VARIATION IN THE S1 CALL TYPE OF SOUTHERN RESIDENT KILLER WHALES (SRKW), *Orcinus orca*

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Introduction

Many organisms ranging from birds to humans rely on communication for reproduction and survival. Humpback whales, *Megaptera hovaeangline*, use complex songs to find mates (Smith et al. 2008). Meerkats, *Suricata suricatta*, use communication to signal to others when a predator is near (Manser 1999). Many birds and insects use visual signals to provide protection for themselves by mimicry. Communication is a necessity for both terrestrial and marine organisms, but challenges in both environments limit which types are used most effectively.

Communication common in terrestrial habitats, including chemical signals, prove challenging in a marine environment. Water exchange occurs constantly causing these signals to dissipate rendering them useless under most marine conditions. Visual communication is beneficial in areas that are wide open and lack obstacles that block the signal. Tactile communication can be very important especially between mother and offspring, but is limited by distance between individuals. Acoustic communication is vital in environments were close distances can not be achieved or are difficult. Sound travels great distances which makes it a great signal for many organisms. In fact, water is a better travel medium for sound than air, thus sound travels faster and further than in air given the right conditions (no masking, no corners, etc.). In marine environments, acoustic communication is used primarily. Thus, it is no surprise that killer whales, *Orcinus orca*, are highly dependent on their vocalizations. (Bain 2011, Erbe 2011, Richardson et al. 1995)

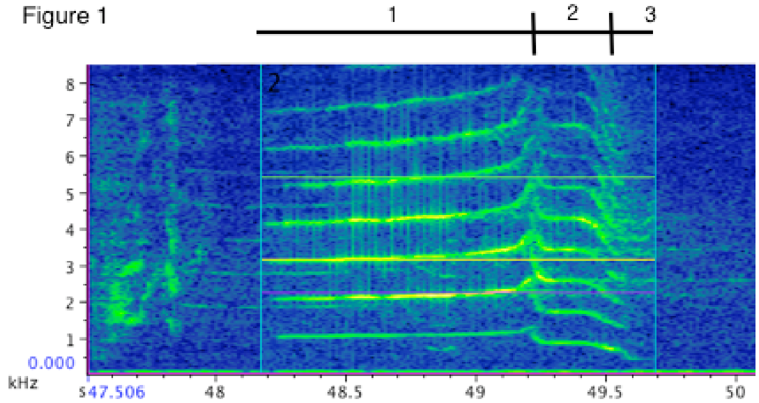
Killer whales use multiple methods for communicating. Tactile communication is often used between a mother and calf, but is limited by distance. Despite killer whales' acute vision above and below the water, visual communication is difficult at night and in murky water conditions (Bain 2011). However acoustic communication overcomes these challenges and is theorized as their primary form of communication (Bain 2011, Erbe 2011, Richardson et al. 1995). Killer whales vocalize in three different ways. They emit short broadband clicks, pulsed calls, and pure tonal whistles. Clicks are used for echolocation, typically when foraging. A click is sent from the whale's melon outward; once it hits an object, it bounces off and is received by the oil filled lower jaw of the animal (Richardson et al. 1995). Multiple clicks sent out over time allow the animal to determine position of an object, for example a fish, even when it may be out of visual range. Calls and whistles have not successfully been linked with behavior although many attempts have been made (Bain 1986, Ford 1989, Morton et al. 1986). LIttle is known about the information being sent out through these acoustic signals. This study aims to better understand discrete calls made by killer whales.

Offshores, transients, and residents are three ecotypes of killer whales that can be distinguished by diet, behavior, vocalizations, social structure and travel patterns (Ford et al.1999). Residents are fish eating mammals who have very stable social structures (Ford et al. 1998). Residents can be subdivided into communities based on where they spend most of their time, specifically in the summer (Bigg et al. 1987). Northern Residents typically occupy inland waters of northern Vancouver Island, while Southern Residents can be found in the Salish Sea (Bigg et al. 1987, Ford et al. 1998).

This area is defined to include the Strait of Juan de Fuca, Puget Sound, the waters around the San Juan Islands, including Haro Strait, and continues up the Strait of Georgia (Washington State Board of Natural Resources), also including the inland waters off the southern end of Vancouver Island. Thus, some overlap in range exists between Northern and Southern Residents.

This study aims to better understand the vocalizations, specifically discrete calls that make the Southern Residents unique. Ford (1987) describes pulsed calls having distinct tonal qualities resulting from the high repetition rate of the pulses. Most of these calls are highly repetitive and can be grouped into discrete categories detectable by the human ear. Visual inspection confirms and brings clarity to call identification. A spectrogram is a visual plot of the frequency versus time of a sound using a color spectrum to measure amplitude or energy produced in a call. Ford defined these discrete calls by frequency and duration measured from their spectrograms. Calls can be segmented by determining shifts in repetition rate of the pulses. In the case of S1, the call can be divided into three parts (see Figure 1). Measurements were taken on each part of the calls in Ford's study (1987). Calls were named alphanumerically. A letter (N, S or T representing Northern Residents, Southern Residents and transients, respectively)

Figure 1



This is a spectrogram (produced in RavenPro 1.4 using cool settings) of an S1 call. The call can be split into three parts as seen here.

distinguishing each call source was followed by a call number, determined by the order in which they were identified. Twenty-six discrete call types were identified for the Southern Residents. S1 will be the focus here. (Ford 1987)

Southern Residents were chosen as subjects of this study because of the large network that exists to monitor their location. This information comes from two main sources. Whale watching is a large industry in the area both from land and on water. Monitoring also comes from a network of hydrophones operated by OrcaSound (Washington State Parks and The Whale Museum). These hydrophones stream live allowing people all over the world to listen and report when calls are heard at any of the five locations in the Salish Sea.

Southern Residents are made up of three pods, J, K, and L (Bigg et al. 1987). As of 2008, the Center for Whale Research lists J-pod as having 25 members. While K and L pods have 19 and 42 members, respectively. This study will focus on J-pod because they are the most cohesive and most studied pod in the Salish Sea. Multiple matrilines spending at least half of their time together make up a pod (Baird 2000, 2002). In the case of residents, male and female individuals who share a common immediate female family member make up a matriline. Members of a matrilineal group rarely separate from each other for extended periods of time (Baird 2000).

