Variations in S6, S10, and S19 calls in Southern Resident Killer Whales (*Orcinus orca*)

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Abstract

In killer whales (*Orcinus orca*), vocal calls appear to be an important aspect of communication. Preferences of prey, travel patterns, and vocal "dialects" are distinguishing features among the different ecotypes of northeast pacific killer whales. Fish eating resident killer whales frequently associate with other whales outside their own pod. A vocally distinct clan may contain up to eight pods. Although clans are classified by their vocal similarities, pods within the same clan only share a fraction of another's repertoire. Southern Resident Killer Whales (SRKW) consist of three pods in a single clan. The S10, S6, and S19 calls have all been claimed to be calls that are shared between all pods of the SRKW: J, K, and L. This study investigates whether or not variations in common calls are pod specific in SRKW. In fall of 2011, a towed underwater hydrophone array was used to record calls of SRKW specifically for this study. L Pod's S19 calls are significantly different from J pod S19 calls in both high frequency and delta frequency. They also consist of a high frequency not present in the majority of J and K S19 calls. Little variation in S6 calls existed between J and K pods. J pod's S10 calls showed a significant variation from K or L pods due to a distinct click train directly prior to the call.

Introduction

Most animals communicate in some way, whether it is for feeding or reproducing. Depending on their environment and their adaptations, some use visuals, chemical signaling, olfactory senses, as well as tactile senses. For cetaceans, the most practical and useful form of communication is sound. Sound travels faster in water than it does in the air, and sound is absorbed less per kilometer in water than it does in air due to water's greater density, which enables sound to travel at far greater distances in water (Brennan 2009). This makes this form of communication ideal for all cetaceans.

Killer whales can hear frequencies within a range of 1 to 100 kHz (Symanksi 1999). They project sounds that are classified as: discernable calls, whistles, and clicks. The focus of this study is on killer whale discernable calls, and are also referred to as pulsed calls.

North Eastern Pacific killer whales are separated into three different ecotypes called residents, transients, and offshores. Ecotypes are distinct due to their social and cultural behaviors, their feeding habits, where they are geographically located, and acoustic distinctions from one another (Ford 1991). Resident Killer Whales have a predictable range of travel, and their diet typically consists of salmonids (Hanson 2010). Due to their prey's inadequate hearing (Hanson 2010), Resident Killer Whales are typically more vocal than others who have prey with keener senses of hearing. Residents are the focus of this study.

Sixteen pods form the Resident orca population, and these are separated into four acoustically distinct clans (Ford 1991). New pods are generated through divergence of call repertoire of the founding group (Ford 1991). Resident orca pods typically have anywhere from seven to seventeen distinct calls, although on average there are 10.7 different calls per pod (Ford 1991).

The southern residents are typically found in the Northeastern Pacific around British Columbia and Washington State in the summer, particularly in the Salish Sea and Puget Sound. Southern residents consist of only one clan, which is classified as the J Clan. This clan consists of 3 pods: J, K, and L. According to the Center for Whale Research, L pod has 42 individuals, J pod has 27, and K pod has 20 (89 individuals total) during our research cruises in September and October. These family groups have been intensely studied since the 1970s (Wieland 2007). Because of the long-term stability of the social structure in southern residents, we are able to examine vocal behavior in much more detail than other ecotypes (Ford 1991). J, K, and L pods frequently reside in Juan de Fuca, Haro Straight, and the Straight of Georgia from April to October.

Southern Resident Killer Whale calls are classified using an "S" as a prefix for each of the numbered calls to signify that the call is from the southern resident clan. Twenty-five different call types have been formally classified from the southern resident killer whales (Ford 1987). Each pod has unique vocalizations that are more often used within each of the separate pods. The call S1 for example is used exclusively in J pod,

according to Wieland, and isn't heard in either K or L pods. Ford in 1991 claimed that both J and K pods used S1. L pod has never been known to use S1. Typically crossover usage is found only two pods in most of the classified calls. Ford proposed that eight calls have crossover qualities in J and K pods, and five calls have crossover qualities with K and L pods, and merely three calls crossover in all three pods of the southern residents: S6, S10, and S42.

	Pod		
Call	J	K	L
S1	×	×	
S2			
i	×		
ii	×		
iii			×
S3	×		
S4	×	×	
S5	×	×	
S6	×	×	×
S7	×	×	
S8			
i	×	×	
ii			×
S9	×		
S10	×	×	×
S12	×		
S13			
i	×		
ii			×
S14	×		
S16		×	×
S17		×	×
S18			×
S19			×
S22			×
S31			×
S33			×
S36			×
S37			
i	×		
ii			×
S40			×
S41	×		
S42	×	×	×
S44	×		
Total	18	10	15

Fig. 1. Ford (1991) classifies calls used among Southern Resident Killer Whales. Note calls that are used among all three of the pods: S6, S10, and S42.

Ford's definitions of the calls have been used ever since his study in the late 1970s and the early 1980s (Ford 1987), and many have used his interpretation of calls as the guidelines for their studies. However recent studies show variation in Ford's results. Wieland showed that there was nine distinct calls that crossed over all three of the pods in a 2005-2006 acoustic study (excluding unknown and faint calls).

