Determining call rate and use in matriarch southern resident killer whales: an investigation into killer whale acoustics and social hierarchy

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ABSTRACT

The highly social killer whale lives in a matriarchical society (Ford 2000). This means that the oldest reproducing female is the head of the social arrangement. Killer whales communicate with a variety of whistles, clicks, and discrete calls. In the Southern Resident Community, which primarily resides in the Haro Strait and the waters surrounding the San Juan Islands, whales communicate with 29 different, identified and catalogued call types (Ford 1987). Three pods, or groups of related matrilines exist, the J, K and L pods (Ford 2000). Each pod is related to each other to some degree. It is known that vocalizations made by killer whales are learned and passed from one generation to another over time (Miller and Bain 2000). It is then of particular interest if matriarchs, presumably the oldest and most knowledgeable animals of the group, vocalize more often, and with specific calls more than other individuals. In addition, since calls are learned, the variation in calls between a mother and her offspring are of particular interest. This paper is an investigation into killer whale communication via discrete calls with respect to the social hierarchy.

INTRODUCTION

The killer whale, *Orcinus orca*, is a highly social top predator. In the waters surrounding Washington state and the greater Puget Sound there are three types of killer whales: resident, transient, and offfshore. Each group has slight differences in physical characteristics, making them easily identifiable to the trained eye. Killer whales are resource specialists, and each group of whales has specialized on hunting prey most suitable for their geographic range. Transient killer whales, which specialize on marine mammals as a prey source, are typically seen in waters off the coast of Washington. Offshores usually stay in deeper waters off the Pacific Northwest and specialize in hunting fish, while residents live in coastal waters spring through fall and specialize on salmon (and other fish) as sources of prey (Ford et al 2000). While their habitats overlap, genetic analysis has determined that transients and residents are genetically isolated (Ford et al 2000). Because of their large pod size and coastal distribution, residents are the most commonly encountered of the groups. The resident whales have been divided into two distinct populations known as the northern residents (primarily inhabiting waters near northern Vancouver Island to southeastern Alaska) and the southern residents (primarily inhabiting waters around the southern tip of Vancouver Island and the greater Puget Sound area) (Ford et al. 2000). This study will focus on southern resident killer whales, (hereafter-referred to as southern residents or SRKW's) in the waters in and around the San Juan Islands.

Natural markings and subtle differences between killer whales, such as variation of saddle-patch coloration (the area of lighter color just behind the dorsal fin), dorsal fin, and tail-fluke shape, have made it possible for photographic identification and cataloguing of individuals over the last three decades (Bigg et al 1990; Olesiuk 1990). This method of individual identification has provided the basis for in-depth studies on association and movement patterns for southern resident killer whales over the past thirty years (summarized by Hoelzel et al 2007). As cataloguing efforts continue, there is more and more certainty about lineage. For older individuals there is some degree of uncertainty however, as some relationships had to be surmised at the onset of the study. Of the 299 resident whales (northern and southern) catalogued, the mothers of 208 (70%) are positively known; probable mothers are known for 46 whales (15%) and possible mothers are known for 15 (5%); 10% are completely unknown (Ford et al. 2000).

Southern resident killer whales have complex social structures, which rely on older female members of the group (matriarchs) to maintain social organization (Bigg et al 1990). Matrilines are groups of closely related individuals linked by maternal descent. An older female, or matriarch, represents the top tier of the matriline (Ford et. al 2000). As many as four generations may exist in one matriline (Deecke et al 2000). Groups of related matrilines (who likely share a common maternal ancestor) join to form pods (Ford et. al 2000). The SRKW population consists of three pods known as the J, K, and L pods. Pods with similar dialects are thought to be more closely related (Ford 1991). In 1991, Ford (1991) suggested that similarity in vocal repertoire reflects matrilineal relatedness and grouped pods with shared call types into acoustic clans. By comparing the acoustic similarity of pods (and matrilines) degree of relatedness can be determined (Deecke et al 2000). Several studies have looked at and classified existing vocal repertoires for all orca pods in the Pacific Northwest region (Miller et al 1999; Deecke et al 2000; Nousek et al

2006). These vocal repertoires have varying degrees of similarity based on relatedness. Studies have recorded calls from identified pods and described pod-specific repertoires of 7-27 call types (Ford, 1991). Ford identified and catalogued these call types in his 1987 call catalogue.