Ford (1999) and Wieland (2007), report J-pod contributed to a large percentage of the calls gathered during each of their studies. Each study categorized calls into call types defined by Ford (1987). S1 composed about 25% of the calls made by J-pod in Wieland’s (2007) study. S1 was also the most common J-pod call type studied by Ford

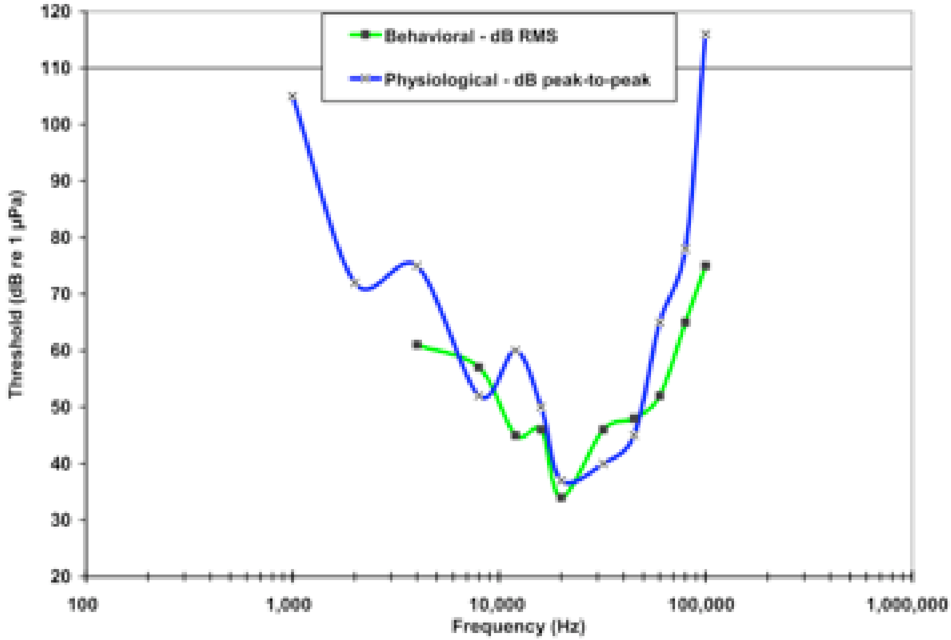
(1987) and has been reported as J-pod's most used call since the 1970's (Ford and Fisher 1983). Therefore, it is thought to be this pod's contact call. Probability that S1 is followed by another S1 also adds to the contact call hypothesis (Weiland 2007). A contact call is used by vocalizing animals for cohesion of a group, in this case a pod, especially when traveling (Ford and Fisher 1983). Contact calls, like S1, may also be a family or individual identifier (Ford 1991) similar to dolphin signature whistles(Caldwell and Caldwell 1965, Caldwell et al. 1990, Janik and Slater 1998). Many other studies have tried to support this idea by comparing dialects in geographically distinct killer whales (Deeke 2010, Sayigh 1990).

The contact call hypothesis suggests a contact call signals information to other individuals. If the signal remains constant over time, the meaning or information portrayed in the signal should remain constant. However if the signal changes, those unaware of the change may be left in the dark on what the signal now means. Take for instance your name. It identifies you to other people as an individual (your first name) and as part of a family (your last name). Consider what would happen if you changed your first name. Confusion may ensue for people when trying to contact you if they are unaware of your name change. Thus, consistency in a call used for contact should remain relatively stable over time to conserve its meaning.

As previously stated, little is known about killer whales and their methods for acoustic communication. More studies have been done on bottlenose dolphins, *Tursiops truncatus*, to better understand their use of signature whistles. Evidence from bottlenose dolphins (McCowan and Reiss 1995) suggests that vocal maturation and learning both play a role in development of whistle contours. The author found: Complex whistles were made in the earlier stages of development. The time at which certain whistles were acquired varied among individuals. Whistle types used by infants were shared with genetically unrelated adults. Together these findings suggest vocal maturation and learning may be contributing to repertoire development (McCowan and Reiss 1995). By analogy, we suggest these factors could also serve as a model for killer whale communication because they are closely related.

Killer whales have a hearing range from 1 to 100 kHz (Symanski et al. 1999). In Figure 2 below (reproduced from Holt 2008), an average of two killer whales' behavioral and physiological audiograms are presented. Audiograms were obtained by using trained killer whales (Symanski et al. 1999). Thresholds were determined by emitting sounds of known frequencies and measuring the killer whale's response. Physiological audiograms were determined by measuring electrical pulses in nerves, a response to hearing a sound, using electrodes along the distal dorsal side of the killer whale's blow hole; Behavioral audiograms were determined by training the killer whale to react, in this case by dipping its head, to signal that a sound was heard (Bain 2011).

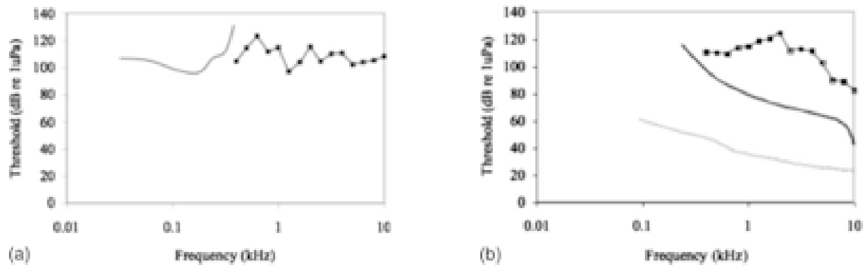
Figure 2



Reproduced from Holt 2008. This shows the behavioral and physiological audiogram of captive killer whales. These experiments help determine what sounds captive killer whales have the ability to hear.

Since sound travels so well in water, it is important to consider what organisms can hear killer whales' calls. Foote and Nystuen (2008) looked at prey hearing ranges and mapped them onto that of a killer whale call. As seen in the audiograms in Figure 3, salmon, the prey of residents, are not sensitive to the resident killer whale call. Conversely, the two marine mammals are sensitive to the transient call. This suggests resident killer whales need not be selective in using vocalizations during foraging activities. Thus, there is no disadvantage in using calls during foraging for the resident killer whales.

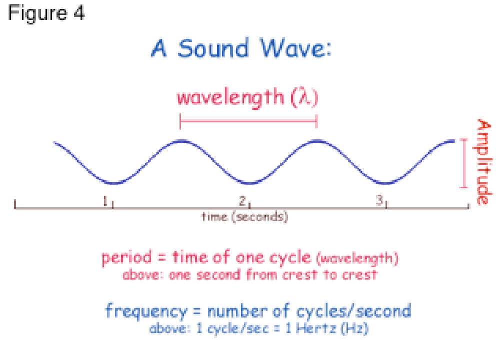
Figure 3



This figure is reproduced from Foote and Nystuen 2008. a) is the audiogram of a salmon (solid line) mapped with a resident killer whale call. Note the killer whale call is not in the hearing range of the salmon since the two curves do not overlap. b) is the audiogram of two marine mammals (solid black and grey line) mapped with a transient killer whale call, which is in the range of its prey since area of overlap exists.

