Discrete Call-Type and Behavioral Event Associations of Southern Resident Killer Whales (*Orcinus orca*) in the Salish Sea

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Abstract

Southern resident killer whales (*Orcinus orca*) are seen in the coastal waters off British Columbia and Washington State. The long-term stability of pods allow for detailed study of their vocal behavior over time. Identifying the behavioral contexts during which specific types of vocalizations occur is a crucial step towards understanding vocal communications. A greater understanding of the communication system of killer whales could give us a better understanding of their customs, health and mental states as individuals or in the whole community. This information would be critical to the protection of the species. Behavioral events were compared with the different discrete call types localized to the group of whales within a 2 minute period of when the event was observed. The proportion of the different call types used in the context of different behavioral events is statistically significant, which signifies that the call-type pattern is not totally random. Peckslaps, breaches, tailslaps, and changes in direction have statistically significant higher counts of one to three discrete call types. This could signify particular meanings of those calls that are related to behavior displayed by a member of that group of whales. Further research and a larger sample sizes are needed for more concrete analysis of these calls and their roll in the communication system of the southern resident killer whales.

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Introduction

Southern resident killer whales (*Orcinus orca*) are seen in the coastal waters off British Columbia and Washington State. They are among the most studied of marine mammal species because of their consistent residence in these waters from June to October. The southern residents are made up of three pods: J, K and L. Together these pods make up a clan, or a group of pods with similar vocal dialects. They are considered to have a much older maternal connection than other pods of killer whales that inhabit close areas, such as the coastal waters of the northeast coast of the Pacific (Ford 1991, NMFS 2006). Killer whales have a highly developed social structure composed of matrilineal pods, descended from a matriarchal female. The long-term stability of pods allow for detailed study of their vocal behavior over time. Identifying the behavioral contexts during which specific types of vocalizations occur is a crucial step towards understanding vocal communications.

Behavior

There are five broad categories of activities that killer whales display on a regular basis, as described by the National Marine Fishery Service (2004). These are traveling, foraging, resting, play and milling. These behavioral states are usually coordinated by the entire group; although there are many exceptions to this generalization (Ford et. al. 2000, NMFS 2006). During traveling, killer whales move in a constant direction with varying speeds, usually 5-10 km/hour, attaining speeds up to 40 km/hour. Traveling whales often line up in tight formations and surface and dive in synchrony (NMFS 2006). A considerable amount of time is spent foraging. Cooperative hunting and food sharing are notable actions of foraging whales. Pursuing prey often involves a lot of subtle changes in direction, speed, and dive lengths. Foraging whales may also have sudden bursts of speed, or occasionally work together to corral fish near the shore (but this has not been observed in the Puget Sound) (NMFS 2006). Resting often follows periods of foraging. The matrilines, or pods, gather together in a tight formation, with animals diving and surfacing in unison and at regular intervals; usually 2-3 minutes at the surface followed by a short 2-5 minute dive (Ford et al. 2000, NMFS 2006). Socializing behaviors are seen most frequently by juveniles and may represent a kind of play (NMFS 2006). The three specific categories are 1) object play, such as with kelp or floats, 2) social interactive play, such as touching, breaching, or percussive behaviors, and 3) solitary play (NMFS 2004). Some of these activities may be used as both visual and acoustic communication (Ford et. al. 2000). Play activities typically involve a lot of physical contact, and male members of the pod often display sexual behavior, such as penile erections and nosing of genital areas (NMFS 2006). Milling is defined as repeated, non-linear, non-directional movement, at slow (less than 2 knots) or medium (2-6 knots) speeds (NMFS 2004).

Vocalizations

Killer whales produce three types of sounds in underwater communication; whistles, pulsed calls, and echolocation clicks (NMFS 2006, Ford 1989). A great deal of these vocalizations may be utilized as a means of communication between individuals or to the entire pod. While there is no conclusive evidence as to the meaning of specific vocalizations, the social complexity and unity of any one pod or community of killer whales suggests that they must have a communication system that allows them to maintain group cohesion through time and space (Simon et al. 2007).