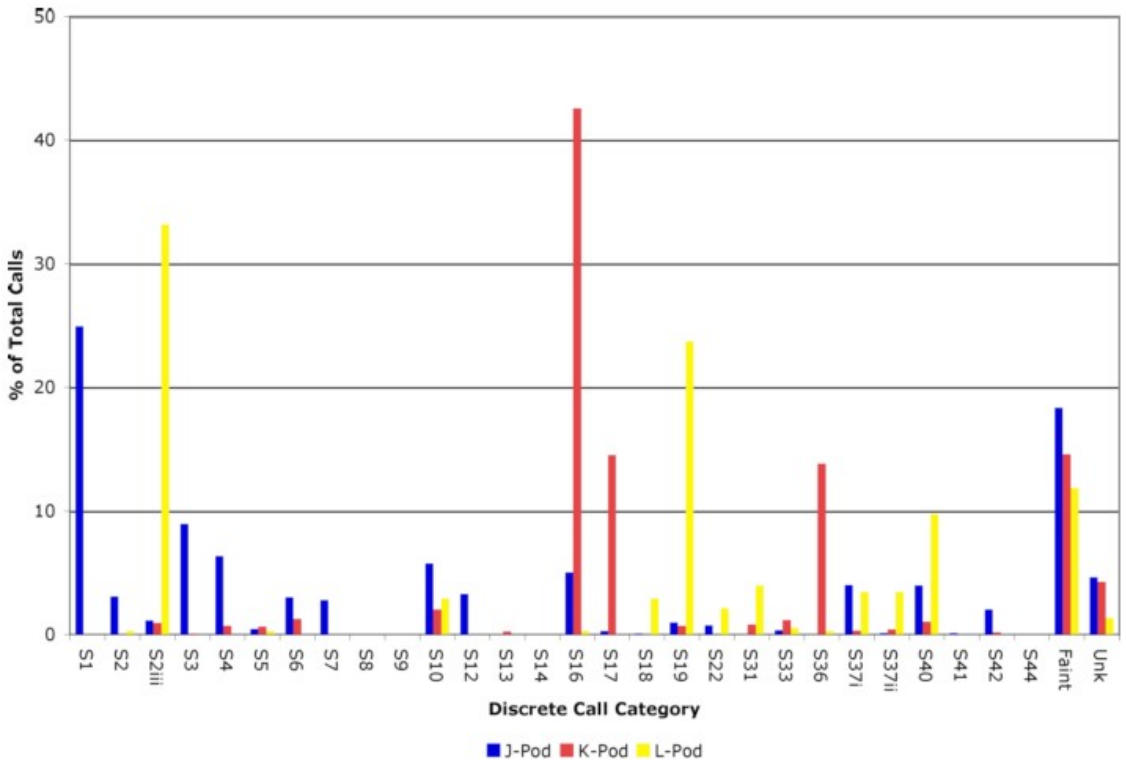

Fig. 2. Wieland (2007). Note the overlapping call types among all three pods of J Clan: S2iii, S5, S10, S16, S19, S33, S37i and ii, and S40.

Although Ford and Wieland had different data from different times, subtle similarities are present in their results. Both reported that the S10 call was used among all pod types. It may suggest it is common to all SRKW. It has also been suggested that S10, or otherwise known as V4, is a universal killer whale 'excitement' call, and is used in all cultures of killer whales (Rehn 2010).

The S10 call is prominent in all killer whales, and proposes biological innateness in killer whales (Rehn 2010). Biologically innate suggests universality in a behavior, such as a specific sound projected. This study aims to measure differences or similarities in calls that have proposed to have been shared among all the pods of the southern resident killer whales. Calls such as S10 (Wieland 2007, Ford 1991), S19 (Wieland 2007) or S6 (Ford 1991) are quantified suggest whether or not they too can be considered to be innate within the southern resident clan, or if the calls deviate from pod to pod.

Methods

A. Killer Whale Recordings

A 42' electric-biodiesel sailing catamaran, Gato Verde, was used for two ten-day research cruises throughout Haro Straight from September 19th to the 29th, and October 2nd to the 13th. Recordings were obtained by deploying a linear mobile 100 meter long four-hydrophone array consisting of Lab-40 models from LabCore Systems with a flat response between .1 and 10 kHz. They array was weighted to a depth of 4 ft below the surface to reduce flow noise, and the Gato Verde cruised at 4 knots or less to reduce flow noise and spread out battery power to avoid the need to use the generator which would dramatically decrease quality of recordings.

Recordings were collected from each of J Clan's pods. Calls were digitized using Sound Devices 702 that had a set sampling rate of 44.1k samples per second. The gain for each individual hydrophone was set according to the sensitivity of the hydrophone: hydrophone 1, 3, and 4 were set to 40.1, and hydrophone 2 was set to 67.4. Individual pods were recorded on September 27th (J Pod), October 4th (L Pod), and October 12th (K Pod) and were used for this study. High-resolution photos were taken throughout recording sessions and were used for pod identification. On September 27th, 36 S19 calls, 42 S10 calls, and 40 S6 calls were measured for J Pod. On October 4th, 55 S19 calls, 28 S10 calls were measured for L Pod (S6 sample size was too low for this study for L Pod). On October 12th, 33 S6 calls, 28 S10 calls, and 25 S19 calls were obtained for K Pod. Archival calls were not used for this study to eliminate any variations that may appear over time (Wieland, 2007).

B. Definition of calls

Different orca calls are discernable with a human ear and are visually unique with

the usage of spectrograms (Wieland 2010). Killer whale calls were classified based on certain criteria for each call. S19 calls were defined, using a spectrogram view, as an exponential curve with little or no drop at the end time of the call.

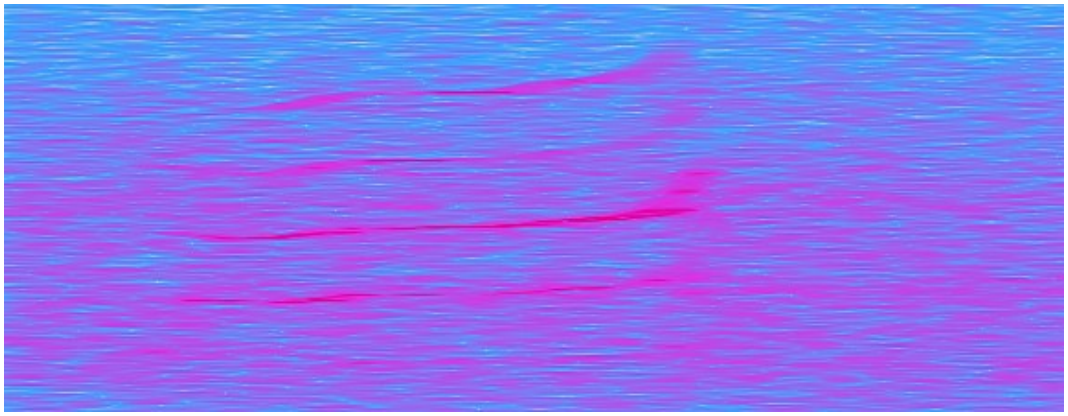

Fig. 3. S19 call taken from J Pod on September 27th.

S6 calls were classified as having a begin and end frequency relatively equal to each other while displaying a rounded even curve.

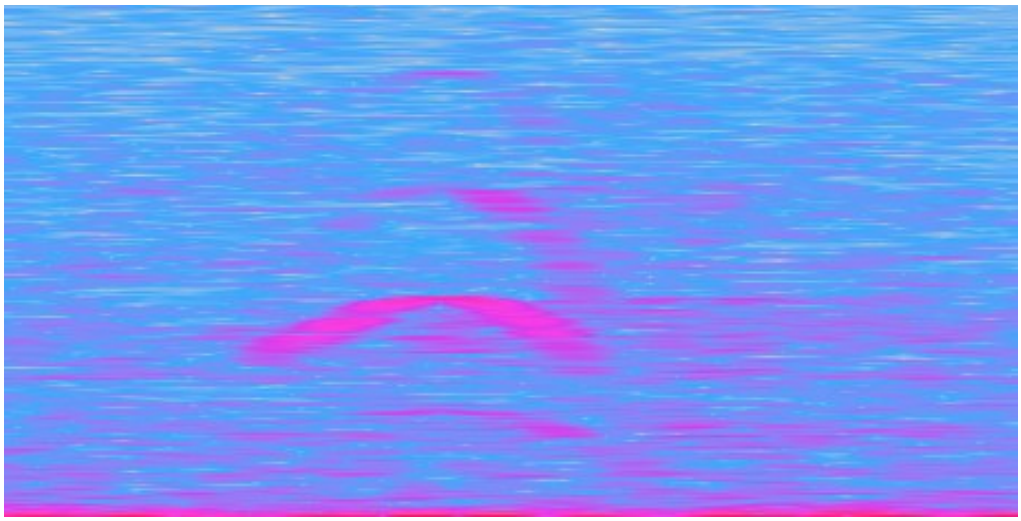

Fig. 4. S6 calls obtained from J Pod on September 27th.