Now, consider how sound travels. Sound behaves as a wave and can be described in terms of an amplitude, frequency, and length (see Figure 4). A single call type may vary by frequency, duration, or amplitude. One study comparing dolphin whistles of different geographic populations considered a list of traits including minimum and maximum frequencies, start and end frequencies, delta frequency, peak frequency, duration, number of inflection points, and number of harmonics (May-Collado and Wartzok 2008). These characteristics will be used to analyze the S1 calls of the resident killer whales. Because whistles of a bottlenose dolphin are not precisely comparable to a killer whale call, it is expected that some of the characteristics listed above may not be significant. However they present a good starting point to investigate variation in the calls of killer whales.

Figure 4



Spectrograms allow for measurements to be made on the calls. The more energy occurs in parts that are brighter, while less energy is contained in areas that are dark (as seen in Figure 1, note color varies with settings and program used). Recall, S1 calls seem to be made up of three parts. Thus, inflection points should occur twice in every call categorized as S1. Typically, the call starts at one frequency and ends at a different frequency, usually lower. Thus minimum and maximum frequency may be the same as start and end frequency. Peak frequency may also be redundant. Harmonic visualizations are often limited by the sensitivity of the recording equipment. In this study, we are limited by the the frequency range of the hydrophone.

Information gathered here led the researcher to develop a foundation for measuring variation in the calls of the Southern Resident. This study aims to test two hypotheses.

1) No variation in S1 calls exists.

2) S1 calls from the same individual will not change significantly.

Investigation of (2) will be limited because it is dependent on localizing more than one cal to an individual.

Methods

A 42' catamaran, the *Gato Verde*, was used to collect data from April 2011 through May 2011 throughout the Salish Sea. The vessel is a hybrid electric-biodiesel sail boat. This limited background noise due to the research vessel when recording whales. We observed the Be Whale Wise guidelines. (Note distance increased from 100 yards to 200 yards perpendicular to the whale's travel path during the data collection period.) The radio system and whale watch company contacts were used to determine the location of the SRKWs.

A four hydrophone array (Labcore 40's Array with peak sensitivity of 5 kHz) was deployed from port stern of the *Gato Verde* when whale sightings are imminent. The most accurate recordings were made when a speed less than three knots was maintained by the boat and a weight was attached to the array keeping it submerged. Hydrophones were calibrated ahead of time using the Inter Ocean Systems Model 902 Listening Calibration System. The sampling rate was set to 48,000 samples/second and the gain setting was adjusted accordingly. Recording occurred once equipment was in place and whales were in sight. Sound Devices 702 recorders assigned labels to the audio files, these were noted in the data sheets to determine day and time the recording was taken. Metadata (weather conditions, number of individuals present, latitude and longitude coordinates, etc.) that does not affect this study was recorded for archival purposes only (stored in SQLShare - http://www.sqlshare.com/).

Photos were used to identify the whales present during recordings. Identifying individual whales in the Southern Resident community has been made possible by extensive photo identification projects (Bigg et al. 1987, Center for Whale Research). Uniqueness of the dorsal fin and right and left saddle patches, the area of the body just behind the dorsal fin, are the characteristics used to determine individuality (Ford et al.

1999, Baird 2002, Bigg et al. 1987) . J-pod was the focus group since they commonly use S1 (Ford 1999 and Wieland 2007). Recordings will be scanned for S1 calls that are visually and audibly separate from other calls and boat noise. An ideal situation would occur when S1 calls are found and it is possible to localize the calls to pinpoint each call to an individual whale. Had this occurred these files would have been used to address the second previously stated hypothesis.

Attempts at understanding how the calls are perceived by the SRKWs were achieved by the following process. Several S1 calls were mapped onto the killer whale behavioral audiogram to determine what parts of the call are in the critical hearing range. These calls were first turned into twelfth octave bands in order to properly display them on the audiogram. Maximum decibel level was calculated and help shift the call to the level in which it was recorded by the Sound Devices. This help us better analyze and interpret data.

Calls that measurements were made on had to meet the criteria listed below.

a) The call must be represented visually and audibly.
b) The call must be separate from background noise in the spectrogram.
c) The call must be separate from other calls in the spectrogram. The spectra of two calls could not overlap one another.
d) A full harmonic must be seen in which start and end components could be captured. The longest and strongest harmonics were typically used.

S1 calls were analyzed in RavenPro 1.4 beta version build 38 (2003-2010: Cornell Lab of Ornithology, Ithaca, New York). Measurements made on each call included start and end time, low and high frequency, center frequency, delta frequency (referred to as frequency range), delta time (referred to as duration), frequency 95%, max frequency, and max power.

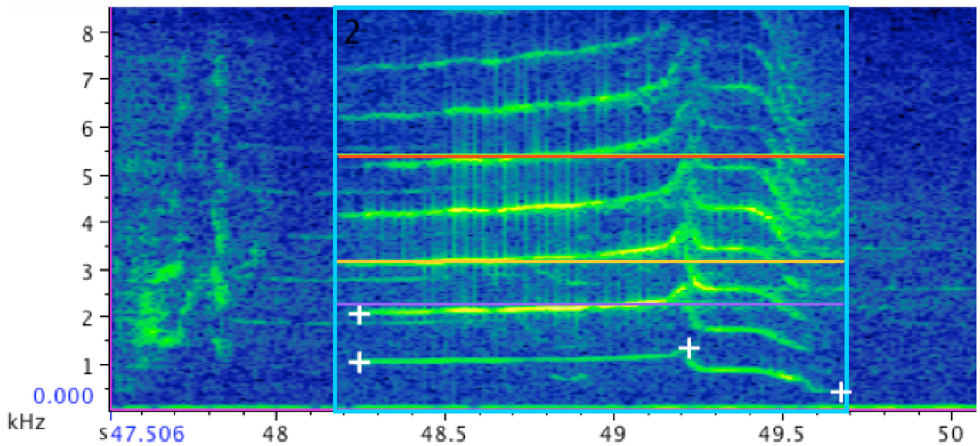
SeaSounds Data (previously categorized):

a) For understanding categorization: RavenPro 1.4 was used to measure known calls using features described above based on May-Collado and Wartzok (2008) for previously categorized calls (S1, S3, S6, S7, S10, S12, and S16). These calls were chosen for comparison by listening to recordings and looking at spectrograms of Wieland and Ford to find some similar and some different calls, with respect to S1. Calls were then put in random order to prevent bias in determining groupings.
b) Principal component analysis (PCA) was performed to distinguish groups formed based on measurements taken.
c) Groups from PCA were used to compare to known call type categorizations previously made.
d) PCA was used to determine what factors if any were causing the separation.