Whistles in killer whales have rarely been studied, and thus their function is still unknown. In a variety of other vocal delphinids, whistles are used as an individual signature (Rehn et al. 2007). Given the social structure of resident killer whales, this is unlikely because group identity is more important than individual identity (Rehn et al. 2007). Also if this was true, we would expect to see a greater variety of stereotyped whistle signatures in order delineate one individual from another (Rehn et al. 2007). Whistles are the dominant sound produced during socializing and also have a high rate of usage during social traveling (when whales from the same or different clans are interacting at close range) (Ford 1989, Thomsen 2002, Simon et al. 2006)). Sequences of pulsed whistles have often been observed to be used in play-fights among juveniles and subadults (Rehn et al. 2007). It is also possible that the transmission of whistles, in contrast with discrete calls, is not restricted to the dialects of related clans (Riesch et al. 2006).

Echolocation clicks are brief pulses of ultrasonic sound used as a type of sonar for the whales (NMFS 2006). They are heard as single clicks, or many times as click trains, used to assist in prey location and spatial orientation (Barrett-Lennard et al. 1996). There is a fairly large database of information that supports this theory, and thus echolocation clicks will not be a focus of this study (Ford 1989, Barret-Lennard et al. 1996, NMFS 2006)

Pulsed calls can be discrete, aberrant, or variable. Discrete calls are used by the whole pod and make up the repertoire of their vocalizations (Ford 1991). These repertoires remain stable within the pods for as long as 20 years and longer (Ford & Fisher 1983, Ford 1989, Ford 1991). Pulsed calls have distinct structural characteristics that can be seen in spectrograms. Aberrant calls are based on discrete calls, but are highly distorted in structure (Ford 1989). Variable calls are more complex than discrete calls, cannot be arranged into any discernable structural categories, and are not repetitive (Ford 1989). Ford (1991) classified discrete pulsed calls in an alphanumeric fashion, cataloging calls in an arbitrary fashion by which calls were identified first. They are preceded with the letter S to indicate that the call was consistent with a call given by the southern residents. In total, the southern residents have 44 discrete call types; four of which have variations particular to one or two of the three pods making up the southern resident community.

Discrete calls are most often used during times of group dispersion, and comprise 95.2% of all calls during foraging, and 94% of all calls during traveling in the northern residents (Ford 1989). This indicates that discrete calls are used as a way to maintain contact between pod members and/or maintain spatial organization (Ford and Fisher 1983, Ford 1989, Riesch et al. 2006). However, this does not explain the large repertoire of calls when only one or two discrete calls could serve this function. Ford (1989) proposed that the repertoires of killer whale calls have evolved in order to "increase the reliability and efficiency of intrapod communication." Discrete calls could also serve other functions, such as reflecting emotional states, behavioral activities or specific features within the environment. Morton et al. (1986) studied discrete calls in captive and wild killer whales. That study found several calls used at significantly higher rates during particular activity states. For example, the call F1 was correlated with behavioral synchrony and calm states, B1 with play or "pleasurable" activity states, and G1 with periods of stress. While this was a very preliminary study, it demonstrates the fact that discrete call-type usage is not random and that each call-type may have a specific significance.

Problem Statement

In previous studies there have been strong correlations between vocalization types and their rate of use and the behavioral state of the whales (Morton et al. 1986, Tarasyan et al. 2005, Simon et al. 2007). However, these studies associating killer whale behavior with vocalizations have looked at a group of animals and summarized their behavioral states. They focused on all calls produced by the group; localization of any one animal was not attempted. The objective of my study is to identify the vocalizations coming from a specific killer whale and relate that directly to the behavior that particular animal is expressing at the same time. This kind of detailed analysis could be very useful in recognizing the patterns that indicate the function or meaning of discrete calls or whistles. The three southern resident pods each have their own dialect shared within the pod and many calls overlap between the pods. These repertoires have remained relatively stable in excess of 25 years (Ford 1991). There is some inherent change that comes with the death and birth of individuals as the community changes, or with changes in their environment. These factors, over an extended period of time, could stimulate the loss or gain of new calls in the pod's repertoire; nevertheless these changes are consistent with the whole pod (Ford 1991). Because the southern residents share a similar dialect, it can be assumed that the calls have similar meanings, even between pods. A greater understanding of the communication system of killer whales could give us a better understanding of their customs, health and mental states as individuals or in the whole community. This information would be critical to the protection of the species.