In an aquatic environment where light degrades quickly but sound travels well, cetaceans rely on acoustic means to communicate and maintain contact with each other under water (Myrberg 1980). Much research has been done on killer whale acoustics to establish vocal repertoires for pods (Ford 1987, 1991, Miller et al 1999; Deecke et al 2005; Nousek et al 2006). There is mounting evidence that killer whale calves learn vocalizations through mimicry rather than genetic inheritance (Janik & Slate 1997; Bain 1988). Since matriarchs are at the top tier of social organization in the killer whale society, it is important to study their vocal repertoire and frequency of calls in the SRKW society. It has been determined in African elephants that the oldest female individuals in groups have the greatest ability to discriminate between familiar and unfamiliar contact calls; that would likely mean greater survivorship for social groups led by older females than younger ones (McComb et al 2001). If this is true among SRKW's, then the matriarch is an invaluable member of the group. In addition, since calls are learned and likely develop through maturity, variation in call characteristics (harmonics) should be evident when comparing an adult's calls to a juvenile's, or a mother's calls to her calf's.

An example of pod hierarchy in the SRKW population would be that of J pod. J pod consists of four matrilines headed by the matriarchs J2, J8, J16, and J9 (Ford 2000). The above-mentioned individuals each are at the top tier of their own matrilines, being the mother, grandmother, and sometimes great-grandmother to anywhere from three to seven individuals. J2, J8, J16, and J9 are likely related through some matrilineal connection (sisters or maternal cousins). Together the J2, J8, J16, and J9 matrilines form J pod, which consists of 25 animals (Center for Whale Research 2007 ID catalogue). In the SRKW population, J pod sporadically associates with K and L pods forming a clan composed of all three pods (this clan is known at the J-clan) (Ford et al.2000). Through acoustic analysis, J and K pods have been shown to be more closely related to each other than either is to L pod (Ford et al. 2000). This study will investigate the possibility that matriarchs communicate more frequently than other individuals. If this is true, documentation of acoustic variation at different levels of social organization for J-clan could prove to be rooted in matriarchical delineation. In addition, I will compare calls made by a calf to her mother's calls. To test for significant variation, I will also compare that calf's call to calls of the same type (S2i) made by other random individuals. Finally, I will compare the calls made by the mother with the same random calls I compared against the calf's calls and test for significant variation. I hypothesize that the calf's calls will be significantly different from the mothers and the other random calls. I also hypothesize that the mother's calls will not be significantly different from the random calls.

There are many parallels between the structure of African elephant society and killer whales of the Pacific Northwest. Determination that matriarchs in killer whale populations indeed vocalize more often than other members of the group would expand on our knowledge of pod structure and the importance of matriarchs. Since it has already been established that vocalizations are learned throughout life, it would make sense that older females have more acquired knowledge (having longer life spans than males) and would therefore be the most beneficial individuals to a pod, as similarly with African elephants (Janik & Slate 1997, Foote et al. 2006). This would firmly establish the importance of matriarchs to the pod and the subsistence of orca populations. To further investigate the passing on of calls from one generation to the next I will compare calls made by an offspring with the same call made by its mother. If it is found that calls develop from birth over a certain number of months or years, development of call structure can be related to age and we can possibly determine an estimate of age by looking at call structure.

METHODS AND EXPERIMENTAL DESIGN

Data collection

Data collection was a joint effort of students working on the *Gato Verde*, a 42-foot, biodiesel sailing catamaran, between August 27 and October 20, 2007. Whales were recorded in the waters surrounding the San Juan Islands in the greater Puget Sound area of the Salish Sea (as shown in **Figure 1**). In order to record calls, hydrophones were dropped off the stern end of the boat and recordings were made of southern resident killer whales in the area. Calls were recorded and analyzed to determine the location of the source relative to the boat. In addition, photo records were taken to identify animals. Through localization, and detailed data taking, individuals can be matched with hydrophone recordings and to particular calls. Since estimated age and identity of all animals is known, statistical analysis will determine the number of calls made by each individual. Comparison of call rate made by identified matriarchs versus call rate of other animals will determine if social status correlates with call rate.