Uncategorized Data:

a) Selections on S1 calls were made given the four criteria above (see Figure 5). A box was drawn capturing the whole call and all its harmonics. Point selections were made at the start, peak, and end frequencies of the same

Figure 5



Five selections were made on each call. Point selections at the start frequency, peak frequency, and end frequency on the same aremonic were made. A point selection was also made directly above or below the start frequency (called next harmonic frequency). Raven measurements were chosen to be calculated on the whole call. Measurements were obtained for begin time (s), end time (s), low frequency (Hz), high frequency (Hz), center frequency (Hz) (yellow line in diagram), delta frequency (Hz), delta time (s), frequency 95% (Hz) (red line in diagram), max frequency (Hz) (purple line in diagram), and max power(dB). Delta frequency (Hz) was renamed frequency range to allow for a delta frequency between the point selections. Point selections on start frequency and next harmonic frequency were used to bring all point selections down to the equivalent on the fundamental or first harmonic.

harmonic for each call. A selection was also made on a harmonic directly below or above where start frequency was measured. (See appendix for measurements taken on several S1s used.) This allowed for correcting the frequencies down to the fundamental in order to compare measurements made on all calls.

b) Selection tables were saved from RavenPro 1.4 and concatenated to provide a master table with all calls measured. Mean, variance, and standard deviation were calculated in Numbers (Apple 2009) for each feature measured.

c) Files were saved as text files and loaded into R (http://www.R-project.org). Pairs comparison and a PCA on the newly acquired data allowed for visualization of the S1s based on the features measured.

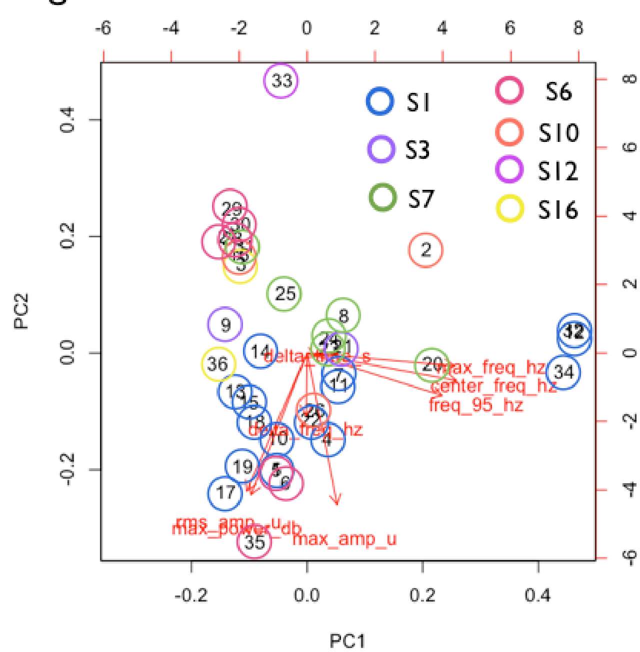
d) Hierarchical clustering allowed the S1 data set to be divided into groups.

e) T-tests were done on these groups using the factors driving the PCA for the S1 data set and the SeaSounds data set (peak frequency, start frequency, center frequency, max frequency, and frequency at 95%).

Results

PCA on SeaSounds files showed that S1 calls did not separate out from some other calls in most cases. As seen in Figure 6, three S1 calls did separate out due to center frequency, max frequency, and frequency at 95%. These factors were used to determine statistical significance between factors and the groupings of S1s determined by the hierarchical clustering.

Figure 6



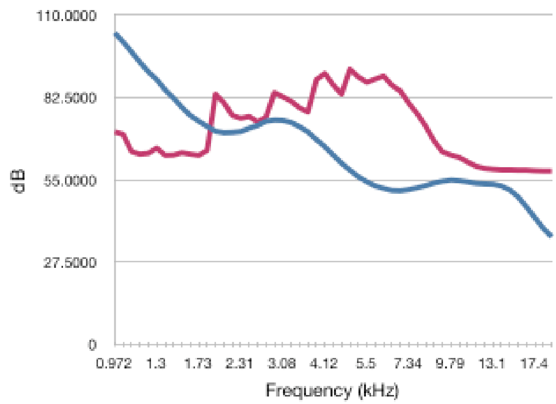
PCA run on known categorized calls (SeaSounds files).

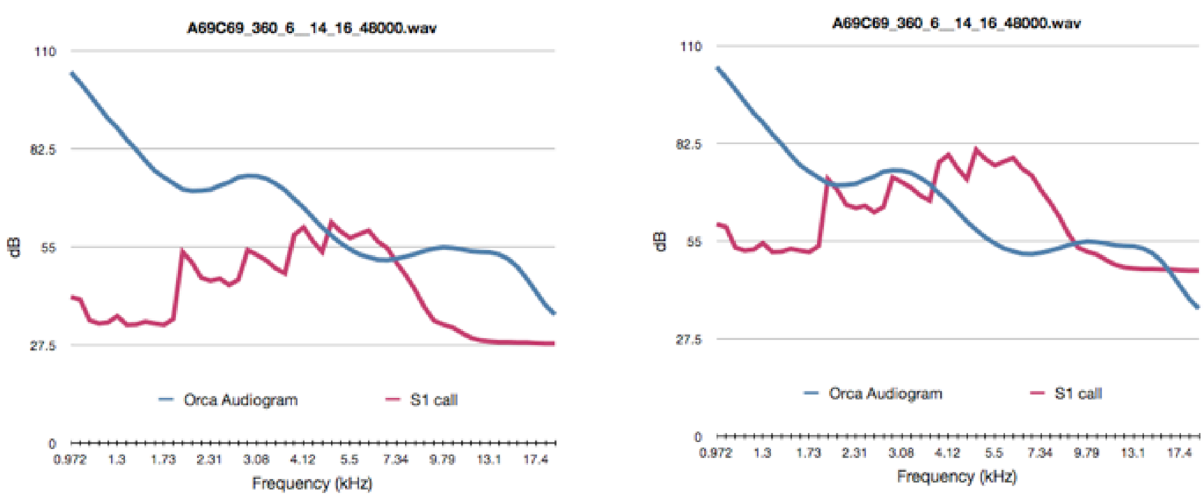
J-pod was seen on a total of five days. Two days consisted of recordings full of vocalizations. The other three days conditions or behavior state made its difficult to get clear recordings of vocalizations. Due to limitations in time 150 S1 calls were analyzed. Many calls heard could not be used because they did not meet all of the four criteria discussed previously.

