Sequential structure analysis in the vocal repertoire of the Southern Resident Killer Whales *orcinus orca*

Ashleigh Kemp

October 27, 2007
Beam Reach Marine Science and Sustainability School
http://beamreach.org/071

Introduction

Killer whales (*Orcinus orca*) are the largest member of the dolphin family (*Delphinidoe*) (Baird 2000). Killer whales are seen throughout the entire world's oceans, but in only a few locations can they be found reliably in protected waters. One such area is off the coast of British Columbia and Washington State, where the whales have been studies intensively since the 1970s. Through field identification of the individuals by means of natural markings on the dorsal fin and saddle patch, the whales of the Pacific Northwest are among the best-known cetacean populations (Ford 1991).

Classification

The killer whales of the Pacific Northwest are classified into three types. Offshore killer whales spend majority of their time out at sea, and are rarely encountered (Center for Whale Research 2007). The other two types are primarily coastal: transients and resident killer whales. Transients are marine mammal eating killer whales and travel in groups of 1-7 members. Residents, whom feed primarily on fish, live in stable family groups containing 5-50 individuals (Ford 1991). The resident killer whale populations are split into 'northern' and 'southern' communities. The communities are then further split into pods, and although pods associate within communities, pods of different communities do not interact (Ford 1987).

Social Structure

Each pod in resident killer whale community is made up of small social units called matrilineal groups, which are compromised of individuals related by matrilineal descent from a single living female (Ford 1991). The long-term stability of killer whale social structure has provided the opportunity to examine in detail the vocal behaviors of pods over extended periods (Ford 1991). There is evidence that resident pods have repertoires of discrete calls that are consistent over several years and that these repertoires differ amongst pods (Ford 1989)

Communicative system

Killer whales have a complex communicative system. Their repertoire is made up of three vocalizations; clicks, whistles and discrete calls (Ford 1989). Clicks are short broadband pulses of sound, which are used for echolocation during foraging and navigation (Ford 1989). Whistles are pure sounds with little harmonic structure. Although dolphins use whistles regularly in their repertoire, killer whales are rarely seen producing them (Ford 1987). Discrete calls are the third type of vocalization, which is the main focus of this study. Discrete calls have a harmonic structure and can be identified by the human ear due to their unique tonal structure. Dr John Ford (Ford 1987) published a catalogue of discrete call types of the northern and southern resident as well as transients. In Ford's research he identified 26 discrete call types for southern residents. It his later research it became apparent that pods had group specific dialect, and each pod had a distinct repertoire of 7-17 call types (Ford 1989, cited in Weiland 2007).

Whether vocalizations that are heard between the killer whales is a form of communication and to what degree, is an issue of controversy between researchers. In a study on semantic combinations in primate calls, putty-nosed monkey *Cercopithecus nicitans martini* were reported to respond to playbacks of what researchers thought to be warning calls. It was reported that the playbacks generally initiated the group to move on to another area (Arnold & Zuberbuehler 2006). Not many direct links have been made between discrete call types and behavioral responses in killer whales, therefore the reasoning behind many call types is unknown. Some research has associated discrete call types with broad behaviors such as foraging and socializing, but many call types are heard regardless of the behavior involved Ford (1989)

Aims

The aim of this study is to contribute data to the complex communicative system of the SRKW. This aim will be accomplished by:

- Sequential analysis – Determining if sequential patterns are evident
- Call frequency – Determining the frequency of call types within the recorded repertoire
- Interval analysis – Investigating into the intervals between call types within a sequences to determine if significant differences occur between various sequences

It is predicted that a sequential structure will be evident in the SRKW discrete call communicative system. It is expected that the frequencies of discrete call types within sequences will be comparable to other studies, such as Weiland (2007). Call sequence intervals are expected to diverge when sequences differ.