Methods

The observation period spanned from September 6, 2007 to October 20, 2007. The study area was the waters surrounding the San Juan Islands, WA, USA. The observational platform was a 42-foot catamaran, the *Gato Verde,* with a quiet, hybrid, electric-diesel engine. A hydrophone array was connected to two solid state recorders and towed behind our research vessel, at known distances from the aft stern. The four hydrophones were LAB-core hydrophones, with peak sensitivity at ~5,000Hz which dropped 30dB at ~200Hz and ~10,500Hz. The solid state recorders used were Sound Devices 702; sensitivity flat from 10Hz – 40kHz (+0.1 to -0.5dB). The sampling rate was set to 44,100 samples/sec and the gain setting to 37dB. An 8 lb weight was attached to the end of the hydrophone array by a bungee cord, and supported by a rope, to sink the array to a depth of 3-5 m. This deployed the hydrophones below the turbulence of the upper layer of water and kept all four hydrophones parallel to the surface. At the start of each recording session, time and file name were logged. During the recording period, surface behaviors were monitored and distinct behavioral events recorded. These behavioral events are defined in Jacobsen (1986) and Osborne (1986). For each behavioral event, the number of times the event occurred, real time (hour: minutes: seconds), estimated bearing and distance, and number of individuals in the group was also recorded. The bearing was estimated with the aid of a protractor with the 0 degree reference point fixed at the head of the boat; regardless of the actual bearing of the boat. The distance was visually estimated with the aid of a Newcon Optik rangefinder (LRM 2000 PRO).

After collecting data, individual behavioral events were reviewed for analysis. Any call within two minutes (one minute before and one minute after) was determined to be associated with the behavior. No other previous research has looked at behavioral events, only behavioral states. Therefore this time interval is appropriate because it allows for some reaction time of the animal on either side of the event, and is short enough to distinguish between events.

The files were split into 1 min, 16 bit files in order to make them easier to analyze. Each call identified in the 1-min interval was localized using the Ishmael 1.0 program (David Mellenger). The sound files were analyzed using the time difference between when a call reached each hydrophone to determine the origin of the call. I used the hyperbolic localization option in the Ishmael program, because it creates six hyperbolae by pairing each of the hydrophones to each other to create the most accurate point of origin of the call by finding the intersection of the hyperbolae.

The localization point of a call given by Ishmael, was matched to the distance and bearing of individual whales while they are displaying surface behavior. The distances were calculated using the Pythagorean Theorem with the coordinates of the call given by

Ishmael. The source points given by Ishmael were incorporated into the analyses if the bearings and distances estimated on the boat were within 15 degrees and 200 meters when the call was localized to a point within a 90 degree range perpendicular to the beam of the hydrophone array. Any calls localized to a point outside of this were incorporated into the analysis if they were within 20 degrees and 300 meters; because accuracy decreased when behavioral data was taken closer to 0 and 180 degrees. This method was chosen due to the large sources of error on both types of measurements, and there is no precedence found in previous studies to distinguish between individuals. The bearing was eyeballed with the use of the protractor on the boat, and thus is subject to a large magnitude of human error. The rangefinder has an error range of plus or minus one meter. However, if it doesn't hit a large enough target, then the distance was estimated by sight only and this produces a large range of human error as well. Acoustic localization error increases with the distance of the source from the hydrophone array (Janik 2000). Ishmael's program also produces cross-correlation graphs that can be used as a qualitative representation of its own level of error and was taken into account.

The calls were visually compared to Ford's call (1987) catalogue of southern resident calls, and acoustically compared to the CallTutor Program (Val Veirs) to determine call type. All data was then assembled into an Excel spreadsheet (Microsoft). This organizes all observed behaviors with associated calls in that two minute period, along with the time, bearing, and distance.

The call-type data for each type of behavior was summarized by taking a simple summation of the number of times each call type was represented within the two minute time interval of the observed behavioral event and divided by the total number of recorded calls during those events. These counts were compared using a chi-square test to determine if there are any calls used at statistically significant higher rates during each behavioral event.