Four of the S1 calls were mapped onto the physiological audiogram of captive killer whales (see Appendix B). Max power (dB) was used to plot the call at the appropriate level. Figure 7 shows one S1 call at the various decibel (dB) levels.

Figure 7

An S1 is mapped on to the physiological audiogram of killer whales. In the graph to the right, an arbitrary decibel level was chosen. A thirty decibel drop was made in the graph below to se what frequency portion of the call would cross over last and thus be the last heard. The last graph (bottom right) uses the max decibel level recorded for this particular S1 and adjusts accordingly.





30 dB drop

11.2 dB drop

The mean , variance, and standard deviation were calculated for all factors measured on the S1 calls. Variance on all factors was greater than zero. Pairs test done on the factors in R showed few correlated factors (see appendix).

The S1 calls clustered into three major groups when a hierarchical clustering in R was performed (see Appendix E). There were 6 calls that formed a small out group. It was noted that these six calls were from the same recording subset. This led to proposing the groupings were based were in time the recordings were made in relation to each other. However no statistical evidence for this was shown. Instead numbers of calls from each recording was proportional to the number of minutes of different recordings (see Table 1). The three groups formed were arbitrarily named A, B, and C (shown in Appendix E). PCA on the S1 data set showed no groupings between S1 calls (see Appendix D). Peak frequency and start frequency were the main factors driving principal component 1.

Table 1

	minutes	% Total	%Expected A	% Expected B	%Expected C	% A	%B	%C
C62	2	0.01	0.32	0.44	0.54	0.00	0.00	1.36
A63C63	14	0.10	2.27	3.11	3.76	1.36	6.12	2.04
A66C66	5	0.03	0.81	1.11	1.34	0.00	1.36	2.04
A67C67	19	0.20	4.70	6.44	7.78	2.04	15.65	2.04
A68C68	28	0.19	4.54	6.22	7.52	14.97	3.40	0.68
A69C69	63	0.43	10.20	13.99	16.91	5.44	6.12	31.29
Total	147	calls						

Expected number of calls versus actual number of calls.

T-tests showed statistical significance existed for distinguishing groups A and B by both center frequency and max frequency. The same was shown for groups B and C. However groups A and C were only statistically significant when frequency at 95% was the factor tested (see Table 2).

Table 2

Groups tested	factor tested	p-value	factor tested	p-value		
AB	peak frequency	p=0.176	start frequency	p=0.723		
AC	peak frequency	p=0.112	start frequency	p=0.410		
BC	peak frequency	p=0.728	start frequency	p=0.275		
Groups tested	factor tested	p-value	factor tested	p-value	factor tested	p-value
AB	center frequency	p=1.246E-04*	max frequency	p=0.1.77E-05*	frequency 95%	1.92E-04
AC	center frequency	p=0.067	max frequency	p=0.393	frequency 95%	3.37E-06*
BC	center frequency	p=2.60E-08*	max frequency	p=5.73E-08*	frequency 95%	p=0.883

T-test results comparing each group with one another.

Discussion

First understand that the audiogram graphs only show the left have of the physiological audiogram. This is limited because of the sensitivity of frequency of the hydrophones. Physiological audiogram was used to account for the hearing of the two captive killer whales since it is obtained using a repeatable experimentation. In the case of the behavioral audiogram, we have no sense of how good or poor the hearing of those two whales is. Since sensitivity occurs amount 20kHz for the killer whales it would be necessary to see what is happening to the right side. Hydrophones of better sensitivities will help accomplish this. Doing this may help determine frequencies and levels at which the whales are unaffected. This could be beneficial in trying to protect the SRKWs from things like boat noise and pile driving.

The PCA on the SeaSounds files did not provide clear distinctions of S1 from the other call types looked at. Perhaps this was due to factors that were measured did not accurately account for all the variation in the S1 calls. Determining more features to better capture the uniqueness of the S1 calls should be looked at in future research.

Variance was measured for all factors. If no variation was present, all _^{2} values would be close to 0. However, all factors varied (_$^2 > 0$). Thus, the null hypothesis can be rejected. This means that there is variation in the S1 calls. The variation seems to be occurring due to center frequency, max frequency, and frequency at 95%. As previously stated, these factors may not be the sole contributors to the variation, but based on those studied these were significant.

The hierarchical clustering also suggests variation since there are three major groups that formed. It would be interesting to add many known discrete categorized calls to see where they lie on the tree. Using cladistic programs and making trees based on the factors we found significant could also see how the variation in the S1 calls separated them from each other. Examining a few calls that are considered distant on the tree no obvious differences were noticed. Separating the data by these groups in more detail may help classify what range of S1 calls exist.

The hypothesis of whether calls from the same individual varied was not answered. No opportunities arose in the data collecting days in this study in which only a few whales were present and thus sounds could be localized to individuals. Closer examination of archived files may turn up files that could be used to asses this hypothesis. This too is an important question. Knowing what whale is calling based on the variation of the call could aid in monitoring efforts using the hydrophones.

Given restricted time during this study period only 150 calls were analyzed from two days with J-pod. More calls would only strengthen the data set. Also changes over time could be examined. This could provide more evidence that the calls are getting louder or longer over time as seen in Holt (2009). These findings may prove vital in establishing no go zones for the whales and finding new ways to help conserve this endangered species.