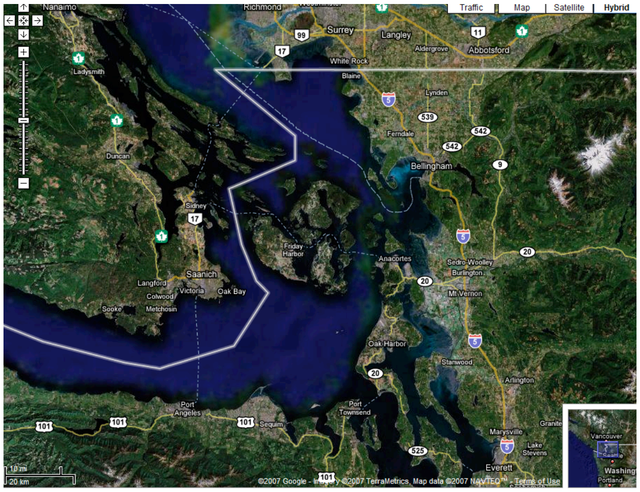

Figure 1 Hybrid satellite/map view of the San Juan Islands and surrounding waters

As mentioned above, we recorded various parameters to identify individual whales and localize their calls from the recordings made. To record calls, an array with Lab Core hydrophones was deployed and recordings of killer whales in the area were made. Peak sensitivity for the hydrophones is about 5000 Hz and it's down 30dB at about 200 Hz and 10,500 Hz. Two Sound Device, 702's, were used to record calls; their frequency response is flat from 10 Hz to 40 KHz (to 0.1-0.5dB). The sampling rate was 44,100 samples/sec and the gain was 37dB. The hydrophone array is a series of four hydrophones connected together and attached to a digital sound recorder onboard the *Gato Verde* (as shown in the diagram in **Figure 2**). To ensure that the hydrophone was deep enough to avoid surface turbulence and interference, an eight-pound weight was attached to the end of the array closest to the boat (after the fourth hydrophone was deployed). We deployed the hydrophones as soon as whales were seen in the general vicinity. Hydrophone specifics such as distance between hydrophones were then entered into the software program *Ishmael*, to be used for localizing the calls. To ensure that localization was as accurate as possible, we noted times at which the hydrophone array was not straight (such as when the boat was turning) and did not consider data from that time.

For data collection several students worked together to ensure detailed and accurate data points. The first step was to identify a focal animal. Each student was assigned a parameter to focus on and obtain detailed data points. To determine the position and identity of a whale, we took a picture of a relatively isolated individual and recorded the time, bearing (of animal relative to boat), and approximate distance from the boat to the animal at that particular moment. Distance was found using a range finder (Newcon Optik x9; LRM 2000PRC); if the animal was out of range, a visual estimate was made by range finding near-by boats and estimating the distance to the whale relative to the boat. Bearing was estimated using a standard protractor. An individual would stand at the stern of the boat and estimate the bearing of the whale relative to the boat.

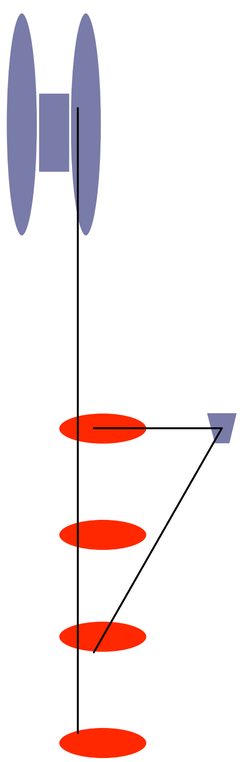

Figure 2 Diagram of *Gato Verde* trailing the 4 hydrophones array

Photographs of the focal animal were taken to later identify the individual. The photo number was recorded with the other parameters to later match photos with respective calls. A single person responsible for recording wrote down data called out for various parameters and recorded the exact time according to a GPS clock.