Results

While my original goal was to localize the calls from individual animals, the grouping behavior of the whales observed during my field time and the large amount of error in my measurements made that unfeasible. However, the localization by Ishmael was able to distinguish calls given by the group of animals where the behavioral events were observed within my acceptable range of error. Therefore I am reporting my results of the call-type associations by the group of animals within my range of error, as described above, and the behavioral events displayed by one member of that group.

Five days of data were analyzed, within which 162 discrete calls were identified, localized and assigned to individual behavioral events. Many of the localized calls were used multiple times; once for each time it was localized within the two minute interval of a behavioral event, regardless if it was associated to another previous event.

The chi-square values were calculated for each call-type represented in the data set, as seen in table 1. The total chi-square value was 352.2, at 308 degrees of freedom and gave a p value of 0.0419. This is below the critical p-value of 0.05, which means that these results are statistically significant. Twenty-two individual chi-square values were significantly different than the expected value, i.e. above the critical value of 3.841, at 1 degree of freedom (Wheater and Cook).

S6	0.080	0.006	0.370	0.012	0.025	0.123	0.031	0.006	0.006	**8.224**	0.006	0.043	0.019	0.056	0.117
S7	0.321	0.025	0.156	0.049	0.099	0.494	0.123	0.025	0.025	0.395	0.025	0.173	0.074	0.222	**13.653**
S8	0.080	0.006	1.070	0.012	0.025	0.123	0.031	0.006	0.006	0.099	0.006	0.043	0.019	0.056	0.117
S10	0.016	0.068	2.320	0.136	**10.999**	0.303	0.340	**12.795**	0.068	3.371	0.068	0.475	0.204	0.247	1.290
S12	1.117	0.074	1.344	**4.898**	0.296	0.156	1.070	0.074	0.074	2.779	0.074	0.519	0.222	2.667	1.407
S13	0.160	0.012	2.141	0.025	0.049	0.247	0.062	0.012	0.012	0.198	0.012	0.086	0.037	0.111	0.235
S14	0.160	0.012	0.741	0.025	0.049	**12.447**	0.062	0.012	0.012	0.198	0.012	0.086	0.037	0.111	0.235
S16	0.181	0.117	0.590	0.235	0.469	2.346	3.407	0.117	**6.644**	1.877	0.117	0.039	**7.720**	0.845	3.447
S17	1.117	0.074	1.469	0.148	0.296	0.181	0.370	0.074	0.074	1.185	0.074	0.519	0.222	0.667	0.118
S19	0.883	0.068	0.283	0.136	0.272	**9.767**	1.285	0.068	0.068	1.086	0.068	0.475	0.204	0.247	0.065
S22	0.321	0.025	1.556	0.049	0.099	0.519	0.123	0.025	0.025	0.395	0.025	0.173	0.074	0.222	0.469
S31	1.043	0.080	**4.815**	0.160	0.321	**12.036**	0.401	0.080	0.080	**17.322**	0.080	0.562	0.241	0.722	0.181
S33	0.802	0.062	3.704	**6.223**	0.247	0.045	1.549	0.062	0.062	0.988	0.062	0.432	3.585	**10.756**	2.847
S36	0.160	0.012	0.741	0.025	0.049	0.247	0.062	0.012	0.012	**16.448**	0.012	0.086	0.037	0.111	0.235
S37	0.049	0.062	**7.574**	0.123	0.247	1.235	0.309	0.062	0.062	0.988	0.062	0.432	0.185	0.556	1.173
S41	0.160	0.012	0.091	0.025	0.049	0.247	0.062	0.012	0.012	0.198	0.012	0.086	0.037	0.111	2.498
S42	0.342	**21.186**	2.235	0.086	0.173	0.864	0.216	0.043	0.043	0.691	0.043	0.302	0.130	0.389	0.821
S44	0.321	0.025	0.156	0.049	0.099	0.494	0.123	0.025	0.025	0.926	0.025	**19.316**	0.074	0.222	0.469

Table 1. The chi-square values for all behavioral events and associated localized calls during the observation period. Significant individual values (>3.841, p=0.05, df=1) are in bold. Total chi-square value=352.2, df=308, p=0.0419.