S10 calls have a distinct "squeaky balloon" sound and are often not easily seen on a spectrogram. All calls measured had to meet quality criteria of having minimal background noise, high enough amplitude to easily distinguish frequencies from, and be visually distinct on a spectrogram.

C. Acoustic and Statistic Analysis

Individual S6, S10, and S19 calls were cropped into separate sound files from the original recordings through Audacity. S6 and S19 calls were measured using RavenPro 1.4 beta version build 38 (2003-2010: Cornell Lab of Ornithology, Ithaca, New York). Begin and end times, low and high frequencies, center frequency, center time, delta frequency, delta time (duration), frequency 95%, max time (time when most power occurs), and peak frequency were all measured for each call in RavenPro.

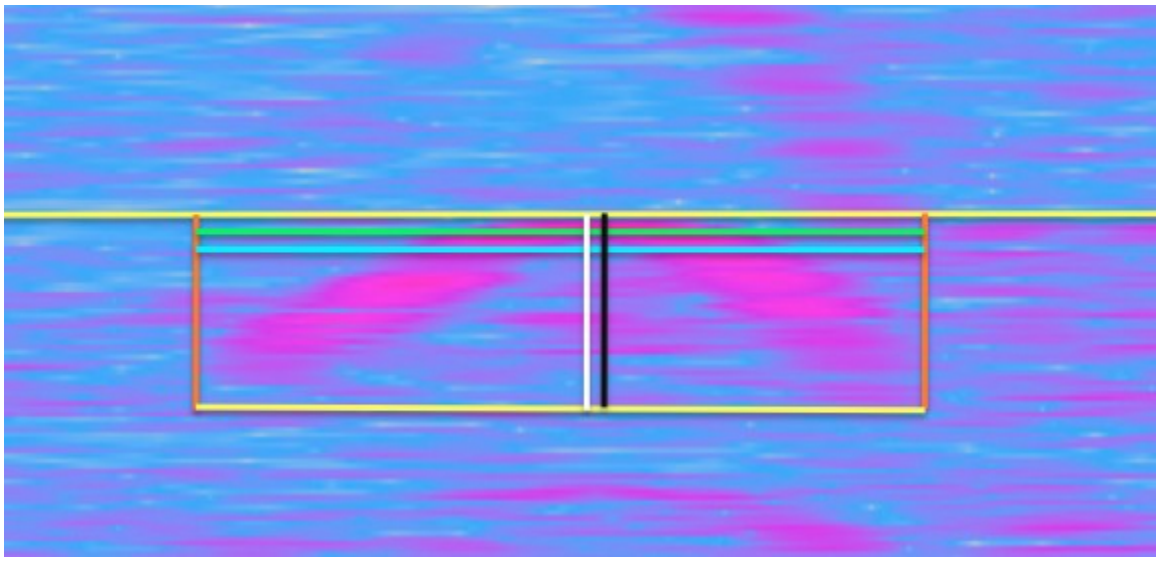

Fig. 5. S6 call from J Pod taken on September 27th, 2011. Colored lines demonstrate parameters measured: high frequency (upper yellow), low frequency and duration (both lower yellow), delta frequency (orange), peak frequency or frequency containing most power (green), frequency 95% or frequency at which 95% of the energy is contained (blue), max time or time containing most power (white), and center time or time when 50% of the energy is reached
through the call (black).

Each of these parameters for each pod were put into histograms in R (Ihaka, Gentlemen) to ensure normalcy of data. Histograms were initially made, and if they looked questionable, QQPlots confirmed normalcy. Ttests found p values for each parameter measured between pods. Hierarchal clusters were used on a parameter that showed the most distinguishing differences in S19 calls. All parameters in S19 calls were also grouped to form a hierarchal cluster.

Each S19 call was measured three times manually. Standard deviations were calculated to account for human error. Standard deviations of individual measurements to parameters were then applied to S6 calls. S10 calls were not quantified using RavenPro due to poor spectrogram clarity. Instead, S10 calls were put into groups based on whether or not they had a click train directly prior to the distinct call.

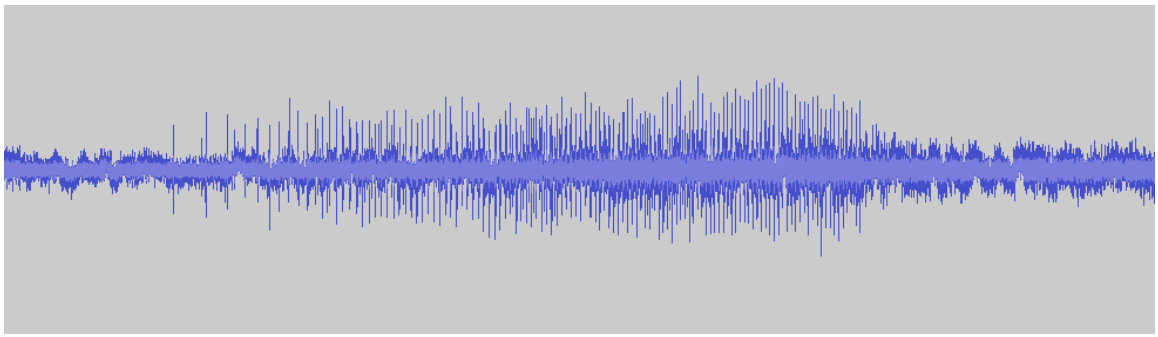

Fig. 6. Click train prior to S10 call from J Pod, taken on September 27th.

Results

The selection of 36 J Pod S19 calls, 42 J Pod S10, and 40 J Pod S19 calls were taken from a single recording from September 27th (from False Bay to OrcaSound) totaling 118 minutes. The selection of 33 K Pod S6 calls, 28 K Pod S10 calls, and 25 K Pod S19 calls were taken from a single recording on October 12th (Lime Kiln and Hannah Heights)

totaling 82 minutes. The selection of 28 L Pod S10 calls and 55 L Pod S19 calls were taken from a single recording from October 4th (Turn Point) totaling 92 minutes. All data was considered normal with the use of histograms and QQPlots.

A. S19

There was significant variation between the mean delta frequency and the mean high frequency between J Pod (12.45 kHz) and L Pod (8.223 kHz) (Fig. 7. p=1.333e-11) as well as between J Pod and K pod (Fig. 7. p=0.0003599). An R t-test indicated L Pod produced calls with a significantly larger high frequency (Fig. 7. p=1.836e-12 between L and J pods; p=0.04973 between L and K pods). The difference between K Pod and J Pod (15.577 kHz) mean high frequency was also significant (Fig. 7. p=0.003275). Mean duration was significantly different between all the pods. K pod had a mean duration of .948 seconds, L Pod had a mean duration of .778 seconds, and J Pod had a mean duration of .948 seconds (Fig. 7. p=0.004953 between J and L, p=0.004781 between L and K, and p=2.59E-05 between J and K). Peak frequency had no significant variations between any of the pods. Mean frequency 95% showed significant variation between J and L pods (p=0.00172). Percent of call that held the most power showed minor variation between L and K pods (p=0.003345).

