-types during SABs (p=0.01676, n=5, t=3.95399) (Figure 4).

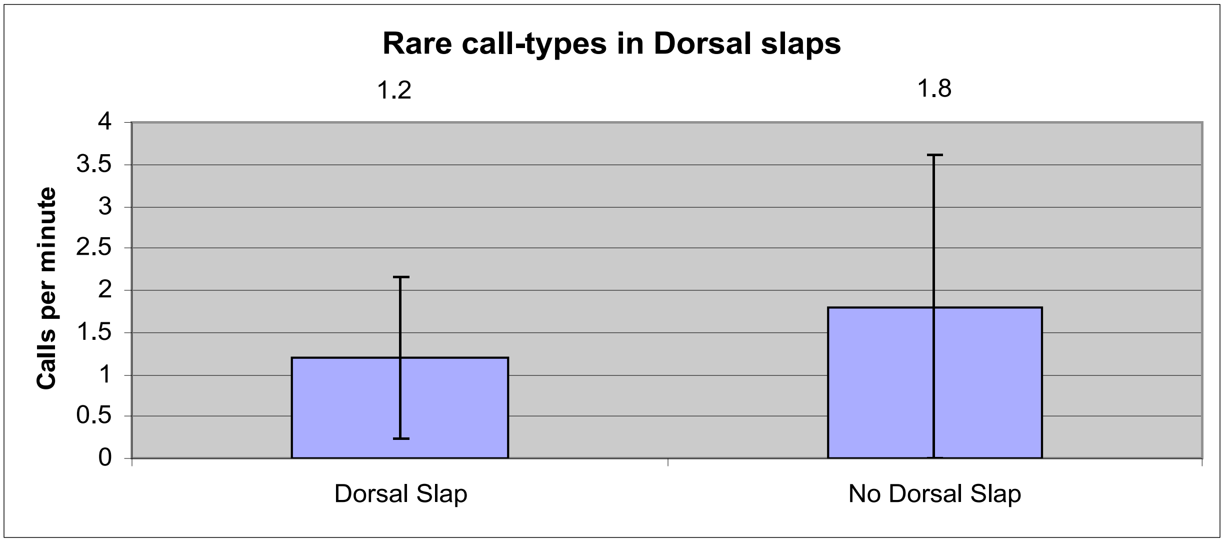


**Figure 4.** Call rates per minute of rare call-types during dorsal slaps. Rare call-types are categorized as all calls other than the common calls listed (Figure 3). A sum of all call rates for each dorsal slap was totaled and divided by 2 minutes, the SAB experimental period. No SAB control period was 1 minute instead of 2. p=0.01676, n=5, t=3.95399, SEM=0.96953597, 1.8

The study data suggested that when vessels were farther away from the whales, there was a higher rate of surface active behaviors (p=0.00416, F[1,28]=9.73514) (Figure 5).

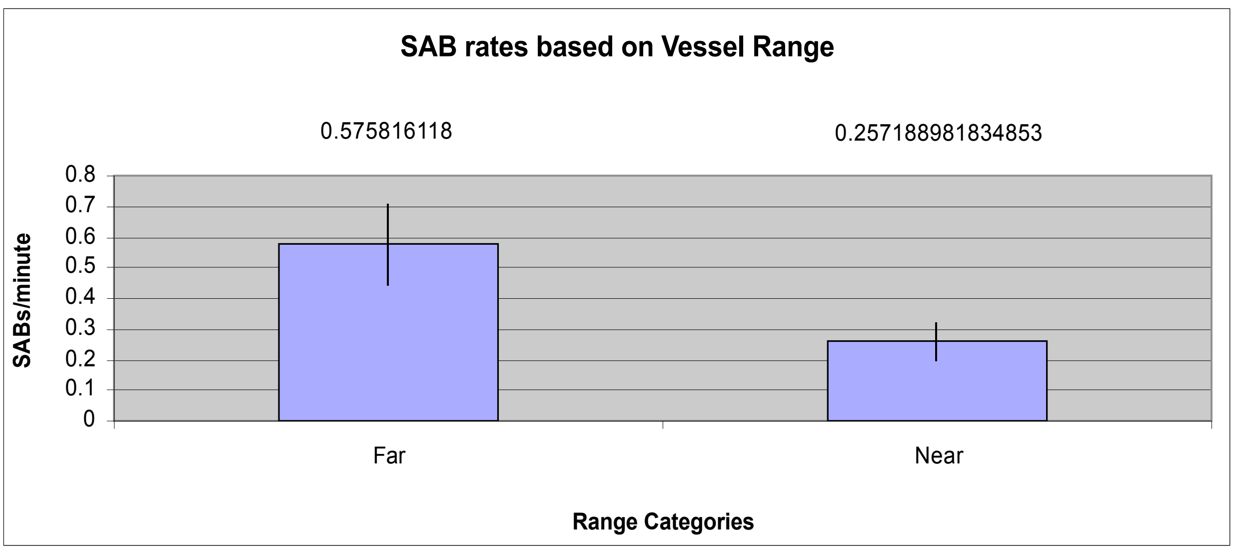


**Figure 5.** SAB rates tend to increase if boat distance is at least 150 meters or farther away. 5 minute increments during the recordings were broken up, and analyzed for SAB occurrences. Increments with at least 1 SAB occurrence were used, totaled, and averaged. p=0.00416, F(1,28)=9.73514, SEM=0.12841, 0.059554

In this study, data showed no statistically significance on the vessel dB levels re 1 μ Pascal dependence on distance (p=0.56234, F[1,28]=0.3438) and surface active behavior rates based on the dB re 1 μ Pascal (p=0.66409, F[1,90]=0.18984, R=0.0588, R^2=0.0021) (Figure 6).