However, because the table is so large the interpretation of any significant associations is very difficult (Wheater and Cook 126). Also, the mean expected observation values should be at least six for tests of association to have more statistically meaningful results (Wheater and Cook 132). Therefore, the behavioral events with a total occurrence of greater than ten were analyzed again in a separate chi-square test. The total chi-square value was 96.2, at 36 degrees of freedom, p=2.159e-7. This is far below the 0.05 critical p-value and therefore is statistically significant. These five behavioral events are shown in table 2.

Call Type	tailslap	breach	porpoising	peckslap	change direction
S1	1.001	0.216	2.263	1.697	1.341
S2	0.008	3.030	1.455	1.091	1.000
S10	0.027	1.689	0.667	**5.456**	0.778
S12	1.095	0.910	0.066	**4.251**	0.889
S16	0.083	0.021	1.778	1.333	**11.677**
S17	0.205	0.240	0.002	1.455	0.083
S19	1.091	0.426	**8.642**	1.091	0.000
S31	1.576	**6.303**	**7.236**	**12.422**	0.137
S37	0.037	**3.555**	1.616	1.212	1.111
S42	0.102	1.503	0.970	0.727	0.667

Table 2. The chi-square values of behavioral events and associated localized calls occurring greater than ten times during the observation period. Significant individual values (>3.841, critical p=0.05, df=1) are in bold. Total chi-square value=96.2, df=36, p=2.159e-7.

In the second chi-square test, eight of the individual chi-square values were significantly different than the expected values. The call-type S16 was significant for change in direction. This is the largest contributing chi-square, with a value of 11.677. This category has an n value of 19; the contribution of each call type is seen in figure 1.

The call-types S10, S12, and S31 were significantly different than the expected value for peckslaps (n=16). The call types S19 and S31 were significantly different than the expected value for porpoising (n=20). The call types S31 and S37 were significantly different than the expected value for breaches (n=60). There were no significant call-types for tailslaps (n=13). The S31 call-type is the only one where the occurrence of the call-type is significantly less than expected in association with breaches; all other significant values represent a larger than expected value for the call-type occurrence. The positive or negative difference from the expected occurrence is summarized in table 3.

Call	tailslap	breach	porpoising	peckslap	change direction
S1	0	0	0	0	0
S2	0	0	0	0	0
S10	0	0	0	+	0
S12	0	0	0	+	0
S16	0	0	0	0	+
S17	0	0	0	0	0
S19	0	0	+	0	0
S31	0	--	+	+	0
S37	0	+	0	0	0
S42	0	0	0	0	0

Table 3. The positive or negative difference from the expected occurrence of calls in association to behavioral events.

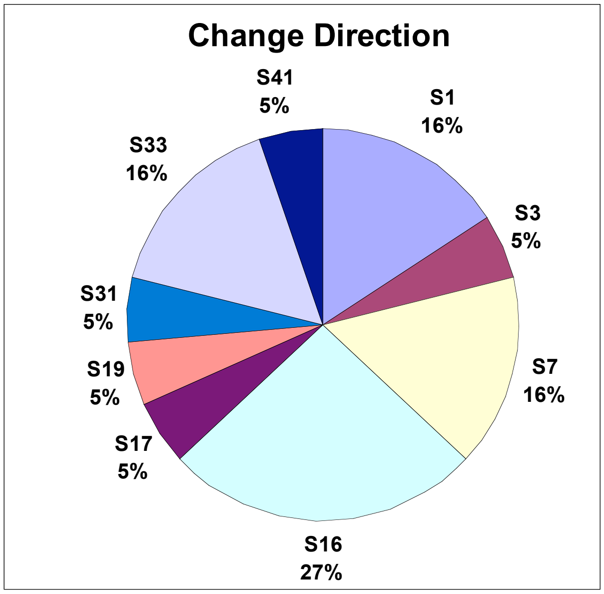

Figure 1.