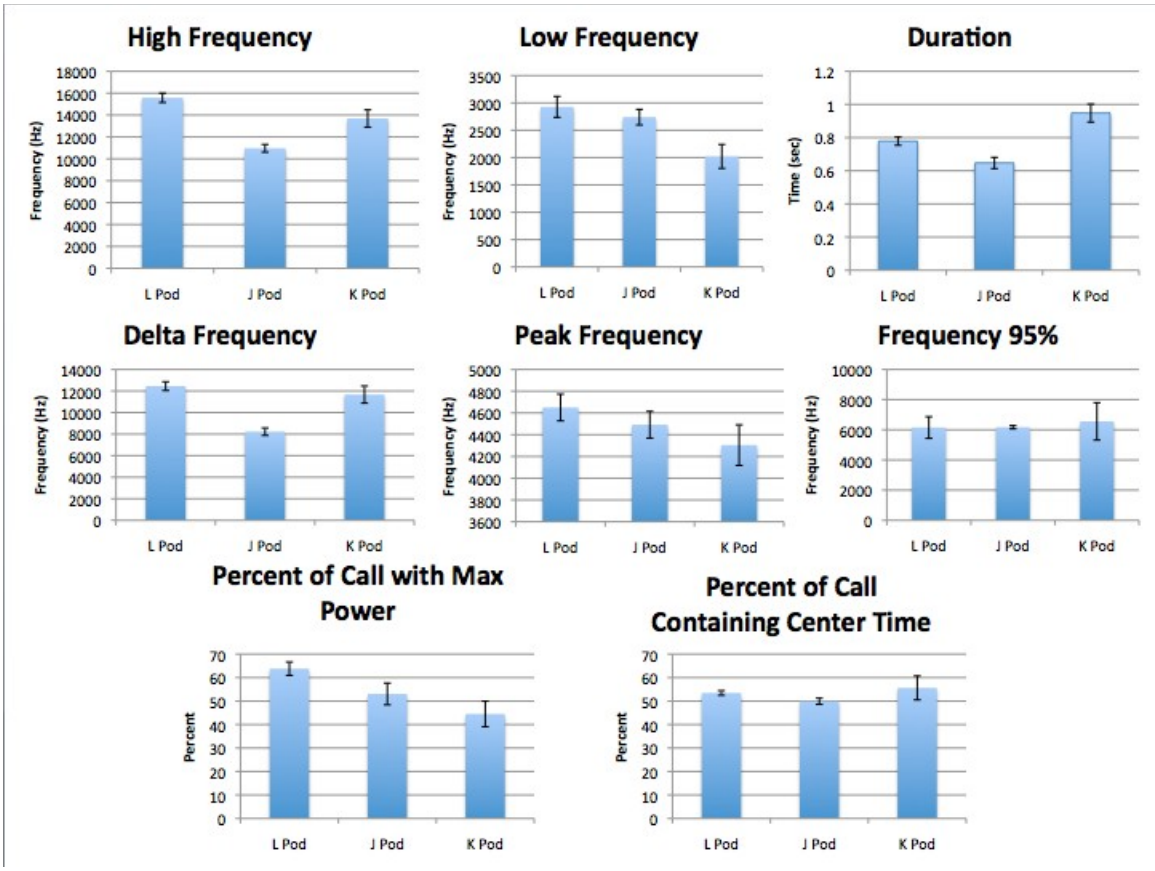

Fig. 7. The means of S19 parameters for each pod in Fall 2011. Significant parameters include high frequency and duration for all the pods, delta frequency between J and K pods and J and L pods, low frequency between K and other pods, and percent of call with max power between K and L pods. Error bars display standard error.

Hierarchal clustering in delta frequencies for all pods calls was made into a dendrogram in R (Fig. 8). No specific groups stood about among the clusters. A dendrogram was made for delta frequencies for just J and L pods (Fig. 9.), and although groups are still mixed, the left side cluster is predominantly J pod and the right cluster is predominantly L pod. All parameters (high frequency, low frequency, duration, delta frequency, peak frequency, frequency 95%, percent of call with max power, and percent of call containing center time) were combined to create a dendrogram (Fig. 10). Specific pod's calls were not cleanly clustered in the dendrograms.

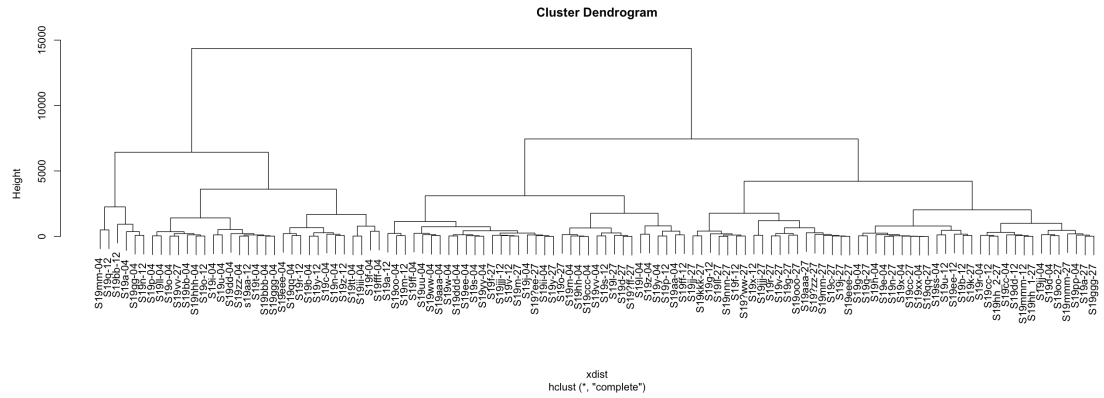

Fig. 8. Hierarchal cluster (Euclidean) for S19 delta frequencies for all calls measured in every pod. Files ending with 04 are L pod, 12 are K pod, and 27 are J pod.

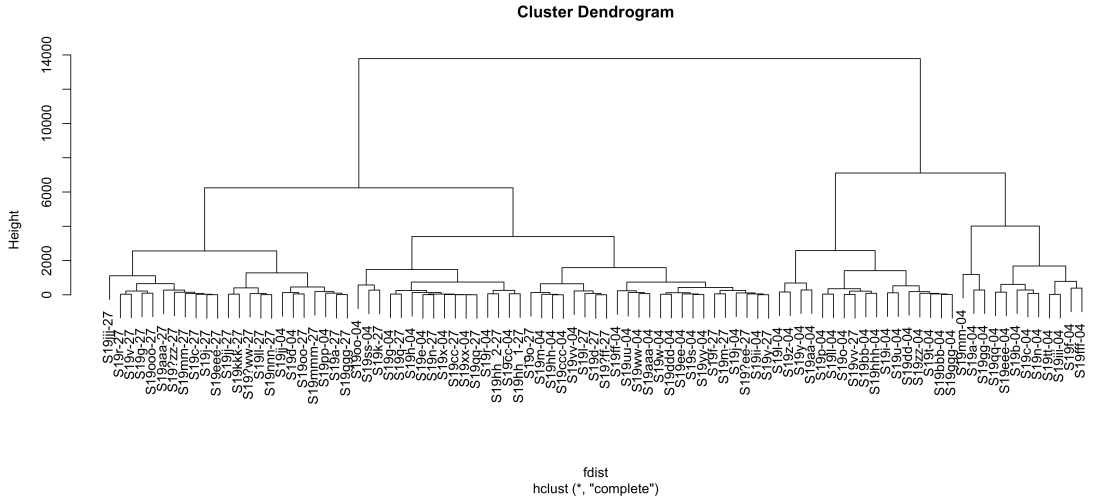

Fig. 9. Hierarchal cluster (Euclidean) for S19 delta frequency for J and L pods. All file names ending with 27 are calls from J Pod, and all those ending in 04 are S19 calls from L pod.