Methods

Definitions

Call Sequence : three identifiable call types spaced no more than 5 seconds apart

Position: ranking in call sequence, for example call type number on in sequence would be position number 1 in sequence

Interval: time elapsed between calls within a sequence

In the field

Discrete call types of the SRKW (J, K and L pods) were the target of this study. Whistles are rare and highly variable among killer whales, as well as clicks, which are primarily used for navigation and not social communication (Wieland 2007), therefore were not looked at in this study. Due to impracticability no pod specification were made during this study. All recordings were conducted from the *Gato Verde*, off the coast of Washington State, during an eight-week voyage during the months of August, September and October 2007. The *Gato Verde* is a 42-foot catamaran, with an electric-biodiesel fueled engine. The battery pack enables the *Gato Verde* to motor silently for up to 3 hours continuously. When extended motoring is required, the on-board biodiesel generator provides enough electricity to power the electric motors. This makes it possible to motor silently whilst recording vocalizations, as well as minimizing disturbances on the whales. A hydrophone array[1], with four hydrophones spaced at 10-m interval was towed behind the *Gato Verde* and used for recording data. The array was deployed either vertically or horizontally depending on the other student's requirements, on the port side steps. When the array was deployed horizontally it was at a depth of approximately 3m. Vertically the array's depths reached approximately 35m. The hydrophone was hooked into an amplifier that converts analogue into digital and records files onto a laptop through a program called 'Oval Locator'. A colleague, Anne Harman, listened to the recordings in real time whilst recording relevant information on a constructed data sheet. This assisted in filtering through sound files once analysis commenced. There wasn't an assigned distance the SRKW must be within of the *Gato Verde* for recordings to be valid, however only clear recordings, where discrete call types were visible and discernable by ear were used. Recordings were made opportunistically when SRKW's were present and ocean condition met acoustical recording requirements.

In the lab

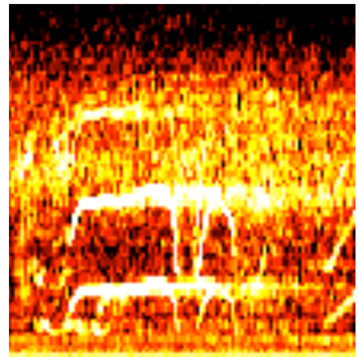
Programs that were used in analysis of recordings were Call Tutor[2] and Ishmael 1.0[3]. Two methods to identify discrete call types were used; visual and discernable by ear. Call Tutor is a sound displaying program, which has a library of pre-selected calls that allow you to listen to specific SRKW discrete call types. Calls could be played through Ishmael 1.0 and compared to Call Tutor for discernable identification. Ishmael 1.0 displayed visual spectrograms that were comparable to previous call cataloging work such as Ford (1987). Calls were classified based on an alphanumeric categories developed by John Ford using his catalogs of discrete calls (Ford 1987). Unique tonal patterns that are distinguishable to the human ear and manifests a pattern of frequency/time contours on a spectrographic representation of a call, characterize each call type (Wieland 2007). 17 discrete call types were identified during the analysis of recordings, therefore the call sequence matrix was composed of 17 call types, see Table 1. Spectrograms showing the distinct tonal structure for each of these 17 call types are shown in Figure 1. When

[1] 1. Lab Core Systems of Olympia Washington

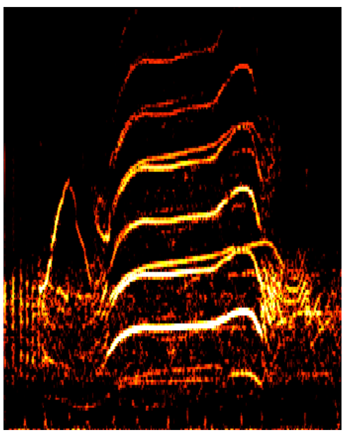
[2] Beam Reach 2006, Designed by Val Veirs

sequence was identified it was stored into the call sequence matrix. Intervals between call types within a sequence were recorded by making measurements using the spectrogram window in Ishmael 1.0.