Conclusion

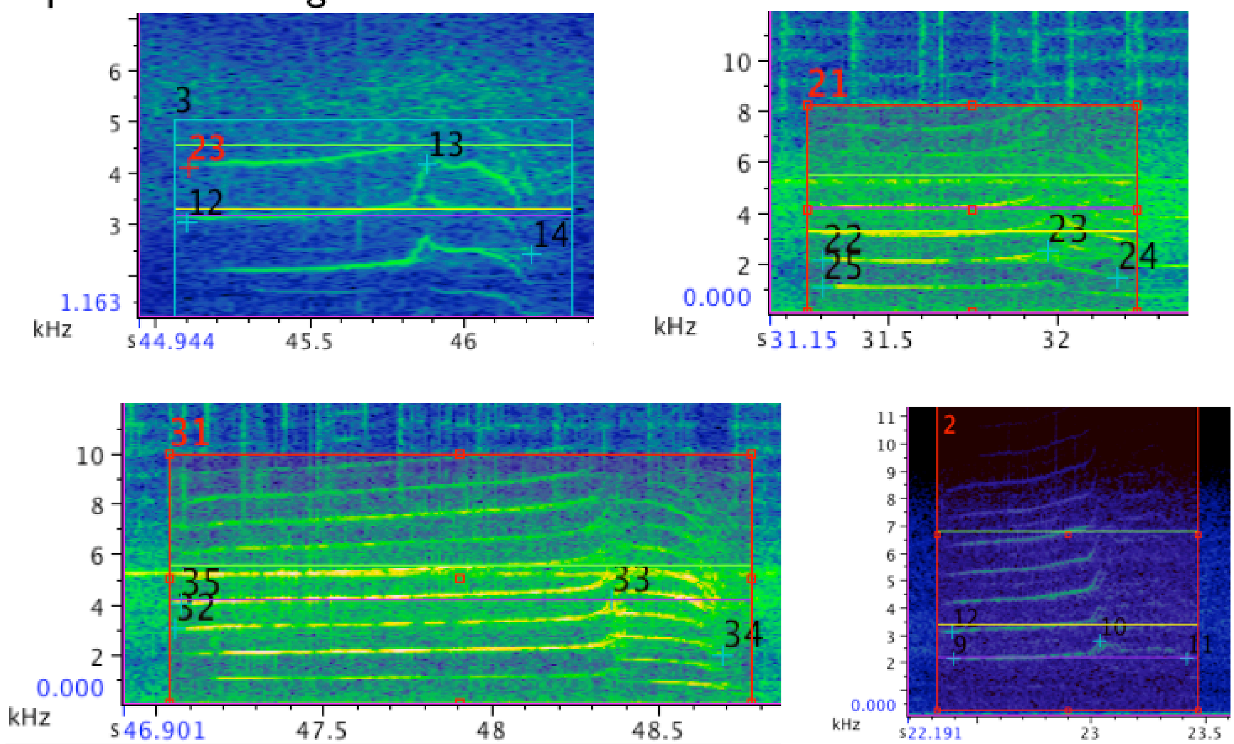
Variation in S1 calls does exist. Further research could pinpoint if the variation is due to a different number of individuals calling or due to some other environmental factor such as increased boat noise. When many instances like this occur were separation of calls can be made down to the individual, cladistics should be used to make a tree inference. This tree could then be compared to trees from photo id projects and from genome sequencing.

It would also be beneficial to see if the same kind of variation occurs for call types other than S1. A greater quantity of calls over a larger time span would also help. This study only scratches the surface in trying to determine variation in calls. Many other factors could be put into consideration.

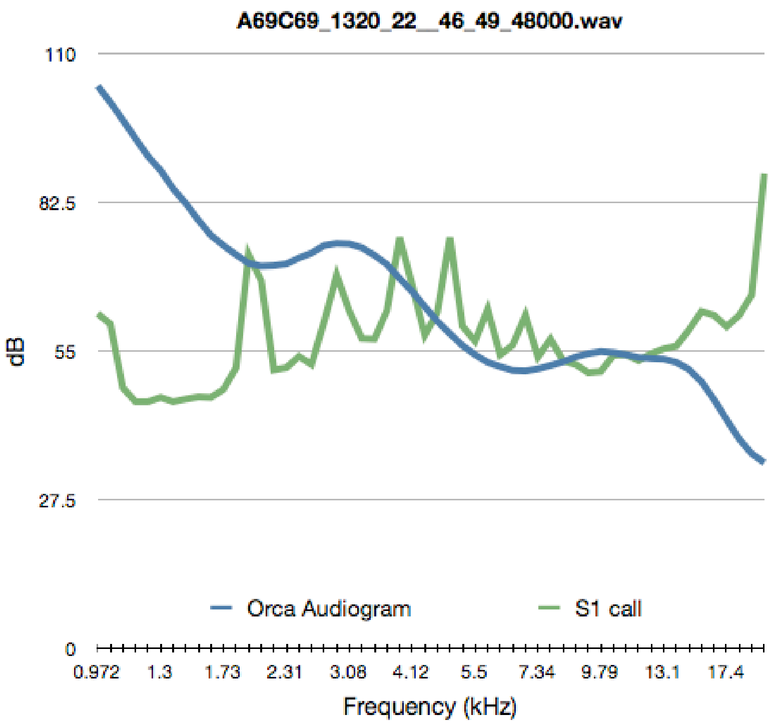
Appendices

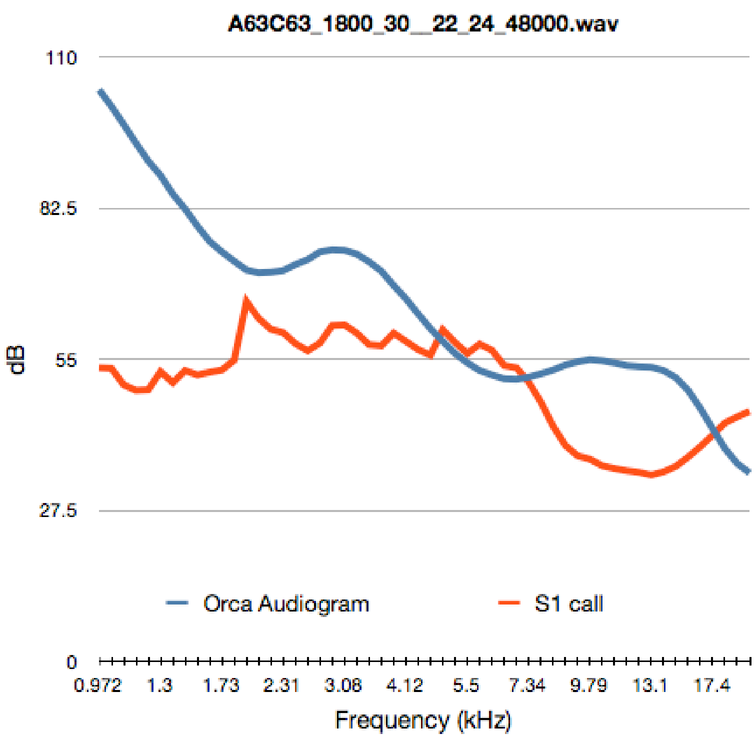
Appendix A

Here are examples of S1 calls analyzed in RavenPro 1.4. Point selections as well as whole call selection can be seen for different S1 calls. Spectrograms were produced using the "cool" color scheme.