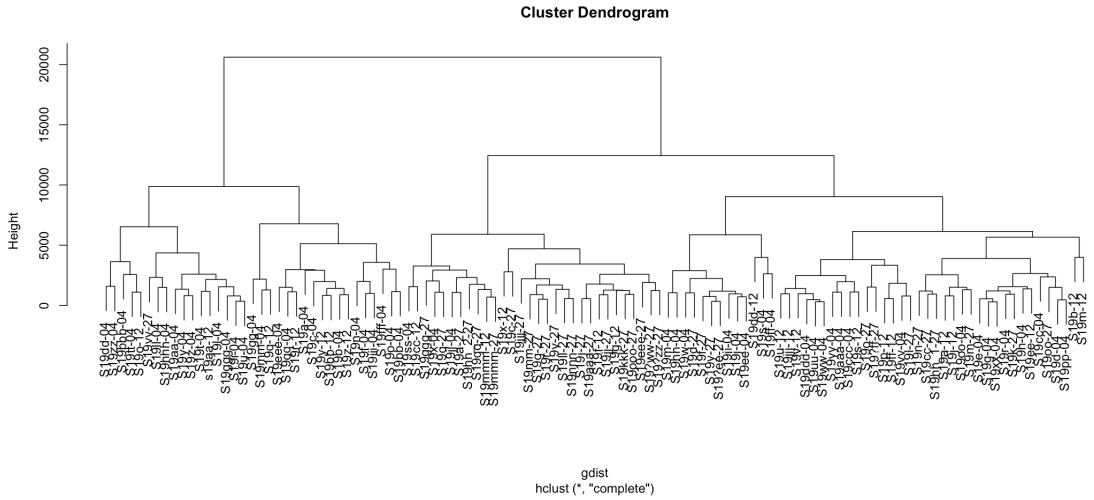

Fig. 10. Heirarchal cluster (Euclidean) for all parameter for S19 calls. All pods are included.

S19 calls were grouped depending on whether or not they displayed an obvious high pitch at the beginning of the call. A percentage of calls displaying a high pitch as opposed to those not displaying a high pitch is significant (Fig. 13).

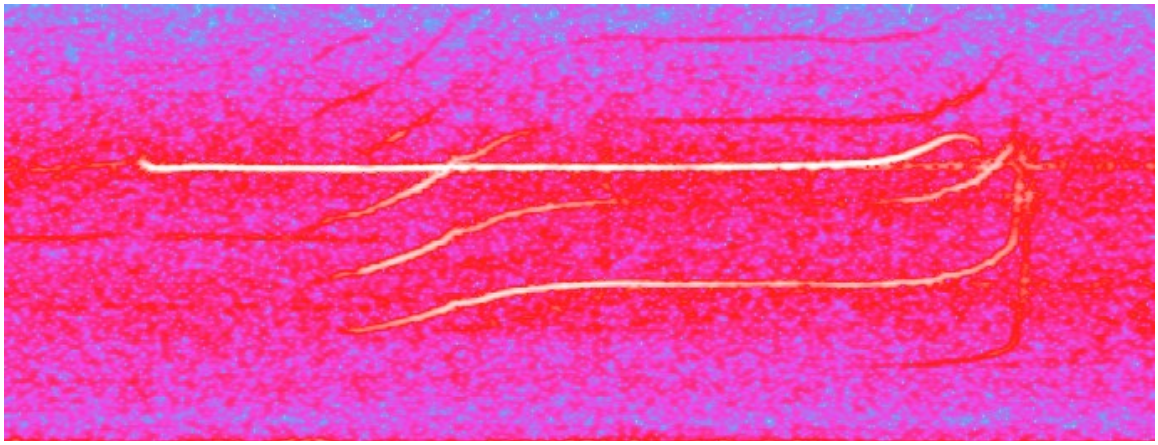

Fig. 11. A spectrogram of an S19 call taken from L-pod on October 4th, 2011 off Turn Point in Haro Straight. Note the upper powerful frequency that begins the majority of L Pod's S19 calls.

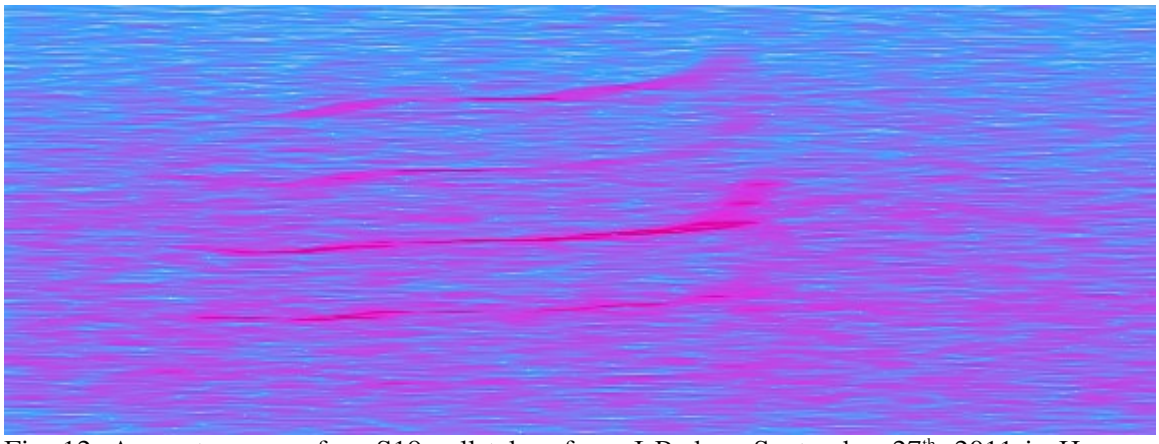

Fig. 12. A spectrogram of an S19 call taken from J Pod on September 27th, 2011 in Haro Straight. Note the lack of the powerful upper frequency that is present in the figure above.

The majority of L-Pod's S19 calls (92.7%) exhibited this high tone, while majority of J pod (8%) and K pod's (12%) S19 calls did not.