Data Analysis

Once the appropriate data was recorded, we localized calls and matched them to individuals. To localize calls, we used a program called Ishmael 1.0 (David Mellinger). In *Ishmael,* we opened a file and highlighted a particular call.

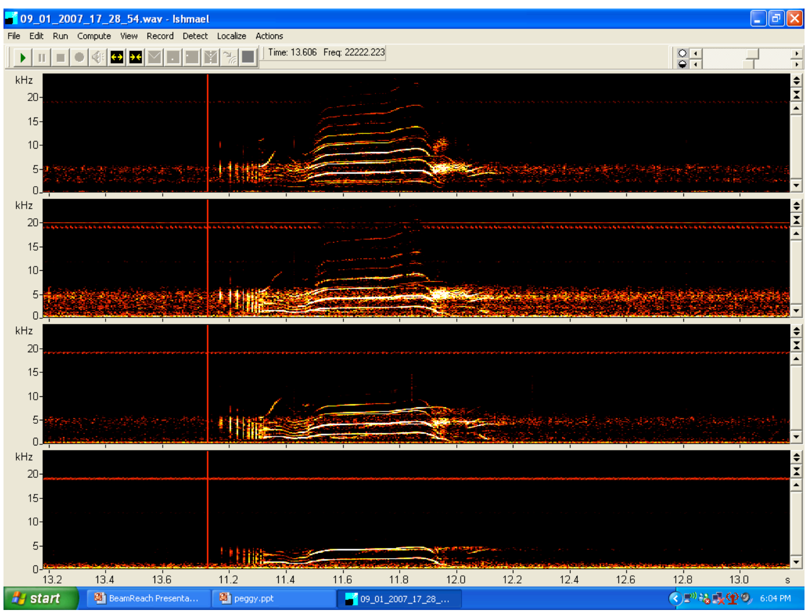

Figure 3 An example of an S2i call in *Ishmael*

An example of a call opened in *Ishmael* is shown in **Figure 3**. If the call was clear, and the background noise low, *Ishmael* gave (x,y) coordinates of that call relative to the hydrophone array. From those coordinates, we used simple geometry to determine the bearing of the whale that made that particular call as well as an estimate of the distance of that source to the hydrophones. Bearing was not one hundred percent accurate, as

Ishmael gave bearings without respect to the positive or negative x-axis. In other words, each bearing *Ishmael* gave was one of two possible positions. However, with detailed data taking, error could be avoided in most situations by paying attention to whether there was a whale was on the opposite side of the boat at the same time we were focusing on an individual in a comparable position on the other side. The numbers *Ishmael* gave were compared with the parameters recorded in the field. If the results in *Ishmael* were consistent with the data recorded, the results were included in the analysis. We accepted the localization if *Ishmael* gave a bearing within 15 degrees of the estimated bearing, distance was given less consideration as *Ishmael* did not always give accurate distance estimates. However when the distance given by *Ishmael* was not accurate we were very careful to consider the possibility of other animals being within range.

Variation in saddle-patch coloration and dorsal fin characteristics were used to identify individuals. Comparisons were made with the Center of Whale Research's (2007) Identification catalogue of southern resident killer whales. If a call was localized to a particular whale, we then matched our photo taken at the moment of the call with those of the Center for Whale Research's catalogue to identify that individual.

After I matched certain individuals with particular calls, I intended to separate the matriarchs calls' from other animals to determine if matriarchs vocalized more frequently than other animals and/or if they used particular calls more than other members of the pod. I was then going to compare the amount of calls matriarchs made with their proportion of the population. For example, if matriarchs were 25% percent of the population of SRKW's, and made 50% of calls, then I would know that they are vocalizing more than other individuals in the population. My intention was to use a t-test to determine if there was a significant difference in calling rate between the two groups (matriarchs and non-matriarchs). My hypothesis was that there would be a significant difference and that matriarchs would have a higher call rate than non-matriarchs.