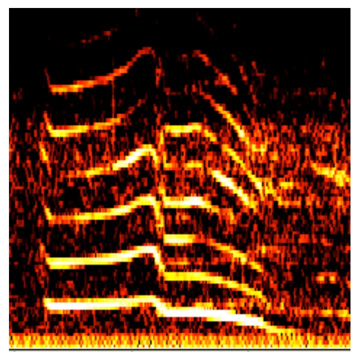
S1



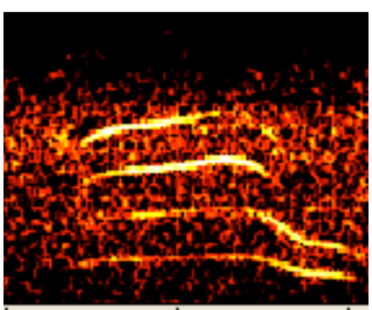
S2i



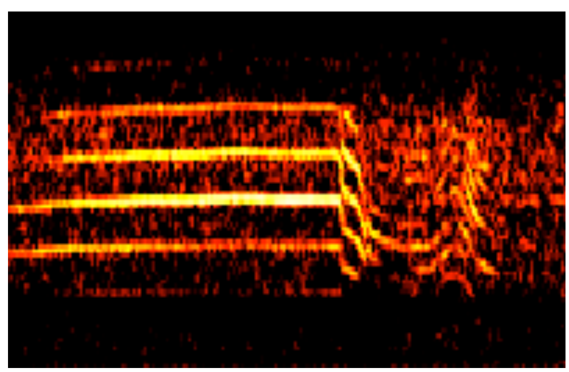
S2ii



S3



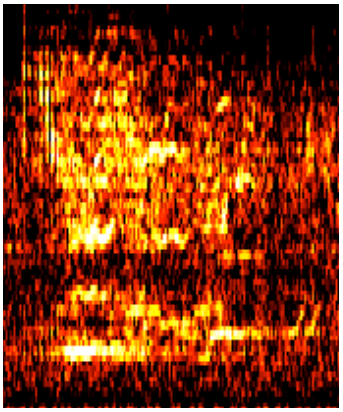
S6

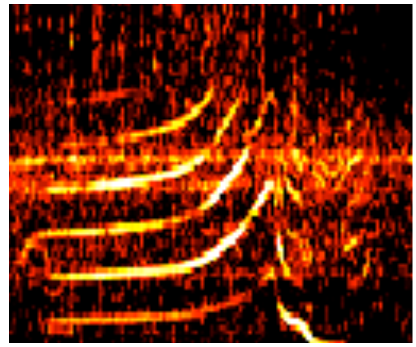


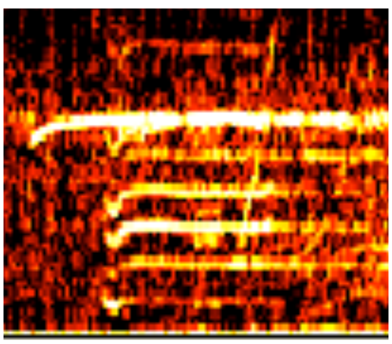
S7

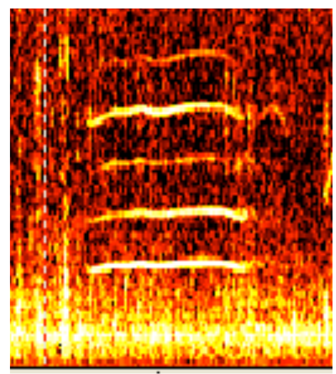
---

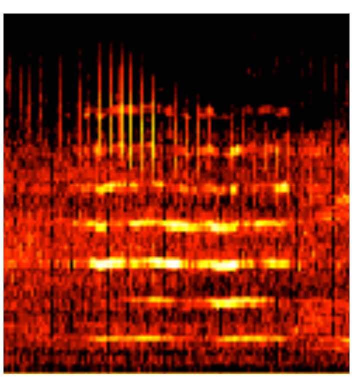
[3] Mobysoft.org

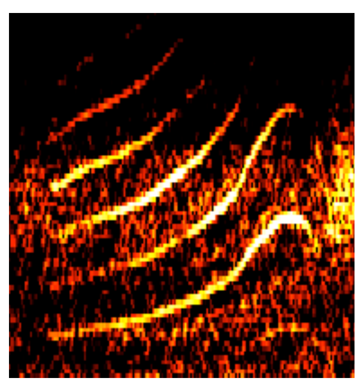

S10


S12


S13


S16


S17


S19

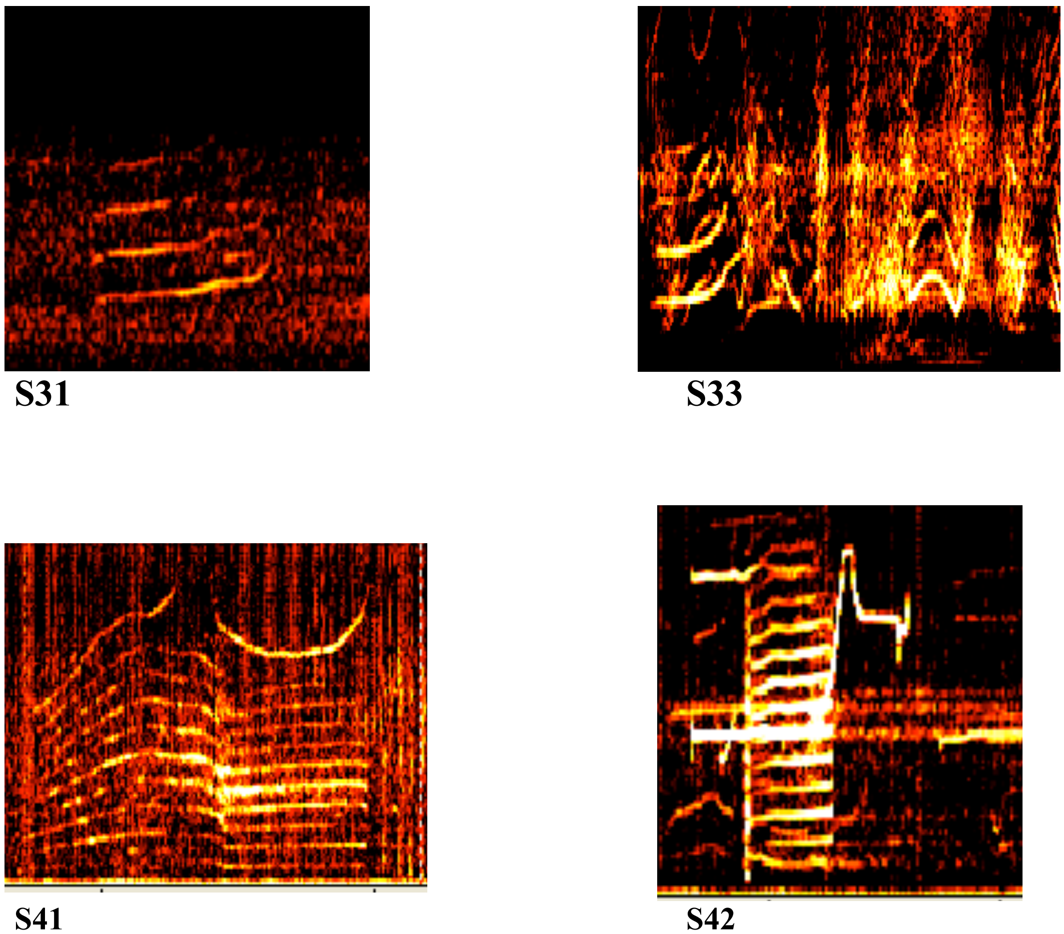


Figure 1. Spectrogram pictures of 16 of the 17 discrete call types identified in this study. Call type S22 was identified however did not have a clear spectrogram picture to display.

Results

A total of four recordings from four separate days were analyzed. After analysis 17 discrete call types and 104 call sequences were identified. Data from this present study was compared to studies from Ford (1987) and Weiland (2007).

Call Sequence classification

Call sequences were categorized into a matrix, see Table 1, then coloured coded into 1 of 4 call sequence classifications. The number of sequences in a particular call sequence classification was then calculated into percentages and graphed, see Figure 2. 44.2 percent of call sequences contained identical call types. 38.4 percentage of call sequences contained identical call types at position 1 and 2 (colour peach), or 2 and 3 (colour turquoise). 9.62 percent of the call sequences contained no identical call types (colour gray), and 7.69 percent contained identical call types at position 1 and 3 (colour green).