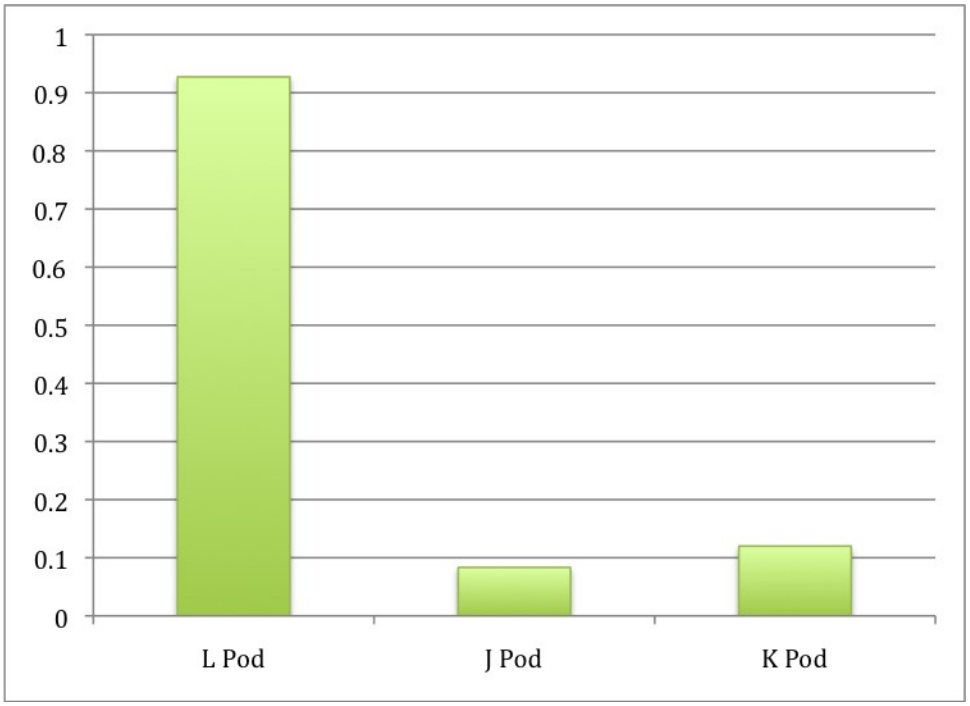

Fig. 13. Percent of S19 calls per pod that contained a distinct powerful high frequency prior to an alternate lower portion of the call.

The means of the duration of this high pitch present was taken for comparison between the pods (Fig. 14). L pod's high pitch is significantly longer (31.25 s) than J

(8.67 s) and K (11.3 s) pods.

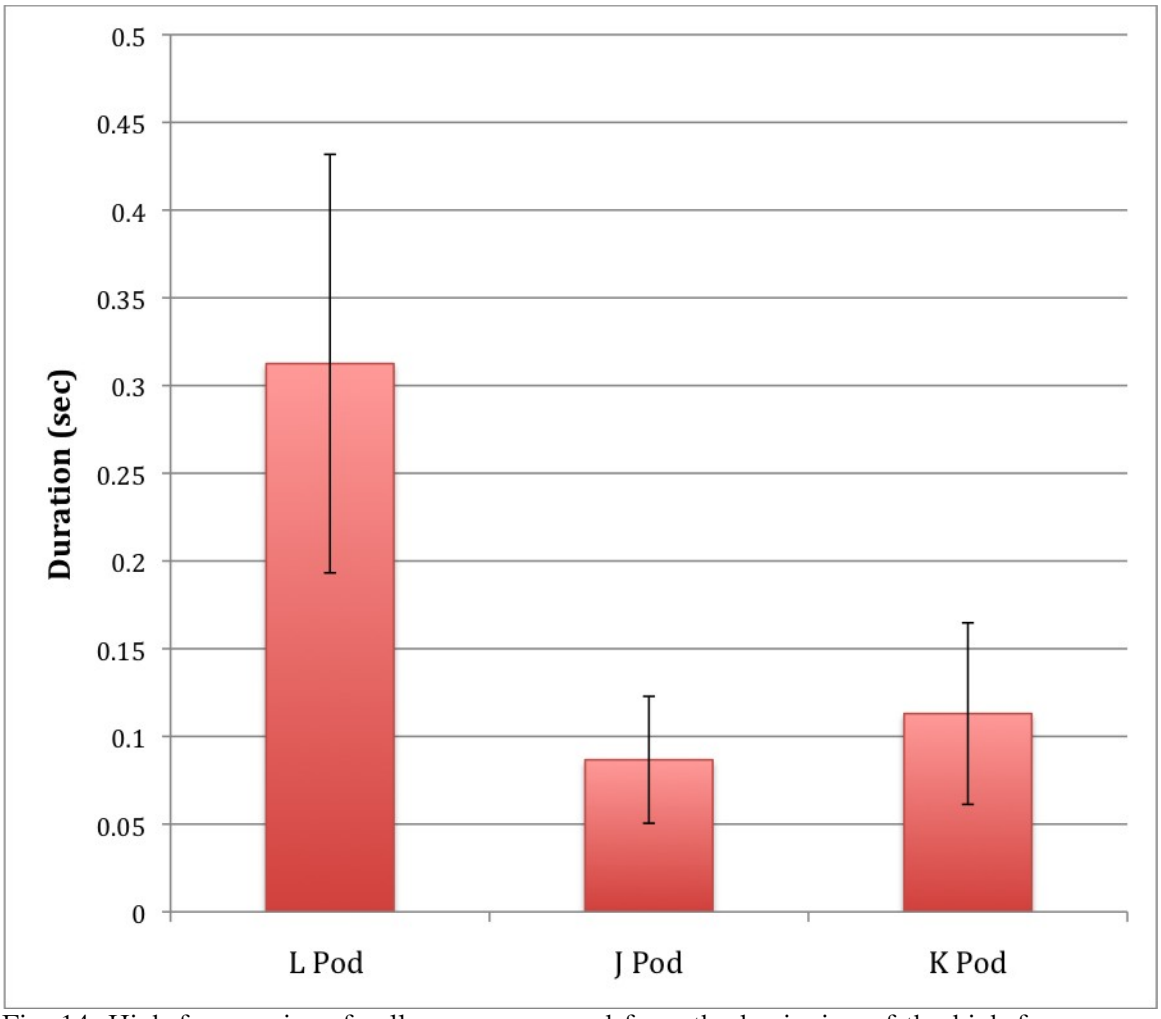

Fig. 14. High frequencies of calls were measured from the beginning of the high frequency to the beginning of the low frequency portion of the call. Error bars display standard deviations.

B. S6

There was significant variation between the mean peak frequency J Pod (4.285 kHz) and K Pod (3.685 kHz) (Fig. 15. p=0.02313). An R t-test indicated J Pod produced calls with a

significantly larger frequency 95% (6.120 kHz) than K pod (5.486 kHz) (Fig. 15. p=0.0001727). The mean percent of call containing center time for J (50.2%) and K pods (52.7%) was significant (Fig. 15. p=0.04691). All other parameters showed less than significant deviation from each other.