The second analysis I intended to make was the difference in use of call type. It may be possible that matriarchs are using particular calls more than other individuals are. For that analysis, I would identify each type of call being made (from those calls that were localized). To identify calls, I referred to John Ford's (1987) SRKW call catalogue. After identifying each call type, I would then compare the amount of times matriarchs used each call compared with other animals (by graphing the calls). A t-test would once again be used for this analysis to see if there was a significant difference in the specific calls being made by matriarchs versus calls made by non-matriarchs.

The final analysis was the comparison of calls made by a mother to her calf. I wanted to determine if calls are modified over time when a sub-adult animal is learning them, and consider the change that occurs from one generation to the next. In reference to **Figure 3**, this call was known to be from a calf calling to her mother. The call was visualized in *Ishmael* to compare it to given call types, and compared to known calls acoustically by listening to Val Veirs' *Call Tutor*. In addition to comparing the calls between mother and calf, I also compared the mother's calls to those of random animals making the same call. Finally, I compared calls made by the calf and those same random animals compared against the mother.

Sample size depended on our ability to track whales and record individual animals suitable for acoustic isolation. In order to ensure replicability, animals were recorded at random and attention was paid to relative pod structure at the time of recording. In order to attain data as error-free as possible, data of calls was only accepted into the data-analyses with certain knowledge of who the source producer is.

RESULTS

Of data taken over an eight-week span of collection, seven calls could be localized and matched with certainty to particular individuals. In addition, seven more calls that were recorded and localized from a previous field-season were included in the data set. Of the 14 data points, none were of matriarchs. However, there was one set of data collected that was calls from a mother and her offspring. The mother, J22, and her calf, J38, were recorded calling back and forth to each other after being separated by some distance. Calls of the offspring were compared with those of the mother, and both mother and calf's calls were compared to calls of the same type by random individuals.

In all seven calls were identified as being from the calf, two from the mother, and seven more S2i calls from random individuals. These calls were compared against each other using an ANOVA. To compare calls the fundamental frequency of each call was found by measuring the lowest frequency contour of each call. The ANOVA reported values of $F_{2,13} = 9.12$, and $P=0.003$. This suggests significant variation between the fundamental frequency of calls between animals. **Figure 4** represents the mean fundamental frequencies of the calls made by a particular animal.