	S1	S2i	S2ii	S3	S6	S7	S10	S12	S13	S17	S19	S22	S31	S33	S41	S42
S1 S1	8			1							1					
S1 S17										1						
S1 S19	1															
S1 S3				1												
S10 S1	1															
S10 S6							1									
S10 S10							10									
S12 S12								2								1
S13 S13									2							
S16 S19														1		
S16 S42																1
S17 S1										1						
S17 S17	1		1	1						2						
S17 S2ii														1		
S17 S3				1												
S17 S7										1						
S19 S1	1							1								
S19 S3				1												
S19 S19	1															
S2i S2i					1											
S2ii S6																1
S2ii S10							1									
S2ii S16											1					
S2ii S2ii		1	5												1	1
S2ii S41			1													
S2ii S42														1		1
S3 S1				1												
S3 S10							1									
S3 S12							1									
S3 S13	1															
S3 S22													1			
S3 S3				12			2	1		1		1				
S31 S3				1												
S31 S31				1						1			1			
S41 S41								1								
S42 S10							1									
S42 S16																1
S42 S19											1					
S42 S2ii			1													
S42 S42			2								1					3
S6 S1							1									
S6 S10					1		1									
S6 S6	1															
S7 S17										1						
S7 S3				1												
S7 S7						1										

C all Sequence Classification	
(yellow)	All calls idenitical
(peach)	Calls 1& 2 identical
(turquoise)	Calls 2 & 3 identical
(green)	Calls 1 & 3 identical
(gray)	No calls identical

Table 1. Sequence matrix is showing the observed frequencies of three-call sequences of SRKW. The legend on the matrix identifies the 'Call Sequence Classification' categories. Yellow represents: all call types identical, peach: call type 1 and 2 identical, turquoise: call 2 and 3 identical, green: call type 1 and 3 identical and gray: no call types identical. Note 88.2 percent of call types are involved in a repetitive state.

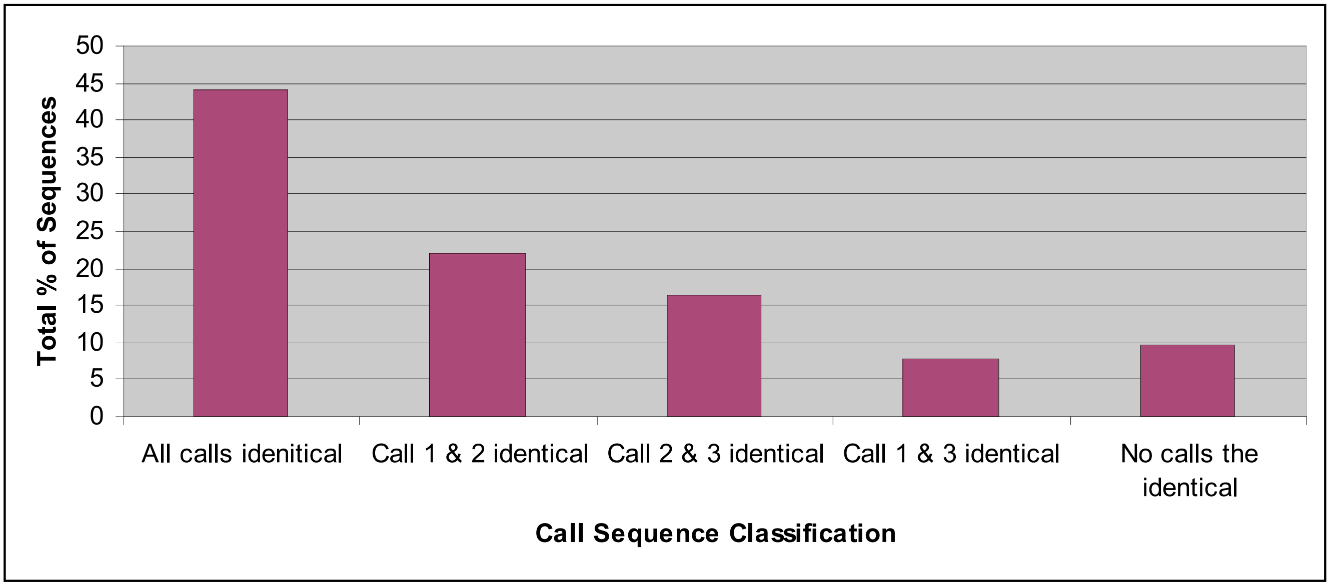


Figure 2. Call sequence classification comparison categories. Note the three highest-ranking call sequence classifications all contain identical call types of two or more. The highest ranking call sequence classification was all call types identical within a sequence