Appendix B


A69C69_1320_22__46_49_48000.wav
110
82.5
55
27.5
0
dB
Orca Audiogram
S1 call
0.972
1.3
1.73
2.31
3.08
4.12
5.5
7.34
9.79
13.1
17.4
Frequency (kHz)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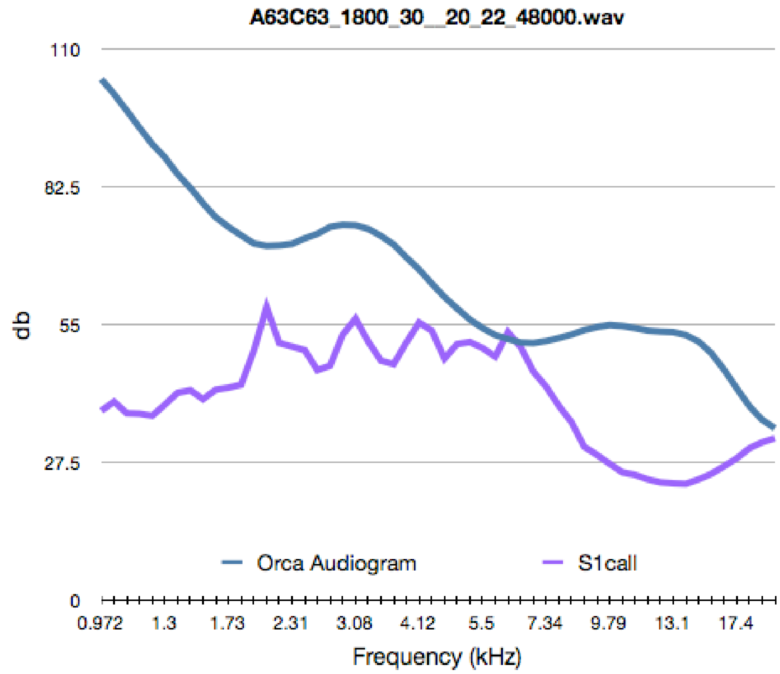
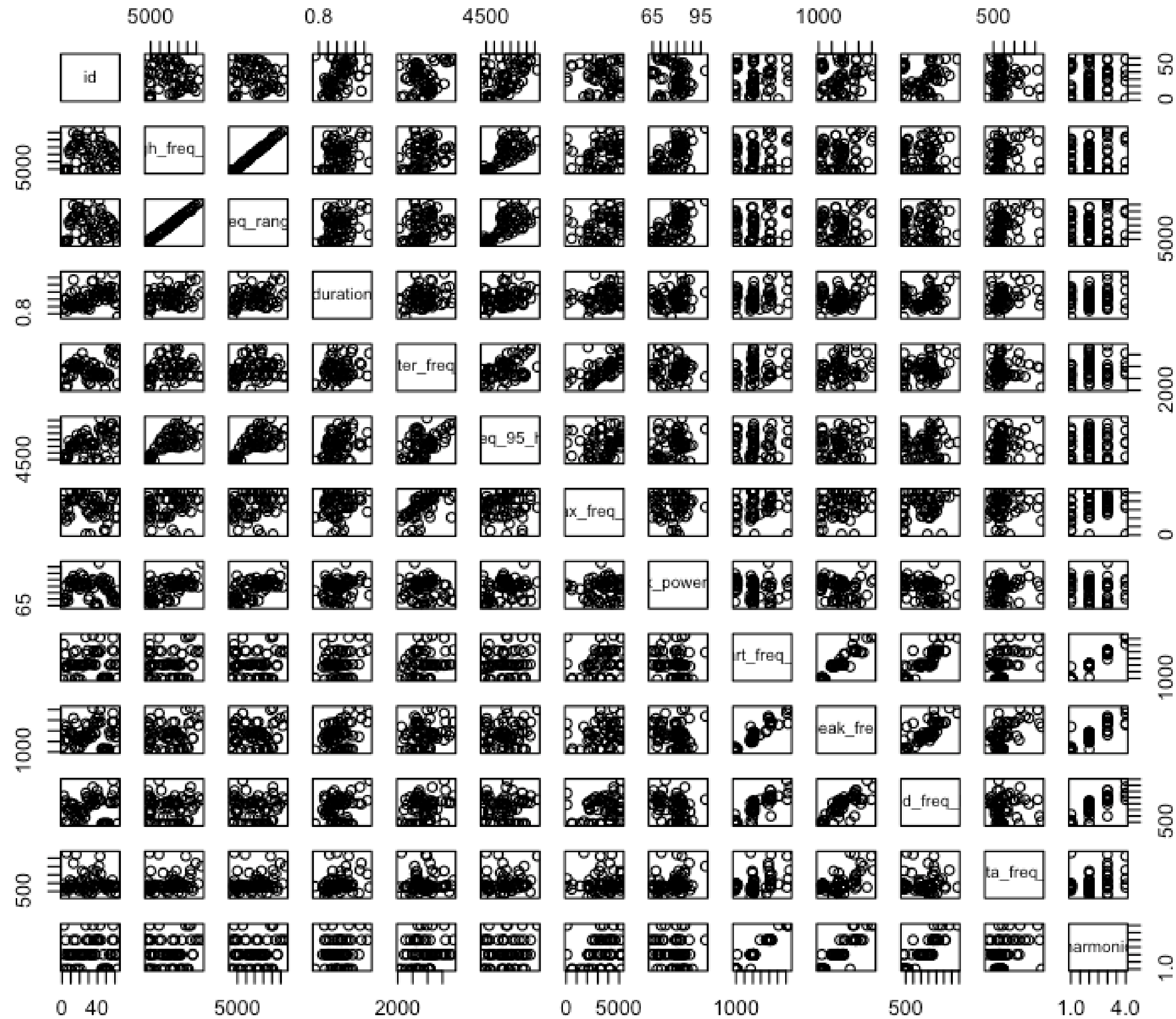
110
82.5
55
27.5
0
dB
Orca Audiogram
S1 call
0.972
1.3
1.73
2.31
3.08
4.12
5.5
7.34
9.79
13.1
17.4
Frequency (kHz)