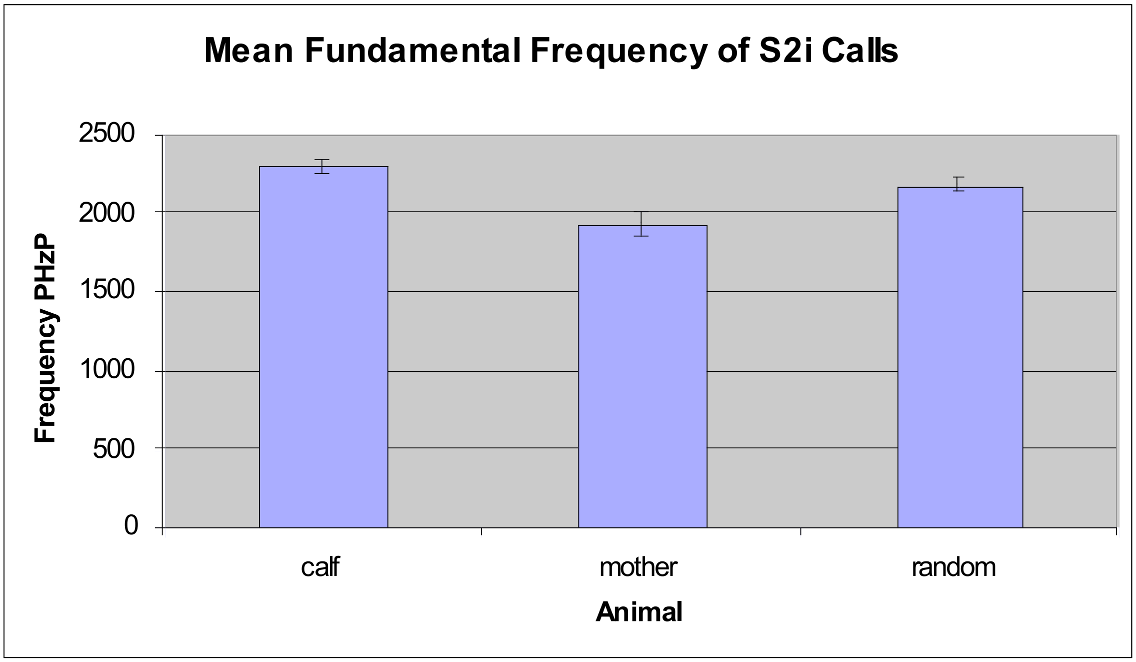

Figure 4 This graph represents the mean fundamental frequency of S2i calls made by the identified calf, mother, and random animals. Error bars are standard errors of the mean.

Animal	Mean	SE Mean
Calf	2301	41.01
Mother	1935	76.72
Random	2180	41.01

Figure 5 Mean and SEM measured from the fundamental of S2i calls

Because I found a significant difference with the ANOVA I ran a series of Tukey multiple pair-wise comparisons to determine which groups were significantly different. In comparing the mother and calf calls, the results were as follows: T = -4.207, P = 0.0027; a p-value of below 0.05 indicates that there were significant differences between the fundamental frequencies of the mother's and calf's calls. Reported values for the calf versus random animals are as follows: T=-2.091, P = 0.1303; there was not a significant difference between the fundamental frequencies of the calf's calls and the calls made by random animals. Finally, the values comparing the mother's calls versus the calls of random animals are as follows: T=2.813, P = 0.0365. There is a significant difference between the fundamental frequencies of these calls.

The results of these tests indicate that the frequencies of the calls made by the calf are comparable to those of random animals. There is no statistical difference between the data points. However, the fundamental frequency of the mother's calls is significantly lower than the fundamental frequency of the calf and random S21 calls.

DISCUSSION

Since there were no matriarchs localized, that part of the experiment could not be completed. Further, more detailed, investigation may lead to conclusive results. It is my hypothesis that matriarchs vocalize with particular calls, and possibly more frequently than other animals, however more data is needed before a conclusion can be made.

Significant differences in the call structure of the mother's calls and her calf's may indicate modification over time. This structural variation may be due to generational variation of calls. Further studies should investigate the change in calf calls over time. Previous studies have concluded that vocal production learning in killer whales starts with listening and memorizing vocalizations from an adult tutor (Kuhl et al 1999; Wilbrecht and Nottebohm 2003). Further investigation may show a learning curve in which the characteristics of the calf's calls approach the mother's in similarity with increasing age. Such learning curves have been proven in Atlantic Bottlenose dolphins, and are likely happening here (McCowen et al 1999). Differences in frequency may also be attributed to physiological differences in the mother and calf's sound production organs. Change over time in the calf's vocalizations may be due to a combination of erudite development as well as the physical development of those sound production organs (Janik and Slater 1997). Comparison should be made to more mother-calf pairs, as well as mothers to adult offspring, to determine if call differences decrease with age.

Significant differences between the mother's calls and S2i calls made by random other individuals of the same clan may indicate that differences between call structures exist outside of the matriline. Due to the small sample size of this study, more extensive data should be taken to come to a stronger conclusion about the relationships defined above.

Contrary to my hypothesis, there was not a statistically significant difference between the calf's calls and the calls made by random animals. This may be attributed to the small sample size and/or coincidence in who the random calls came from. Since they were random, they may have possibly been from young individuals or small adult animals that may have similar physiological conditions as the young calf. Further, detailed data should be obtained for continued investigation into this possibility.

Continued investigation into southern resident killer whale vocal communication as it relates to social hierarchy should be pursued. Only with extensive detailed data taking will we come to strong conclusions about the learning of vocalizations from one generation to the next. Matriarchs at the top of this social hierarchy may be determined to be significant or not in the cultural transmission of communication in the SRKW community. Only continued efforts will bring any such conclusion.

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