Frequency of call types in sequences

Frequencies of call types per position within the total repertoire of the matrix were the calculated into percentages and graphed, see Figure 3. Based on average calculations, discrete call type S1, S3 and S10 ranked the highest percentage of frequency in the repertoire of the recordings, 13.8, 20.8 and 14.7 percent respectively.

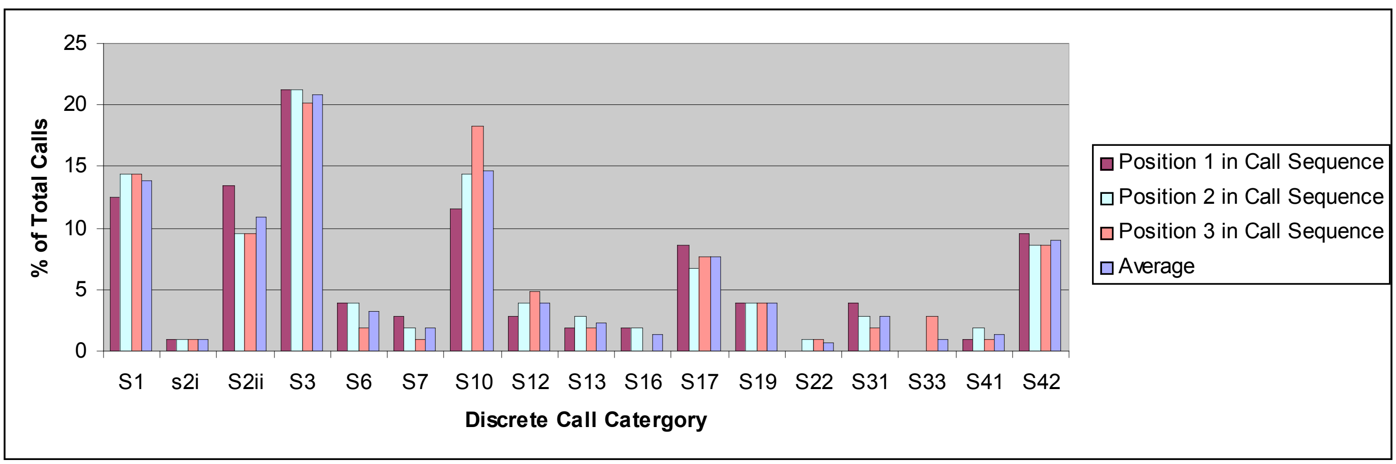


Figure 3. This graph shows the total percentage of call types within the recorded repertoires. The graph compares the frequencies of the call types within the different positions in a sequence, and hence gives an average.

Call intervals

During analysis all call intervals between positions within a sequence was recorded. The aim of this section of analysis was to discover if a significant difference occurred between the intervals in call sequences containing all identical call types (colour yellow) and call sequences containing no identical call types (colour gray). Call sequences containing no identical calls was expected to carry longer interval durations than sequences containing all identical call types. Two statistical test were run to compare mean intervals within a sequence (see Table 2.). The first test was run to compare the intervals between position 1 and 2 within a sequence. A t-test was chosen, as the variables were both independent of one another. The p value of the first t-test was 0.15267, which signifies that there is only approximately 15 percent chance that there is a significant difference between these intervals.

	All call types the same (yellow)	No call types the same (grey)
n	46	11
Mean (sec)	1.78261	2.36364
Standard deviation	1.11381	1.50151

Table 2. The mean interval difference (seconds) between calls in position 1 and 2. The t value calculated was –1.4502. As this number is not larger than 1, there is an unlikely chance that the data is significantly different

.