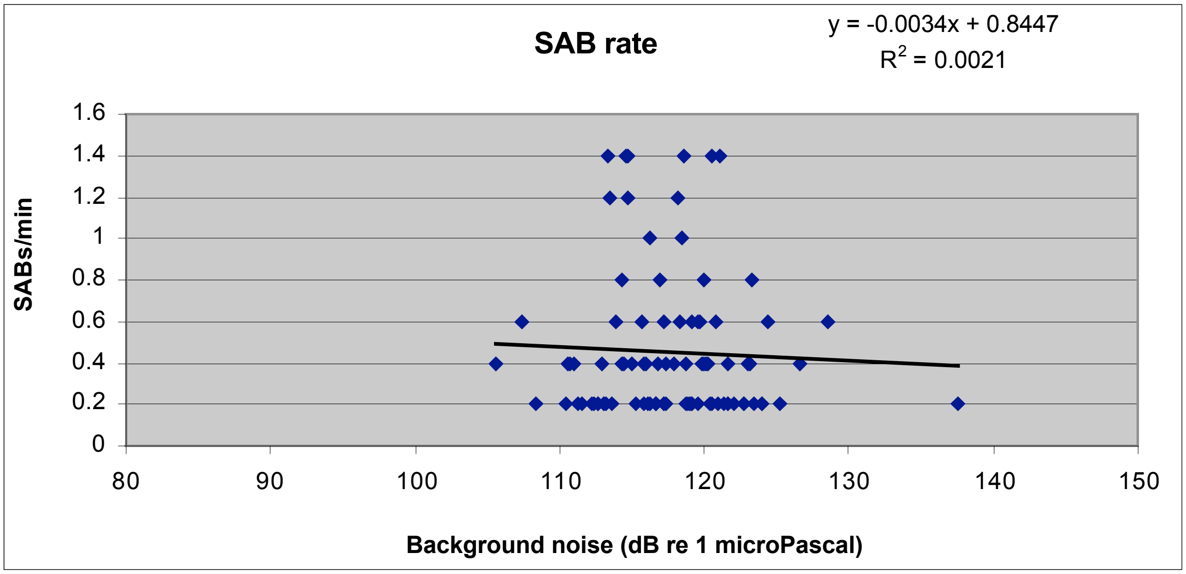


**Figure 6.** SAB rates based on dB levels re 1 µ Pascal. Each scatterplot is an average of a 5 minute time interval in which at least one SAB occurred. Average dB was measured in Audacity. p=0.66409, F(1,90)=0.18984, R=0.04588, total number of cases=92

Discussion:

Results of these observations show that Southern Resident killer whales use their common calls more often when performing surface active behaviors. Further research is encouraged to look at specific call-types instead of categorizing all the common and rare ones together. The first goal of this research was to find meaning behind each individual call-type. Most recordings consisted of a repeated call-type. For instance, one J pod 2 minute increment during a breach contained over 20 S1 calls. Because we had few days with the whales and a small data set on calls other than S1, it was unreasonable to statistically test every single call-type. However, the data set showed that there was a huge S1 call total compared with the rest of the discrete calls, doubling the next largest, S6 (Figure 7). S6 was a call that was not considered a common call used by the Southern Residents, and the data shows that the total is the second highest value (Figure 7). There are barely any S17 and S19 calls (Figure 7). This data could be a result of more frequent J-pod encounters compared with K and L.