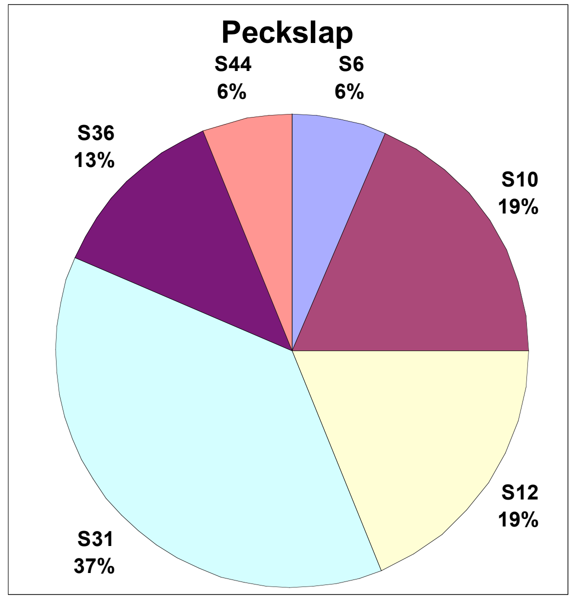

Figure 2.

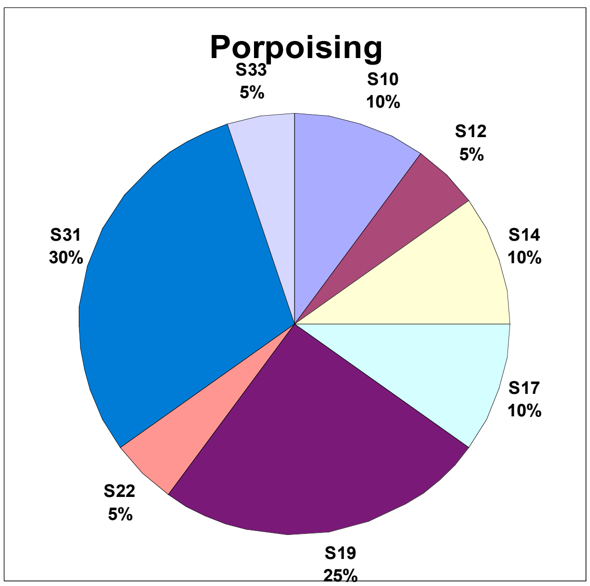

Figure 3.

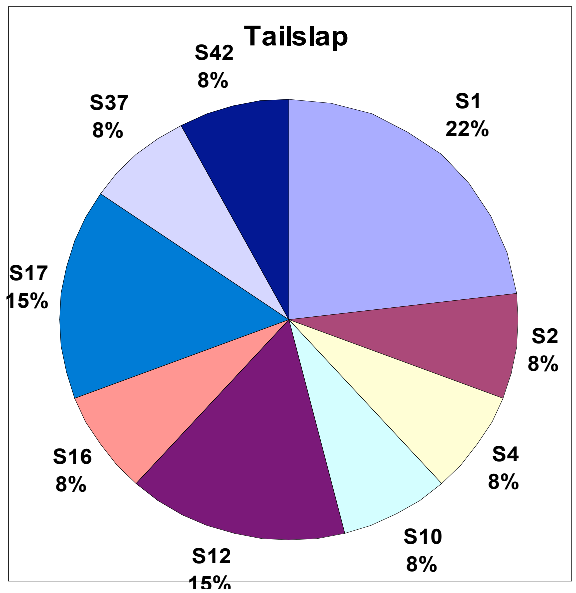

Figure 4.