The second statistical test was also a t-test, and the mean intervals between position 2 and 3 in a sequence were compared (see Table 3.). The p value for this test was 0.15346, which is comparable to the previous t-test, and also suggests an insignificant difference in the data. Therefore the study fails to reject the null hypothesis that there is no significant difference between call sequences with identical call types and call sequences with no identical call types

	All call types the same (yellow)	No call types the same (grey)
n	46	11
mean	1.77174	1.27273
Standard deviation	1.07345	0.78625

Table 3. The mean interval difference (seconds) between calls in position 2 and 3 within a sequence. The t value calculated was 1.41739. As this number is very small there is an unlikely chance that the data is significantly different.

Discussion

Killer whale acoustic communication is vastly intriguing because of their highly social nature, their intelligence, and the fact that their communicative system is unique and complex, where many questions are yet to be answered (Wieland 2007). The SRKW in this study were observed to make 17 different call types, which were classified into a three-call sequence matrix. The purpose of this study was to better understand discrete call usage in order to help guide further studies. This goal has been met by revealing patterns in three-call sequences and by establishing call type frequency within a repertoire. This study provides first examination of call interval between positions within a three-call sequence.

Call sequence classification

Call sequences were coloured coded into 5 classifications that are referred as 'Call Sequence Classification'. The first classification represented call sequences that contained identical call types and were coloured yellow. The second represented call types being identical in positions 1 and 2 were coloured peach. The third represented call types being identical in position 2 and 3 and were coloured turquoise. The fourth represented call types being identical in position 1 and 2 and were coloured green and the final classifications represented no call types being identical and were coloured gray. 44.2 percent of the total call sequence matrix were call sequences containing three identical calls. These results coincide with similar studies that conclude the production of a particular call type is not an independent event. A call type is more likely that expected by chance to be followed by the same call type (Wieland 2007, cited Ford 1989, Miller et al 2004). Hoelzel and Osborne (1986) reported repetitive sequences made up 87 percent of the vocalizations they recorded. Similar results were reported in Wieland's (2007), call types that were involved in a repetitive sequences made up a 85 percent of the total vocalizations. 50 percent of the call types Hoelzel and Osborne (1986) heard were never heard in a repetitive sequence and only occurred sporadically. Similar results once again were found in Wieland's (2007) study with 48 percent of call types never occurring in a repetitive sequence. However in this present study 17.6 percent of call types were involved in a repetitive sequence, which is a considerable lower figure than previous studies have reported. This may be due to only 17 call types being identified throughout this study, opposed to Wieland's (2007) 24-call types in her study. Also this present study's sample size consists of 104 call sequences. At a minimum, the sample size should be at least 4 or 5 times the number of cells in the transition matrix (Wickens 1989). Based on the matrix in this study, assuming no other sequential orders were supplemented a sample size of 2944 would of been ideal. However due to time constraints this was implausible. As a result of a small sample size only strong correlation will be apparent.

In Ford's (1991) study it was found there was an association trend between specific call types, for example S16 and S17 for K and L pod, and S22 and S18 for L pod. However no associated trends aside from repetitive sequences was discovered in this study.

Call Frequency in three-call sequence matrix

On average percentage comparisons (Figure 3.) discrete call types S1, S3 and S10 ranked the highest percentages for frequency presence in the call matrix. In Wieland's study (2007) it was reported that call types S1, S3 and S10 were the most frequently used call types in J pod's repertoire. According to Wieland S1 and S3 call type was only found to be made by members of J pod, and S10 call type being mostly used by J pod but have been heard by members of K and L pod. This strongly suggests that members of J pod were producing majority of the vocalizations recorded. If that is plausible, then this present study emphasizes Wieland's study, that J pods most frequent three vocalizations are call types S1, S3 and S10. These three call types made up 49.3 percent of the total vocalizations in the sequence matrix. The fourth highest-ranking call type found in this study was S2ii, making up 10.9 percent of the sequence matrix. According to Wieland S2ii is L pods most frequently used call type. S2ii is minimally by K and J pod, which strongly suggests that L pod vocalizations were recorded during this study. Call type S17 was the sixth highest-ranking call type in this study. S17 is the second most frequent call type used by K pod (Wieland 2007). S17 is almost primarily used by K pod, which suggests that members were present during a time of recording. Overall these results indicates that all three pods were present at one time or another throughout the recording sessions. This study correlates with Wieland's results of the main call types of each pod making up majority of the repertoire in the call sequences.