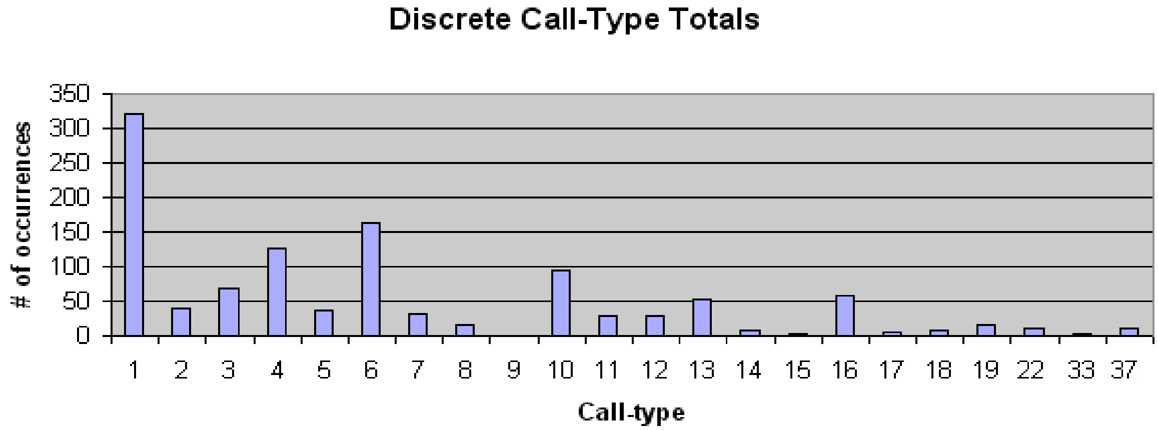


**Figure 7.** The totals of all call-types accounted for. Common calls are: J – S1 and S4, K – S16 and S17, L – S2 and S19. S1 has a total of 320, which may have biased data. S6 call and S10 call occurred often as well.

Only the behavioral event of dorsal slaps showed significance in this study, emphasizing that during dorsal slaps, uncommon calls are used more often than common calls. This is highly unlikely to be true, even though the statistical test showed significance. Flaws in this result resulted from the small sample size and almost no occurrence of calls during the observation period. This may result in bias in the test. Another major flaw in the data analysis was the lack of normalizing of the number of animals. Group numbers were difficult to count due to widespread whale groups, and the fact that the animals surfaced only for a few seconds at a time. Rates of the SABs could have been skewed completely because, without normalization, it is assumed that there was only one animal doing SABs the entire study period. That does not hold true during data collection. Therefore, my first hypothesis has not yet been answered, because it was unreasonable to look at individual call-types with such a small sample size.

Data from this study shows that there are a higher frequency of SABs when vessels are farther (150m<more) rather than closer. It is most plausible that the whales were practicing avoidance. This refutes my second hypothesis stating that there would be an increase of SAB rate when vessels are in closer proximity. In a previous study, Noren (2009) tested how boat

distance affects the rates of SABs. Her study was undertaken from a motorized vessel, recording the behavior of one focal killer whale at a time that was photo IDed. By concentrating behavioral data collection on one whale, Noren (2009) was able to discern any erratic changes in behavior of that individual. This study accounted for all SAB occurrences from every whale, and whale numbers were not counted exactly, which may have skewed the data analysis. Noren's (2009) study result showed that Southern Residents perform more SABs when boats are closer. She pointed out that the whales might be reacting more to the noise produced by the vessels instead of the presence of the vessels alone (Noren, 2009). The main difference in this study and hers was that she did not include sound measurements in her boat data (Noren, 2009). The purpose of this study was to distinguish whether it was boat presence or noise that influenced SABs and to continue to find patterns in SAB rates based on boat distance.

Erbe's (2002) study concerning underwater noise impacts on killer whales showed a trend suggesting that the cetaceans would practice avoidance of both fast moving vessels at 200 meters and slow moving vessels at 50 meters. Erratic changes of direction were observed (Erbe, 2002). Williams (*et. al*, 2002) studied the effects of leapfrogging vessels, in which male killer whales would make huge changes of swimming direction when a vessel sped up and parked in front of the predicted swimming path. However, the linear regression statistical test measuring SAB rates in comparison to background dB in this study showed no significance. This may be a result of the measurements of general background dB only.

There were several limitations to this research study. I did not measure individual vessel noise source levels, nor did I notice the group spread and swimming patterns of the Southern Residents when vessels were around. Sample size for both ANOVA tests was small, since Wieland's (2007) data was not used because of her different methods of distance categorization.

Further research studies on this subject may be able to discover meanings behind the call-types of Southern Residents when they breach, for example.

Surface active behaviors still remain a mystery. As whale watching becomes more popular, the effects of whale watching can cause greater impact on the Southern Residents, including echolocation masking when foraging, and wasteful energetic avoidance patterns (Bain, 2002). Analyzing each call-type during an SAB can help to distinguish more fully the relationship between discrete calls and SABs. Further research with a larger sample size is encouraged to unlock the communicative purposes behind behavioral events.

**Acknowledgments**

Many, many thanks to Dr. Jason Wood, Dr. Val Veirs, and Dr. Scott Veirs for their guidance, teachings, and humor during the ten week Beam Reach program. Thank you to Captain Todd Shuster for teaching me how to sail and letting me perform research on the *Gato Verde*. Thank you to my peers, Kathryn Scurci, Nora Carlson, and Libby Whiting for a great ten weeks of supportive camaraderie. Thank you to Monika Wieland for her behavioral data. Thank you to all the ones that helped to formulate this paper. Thank you so much to all guest lecturers and all who took part to make Beam Reach successful. Thank you to Friday Harbor Labs for hosting me during the days on land. Thank you to everyone else that impacted my awesome experience here in Friday Harbor Labs. I extend my personal thanks to my mom and dad for their love and aid when I needed it most.

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