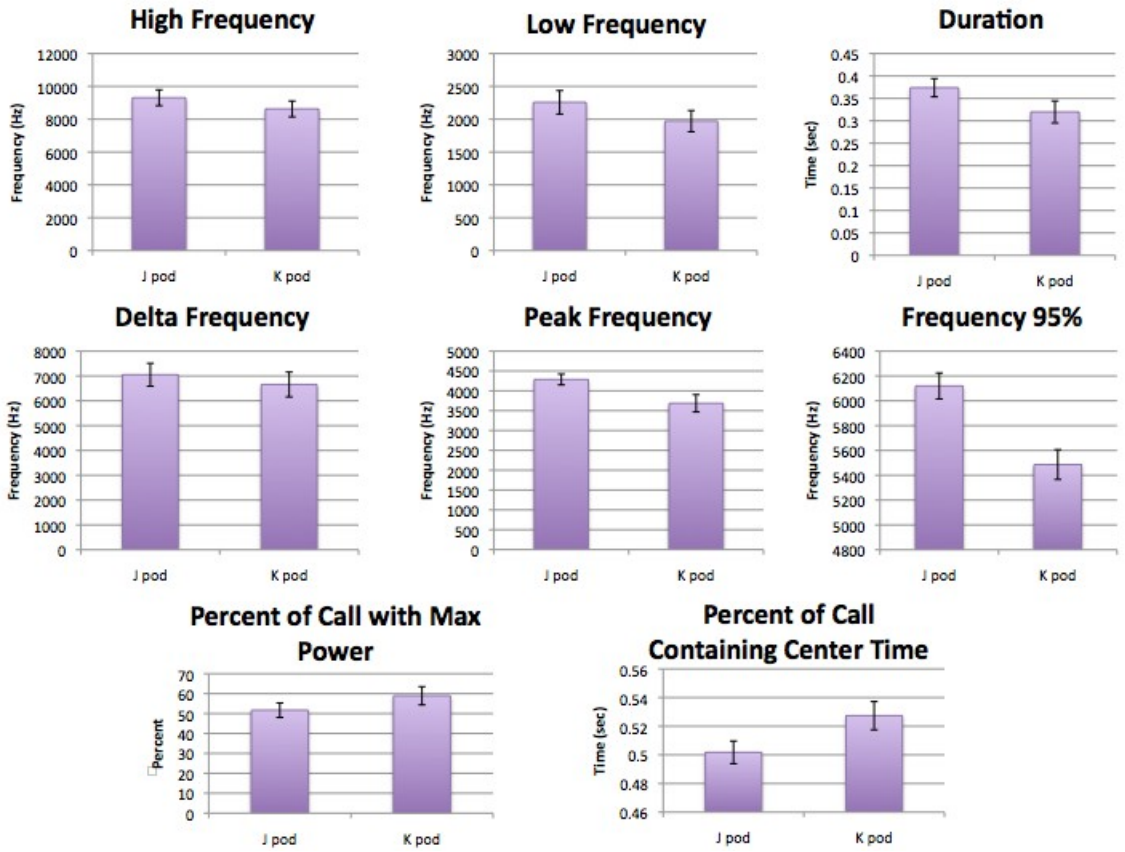

Fig. 15. The means of S6 parameters for J pod and K pod. L pod was eliminated due to insignificant sample size. Significant factors include peak frequency, frequency 95%, and percent of call containing center time.

C. S10

A significant difference presented itself in the form of the presence of click trains prior to S10 calls as opposed to those that did not have click trains. Percentage of calls that had click trains present were measured for each pod (Fig. 18. J pod, 31%; K pod, 14.3%; L pod, 14.3%) The presence of observed foraging behavior for each day recordings were taken from was then graphed next to the percentages of click trains present prior to S10

calls (Basran, 2011. Fig. 18).

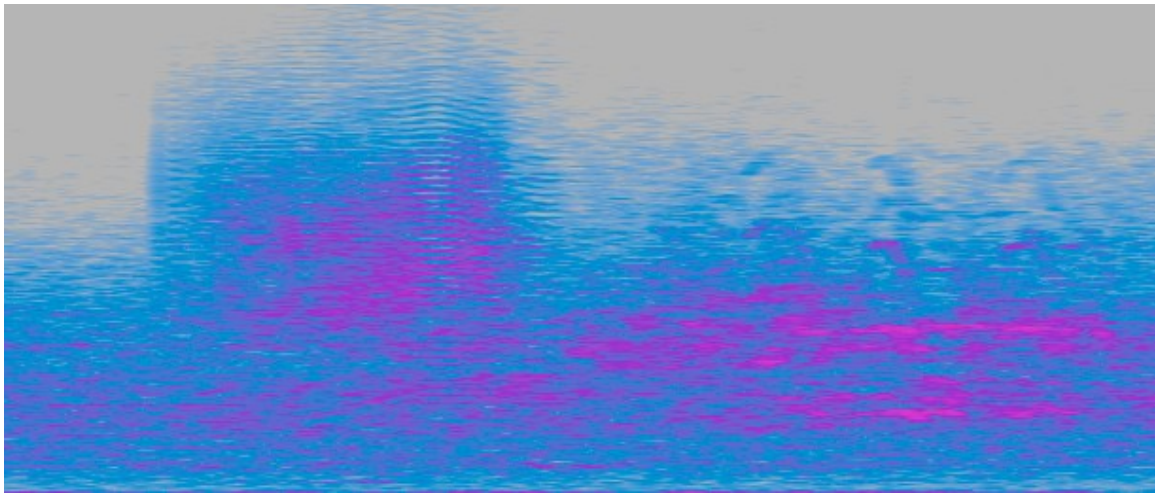

Fig. 16. A spectrogram view of a click train directly prior to an S10 call from J Pod, September 27th, 2011.

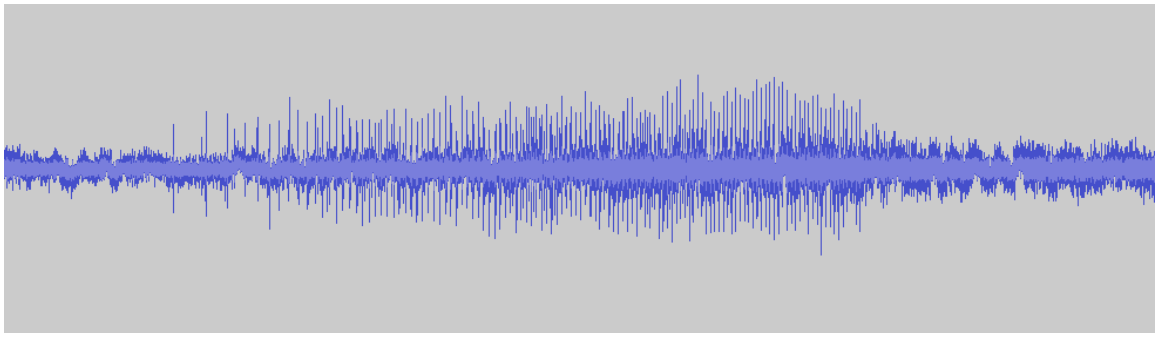

Fig. 17. A waveform view of clicks in the same spectrogram above. Note the click qualities of the waveform view as opposed to the spectrogram view.