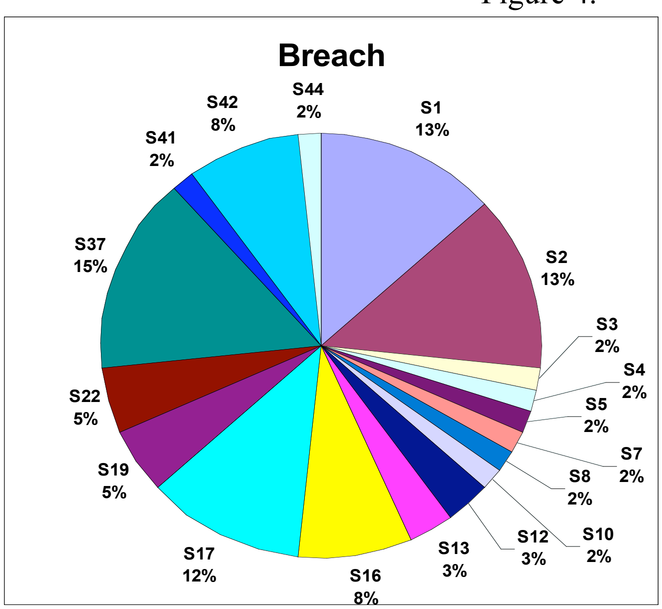

Figure 5.

Figures 1, 2, 3, 4, & 5. Call-type percentage contributions to calls made by one member of the group of whales within the 2-minute time interval of a change indirection (figure 1), peckslap (figure 2), porpoising (figure 3), tailslap (figure 4), and breach (figure 5).

Figures 1, 2, 3, 4, and 5 show that many call types are present within the two minute interval of the behavioral event. Many of these calls may have nothing to do with the occurrence of the behavioral event. However, they also illustrate that it is a not a random distribution, which may have significance to the communication of whales within the group or among the other whales in the area.

Discussion

The ultimate goal of this kind of research is to learn about the communication system of the southern resident killer whales. Each discrete call-type may have a specific meaning. These meanings could be inferred by looking at the context in which they are used. The small sample size and degree error in my study is far too small to make any conclusions about the meaning of any one call. However, the fact that both chi-square tests were statistically different from the expected total chi-square value, and significant results found in the second chi-square test, with $n>10$, show that the use of different call types with the context of certain behavioral events is not totally random.

The occurrence of S16 by a group of whales during a change in direction of one of the whales compromised, on average, over a quarter of the calls used in that two-minute interval, indicating that the S16 call-type may have a connection, or meaning, with changes in direction of travel. This could possibly be a command to change directions, or to notify other whales in the vicinity that there has been a change in the direction of travel by at least one whale.

Over 50% of calls during porpoising were consisted of S19 and S31. Both of these calls are very short, about 0.5 seconds, they have only one part, or subdivision, to the call, and have a contour that shifts to a high frequency at the end of the call. This resemblance may signify that the calls have a similar meaning; especially within the context of porpoising since they were both used in large proportions during that event.

Call composition during peckslaps was markedly different. Calls S10, S12 and S31 comprised 75% of all calls made during that period. These three calls do not look or sound alike. S10 and S12 are two part calls that last at least one second on average, unlike S31 as described above. The contours of S10 and S12 are very different, and thus they sound very distinct from each other.

The call S31 was conspicuously absent from periods when breaches occurred. This is the only instance of this. There may be something considerably different communicated during peckslaps and porpoising where S31 contributed a lot to the number of calls made from that group. S37 contributed 15% of the calls occurring during breaches. The call itself is very distinct from S31. It is a two part call, lasts about 1 full second and has a very different contour, ending in a steady frequency rather than shifting up at the end. This may signify that S31 and S37 have very different implications in the context of a breaching whale, which is why they are not used in the same ratio.

There could be many reasons for these results. The calls represented in my data analysis could be a call by the individual who displayed the behavioral event, or from one of the group members. However, the action could be a response to a call, or the calls could be a response to the action. This is an area for further technique development and research that can more accurately pinpoint the origin of the call and distinguishing whether the calls came before or after the event in the statistical analysis.

Each call-type may also have multiple meanings in different contexts, or variations. This requires a different kind of analysis that looks at variations in discrete calls from individuals, behavioral states, or any number of other variables that could affect the intention of the call.

The proportions of the different call types used in the context of different behavioral events is not a totally random pattern. Peckslaps, breaches, tailslaps, and changes in direction have statistically significant higher counts of one to three discrete call types. This could signify particular meanings of those calls that are related to behavior displayed by a member of that group of whales. Further research and a larger sample sizes are needed for more concrete analysis of these calls and their roll in the communication system of the southern resident killer whales.