Intervals between positions in a sequence

Wieland's (2007) study presented findings that 2-call sequences occurred significantly often, which raises the questions of whether intervals between call types are also structured and contains information. Intervals between positions 1 and 2 in a sequence were compared to call sequences containing all identical call types, and to sequences containing no identical call types. Intervals between position 2 and 3 in a sequence were also compared in the same way. A t-test was run to see whether a significant difference in intervals between to the two call sequence classification occurred. It was hypothesized that call sequences containing all identical call types would have shorter intervals. Sequences containing all identical call types contributed up 44.2 percent of the total vocalizations in the matrix. It would be expected that the animal would more likely to repeat the same call, therefore have less hesitation, and hence a shorter interval between calls. However this is not what was presented in the results of this study. A comparison on mean intervals between positions and the two call sequence classifications found no significant difference with either test. This may be due to a small sample size of n=46 and n=11 for all identical call types and no identical call types respectively. It may also be due to the fact that the animals do not hesitate when making vocalizing call sequences that contains no related call types. No other studies could be found on a similar topic so no comparisons could be made. Due to the results, this study fails to reject the null hypothesis that there is no significant difference between call sequences containing identical call types, and sequences containing none identical call types.

This study showed that three-call sequences are evident and are constituted of categorical patterns. Call sequences containing identical call types were most frequently abundant within the matrix, which coincides with studies that a particular call type is most like to have the identical call type follow (Ford 1989, Miller et al 2004). No significant difference was found between the mean intervals between positions within a call sequence between two-call sequence classification groups. From the results presented here, even more questions have arisen. This study forms the basis for more research into the call repertoire of Southern Resident killer whales.

References

Arnold, K. and Zuberbuhler K. 2006. 'The alarm-calling system of adult male putty-nosed monkeys *Cercopithecus nicitans martini'. Animal Behaviour,* 72: 643-653

Baird, R. W. 2000. 'The killer whale- foraging specializations and group hunting'. *Cetacean Societies,* University of Chicago Press. 127-153

'Center for Whale Research' 2007
[http://www.whaleresearch/thecentre/research.html] Center for Whale Research
Accessed: September 2007

Foote A D. 2005. 'Correlates of variability in killer whale stereotyped call repertoires', Thesis, University of Durham.

Ford, J. K. B. 1987. 'A Catalogue of Underwater Calls Produced by the Killer Whales (*orcinus orca*) in British Columbia'. *Canadian Data Report of Fisheries and Aquatic Sciences.* Canadian Journal of Zoology. No. 633

Ford, J. K. B. 1989. 'Acoustic Behavior of Resident Killer Whales (*Orcinus orca*) of Vancouver Island, British Columbia'. *Canadian Journal of Zoology*, 67 (3): 727-745

Ford, J. K. B. 1991 'Vocal Traditions Among Resident Killer Whales (*Orcinus orca*) in Coastal waters of British Columbia'. *Canadian Journal of Zoology*. 69 (6): 1454-1483

Hoelzel, R A. and Osborne R W. (1986). 'Killer Whale Call Characteristics: Implications for Cooperative Foraging Strategies'. *Behavioral Biology of Killer Whale.* 373-403

Miller P. J. O. 2002. 'Mixed- directionality of Killer Whale Stereotyped Calls: A Direction of Movement Cue?' *Behavioral Ecology and Sociobiology. 52: 262-270*

Miller, P. J. O., Shapiro A. D., Tyack P. L. and Solow A. R. 2004. 'Call-type matching in vocal exchanges of free-ranging resident killer whales, *Orcinus orca'. Animal Behaviour,* 67: 1099-1107

Wickens, T. D. 1989. *Multiway Contingency Tables Analysis for the Social Sciences,* Hillsdale: Lawrence Erlbaum Associates.

Weiland, M. 2007. 'Repertoire Usage of the Southern Resident Killer Whales (*Orcinus orca*)' Thesis, Reed College