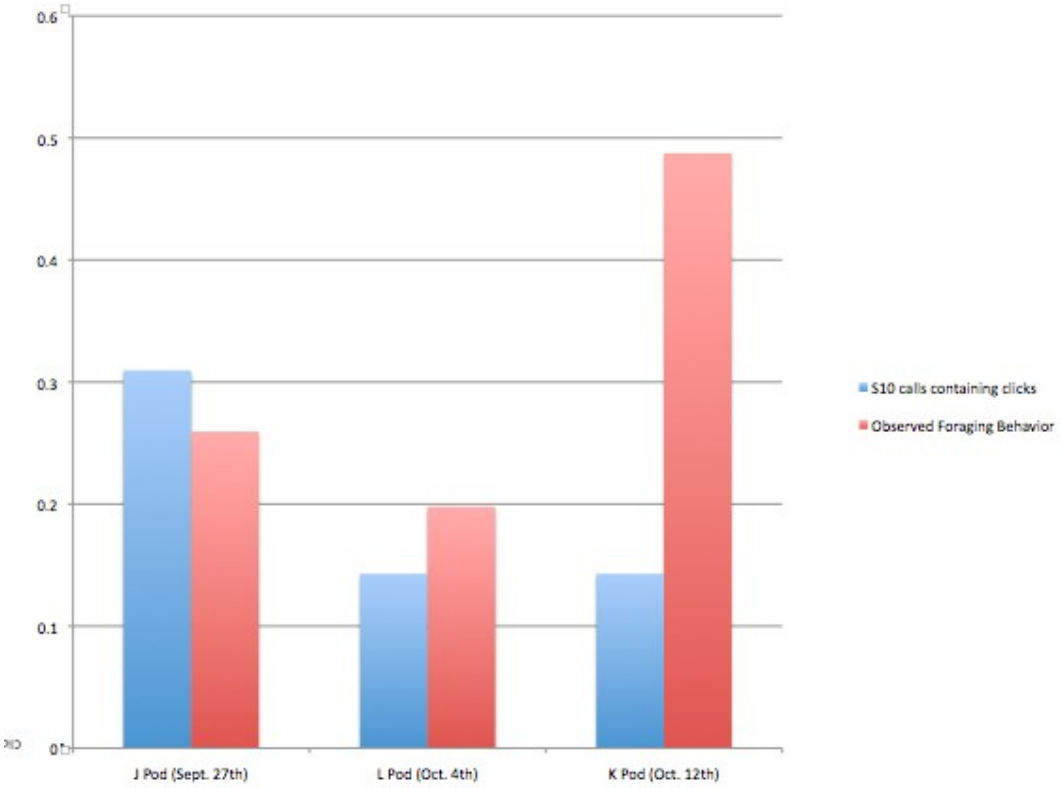

Fig. 18. Percentage of S10 calls within each pod that contained consistent click trains (represented by the blue bars). These consistencies were compared to percentage of observed foraging for each day (represented by the red bars).

Discussion

Variation in S6, S10, and S19 exist. These pods are all in the same vocally distinct clan, and therefore calls shared between pods weren't expected to differ much from each other. Sample size was limited to eliminate speculation on variations occurring through time (Wieland 2010). It is likely that taking calls from a different year, or even from last spring would alter the results significantly. By limiting sample size to avoid variations through time, a sampling of the pod as a whole was limited; perhaps only a few individual whales contributed a certain type of call for that particular day.

S6 calls were only measured in J and K pods due to sample size in L pod being too small. Overall S6 calls did not show very many significant differences between the two pods. Peak frequency and frequency 95% may have been significantly different from each other due to differences in background noise for that particular day. J pod calls did have noticeably more boat noise in their recordings than the other two pods. Percent of the call containing center time was also significant, and may be the only pod specific differing parameter measured in S6 calls. These calls did not differ significantly, as John Ford originally proposed (1987).

Parameters in S10 calls could not be measured using RavenPro due to lack of clarity in spectrograms. S10 calls were quantified upon whether or not a click train occurred prior to the call. Click trains were used significantly more the day J pod was recorded than on the days L and K pods were recorded. In order to suggest pod specificity, the occurrence of these click trains were measured against the percentage of foraging behavior observed, which may be an indicator of clicks (Au, 2004). No correlation was present. Observed foraging behavior may be inaccurate and foraging has actually present more or less on different days. The click trains may have little to do with foraging (Dorrance 2011) and may suggest pod specificity.

Significant differences occurred in many of the parameters measured from pod to pod. High frequency significantly differed in each of the pods, yet only J pod stood out among delta frequencies; so although high frequencies differed, frequency ranges remained

similar between K and L pods as opposed to J pod, whose range is significantly smaller than the others. Durations significantly differed between the pods, although the percent of the call containing half the power (center time) did not vary much at all between them. This suggests that the calls are similar, despite their duration differences. Percent of call containing max power is significantly different from L pod to K pod; K pod typically emphasizes their call earlier than L pods S19 call, which has an emphasis on the call later. This earlier part of the call is also the lower part of an S19 call, and therefore could contribute to K pod's significantly lower low frequency.

Cluster dendrograms were used to quantify variations in S19 calls. First, a clustering of high frequencies within all the pods was made. No stark clusters of any pod stood out. K pod was then eliminated for another cluster dendrogram of high frequencies, and although clusters of calls are slightly more pod specific, they are not significantly different from each other unless an L pod member was traveling with J pod and vice versa. All parameters measured in RavenPro were also conjoined to create a dendrogram, which also didn't show significant clusters. Only one type of dendrogram was used to make clusters (Euclidean) and experimental uses of other dendrogram forms may produce different results.

S19 calls showed a noticeable variation between L pod and J and K pods. The majority of L pod's S19 calls contained a high tone at the beginning of the call, whereas the majority of other pod's S19 calls did not (Fig. 13). Those that did have a high tone present was measured from the beginning of the high tone to the beginning of the lower audible portion of the call, and suggests that L pod's S19 calls are significantly different from J or K pod S19 calls. S19 has been considered to be an L pod indicator call, and may suggest that S19 calls taken from J and K pods may not be true S19 calls, but rather unfinished S1 or S3 calls.

More research is required to ensure that these results remain consistent between the pods. Further research is also required to pinpoint if these variations are due to large

amounts of calls from certain individuals from each pod or due to environmental factors such as bathymetry or increased surrounding vessel activity. Locations of each pod's recordings were different and may contribute to variations in calls. All parameters measured using RavenPro have a source of human error involved in their measurements, and therefore could significantly offset results.

Further research could also indicate whether or not culture fluctuations exist among killer whales within ecotypes such as residents. Through consistencies or inconsistencies in the variations of calls used among all pods of a clan through time, suggestions of whether or not killer whales with highly stable hierarchically structured social units (Parsons, 2009) have a stable repertoire or a varying one due to intermingling of pods.

Conclusions

Based on this study, L pod S19 calls are distinguishingly different from J or K pod S19 calls. S6 calls have trends to suggest that there are power placement differences in J and K pods, but L pod's S6 calls remain unknown. J pod's S10 calls are more likely to have a distinguishing click train prior to the call than other pods. More research in this area is required to confirm consistency in results.

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