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Literature Cited

Barrett-Lennard, Lance G., John K. B. Ford and Kathy A. Heise. (1996) "The mixed blessing of echolocation: differences in sonar use by fish-eating and mammal-eating killer whales." Animal Behaviour, 51: 553-565.

Ford, John K. B. and H. Dean Fisher. (1983) "Group-specific dialects of killer whales (*Orcinus orca*) in British Columbia." In: Communication and Behavior of Whales (ed. Roger Payne), pp.129-161. Boulder, Colorado: Westview Press, Inc.

Ford, John K. B. (Jan 1987) "A catalogue of underwater calls produced by killer whales (*Orcinus orca*) in British Columbia." Canadian Data Report of Fisheries and Aquatic Sciences No. 633.

Ford, John K. B. (1989) "Acoustic behaviour of resident killer whales (Orcinus orca) off Vancouver Island, British Columbia." Canadian Journal of Zoology, 67 (3): 727-745.

Ford, John 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.

Ford, John J. B., Graeme M. Ellis and Kenneth C. Balcomb. (2000) Killer Whales Second Edition: The natural history and genealogy of *Orcinus orca* in British Columbia and Washington. University of Washington Press, Seattle WA.

Jacobsen, J. K. (1986) "The behavior of *Orcinus orca* in Johnstone Straight, British Columbia." In: Behavioral Biology of Killer Whales. (ed. B.C. Kirkevold & J. S. Lockard), pp.135-185. New York: A. R. Liss.

Janik, V. M. (Apr 2000) "A two-dimensional acoustic localization system for marine mammals." Marine Mammal Science, 16 (2): 437-447.

Morton, Alexandra B., John C. Gale, and Renee C. Prince. (1986) "Sound and behavior correlations in captive *Orcinus orca*." In: Behavioral Biology of Killer Whales. ed. B.C. Kirkevold & J. S. Lockard), pp.303-333. New York: A. R. Liss.

National Marine Fisheries Service. 2004. "A consensus coding scheme for killer whale behavior." SRKW Behavior Workshop, NOAA NMFS NFSC, Seattle WA.

National Marine Fisheries Service. 2006. Proposed Recovery Plan for Southern Resident Killer Whales (*Orcinus orca*). National Marine Fisheries Service, Northwest Region, Seattle, Washington. 219 pp.

Nielsen, Bjarke Klit and Bertel Mohl. (2006) "Hull-mounted hydrophones for passive acoustic and tracking of sperm whales (*Physeter macrocephalus*)." Applied Acoustics, 67: 1175-1186.

Osborne, R. W. (1986) "A behavioral budget if Puget Sound killer whales." In:

Behavioral Biology of Killer Whales. (ed. B.C. Kirkevold & J. S. Lockard), pp.211-249. New York: A. R. Liss.

Rehn, Nicola, Stefanie Teichert and Frank Thomsen. (Feb 2007) "Structural and temporal emission patterns of variable pulsed calls in free-ranging killer whales (*Orcinus orca*)." Behaviour, 144: 307-329.

Riesch, Rudiger, John J. B. Ford, and Frank Thomsen. (2006) "Stability and group specificity of stereotyped whistles in resident killer whales, *Orcinus orca*, off British Columbia." Animal Behaviour, 71: 79-91.

Simon, Malene, Peter K. McGregor, and Fernando Ugarte. (2007) "The relationship between the acoustic behavior and surface activity of killer whales (*Orcinus orca*) that feed on herring (*Clupea harengus*)." Springer-Verlag and ISPA 2007.

Tarasyan, Karina K. Olga A. Filatova, Alexander M. Burdin, et al. (2005) "Keys or the status of killer whales in Eastern Kamchatka, Russia: foraging ecology and acoustic behavior." Biosphere Conservation, 6 (2): 73-83.

Thomsen, Frank, Dierk Franck, and John K.B. Ford. (2002) "On the communicative significance of whistles in wild killer whales (*Orcinus orca*)." Naturwissenschaften, 89: 404-407.

Wheater, Philip C. and Penny A. Cook. Using Statistics to Understand the Environment: routledge introductions to environment series. London and New York: Routledge Taylor & Francis Group, 2000.