A63C63_1800_30__20_22_48000.wav
110
82.5
55
27.5
0
db
Orca Audiogram
S1call
0.972
1.3
1.73
2.31
3.08
4.12
5.5
7.34
9.79
13.1
17.4
Frequency (kHz)

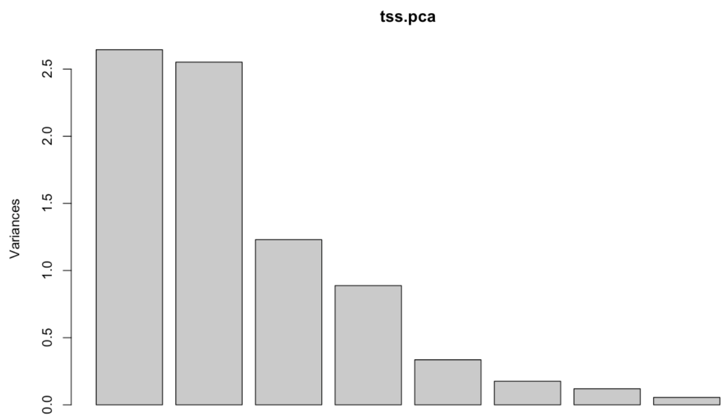
Appendix C


5000
0.8
4500
65
95
1000
500
id
h_freq_
eq_rang
duration
ter_freq
eq_95_
x_freq_
_power
rt_freq_
eak_fre
d_freq_
ta_freq_
armoni
0
50
5000
2000
0
1000
500
1.0
0
40
5000
2000
0
5000
1000
500
1.0
4.0
5000
0.8
4500
65
1000
500

Appendix D

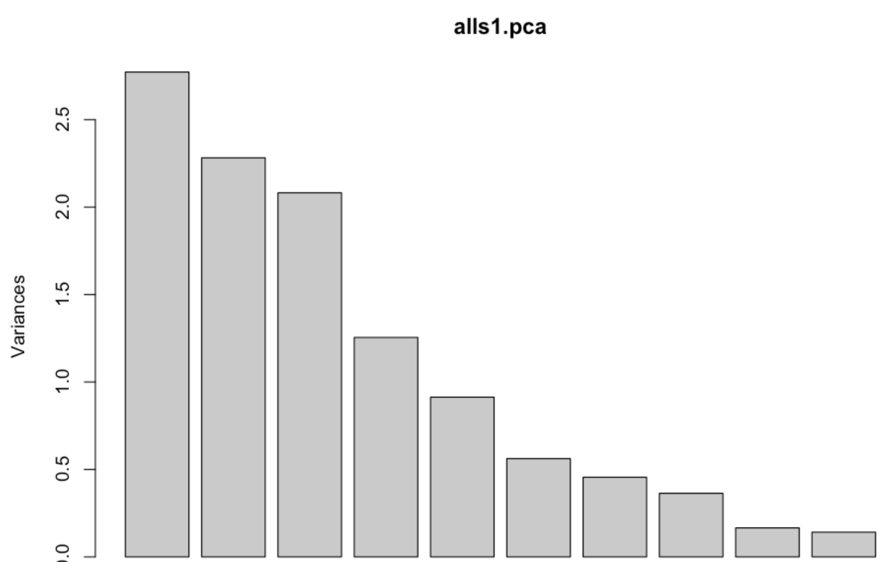
PCA analysis for SeaSounds files

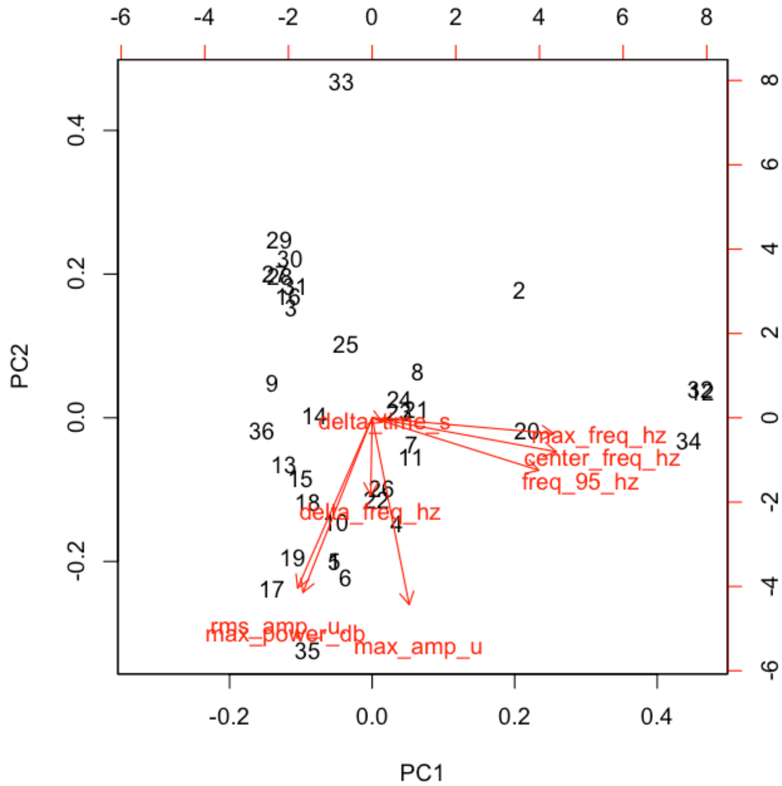
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
center_freq_hz	0.564163023	-0.10512269	0.16523281	-0.05783965	0.29267485	-0.09522678	0.717734306	0.17364548
delta_freq_hz	-0.004423596	-0.23919596	-0.27686606	-0.92275218	-0.09021675	0.06050830	-0.010023844	0.05233102
delta_time_s	0.030839081	-0.01396796	-0.84704819	0.23898707	0.39772018	0.23883963	0.036240682	0.08780255
freq_95_hz	0.510672437	-0.16248471	-0.28275550	0.14527587	-0.57145361	-0.07811082	0.002071977	-0.52829140
max_amp_u	0.113492549	-0.57778148	0.03199357	0.22241085	-0.32901442	0.17250385	-0.166189235	0.66118900
max_freq_hz	0.556806743	-0.04928619	0.19448962	-0.08500403	0.45284675	0.07342248	-0.652719854	-0.07733678
max_power_db	-0.212004920	-0.54025965	-0.07970383	0.08254979	0.26360599	-0.74503771	-0.057869579	-0.14862053
rms_amp_u	-0.228260234	-0.52630511	0.23108330	0.05879084	0.19660367	0.57783675	0.162567990	-0.46375390



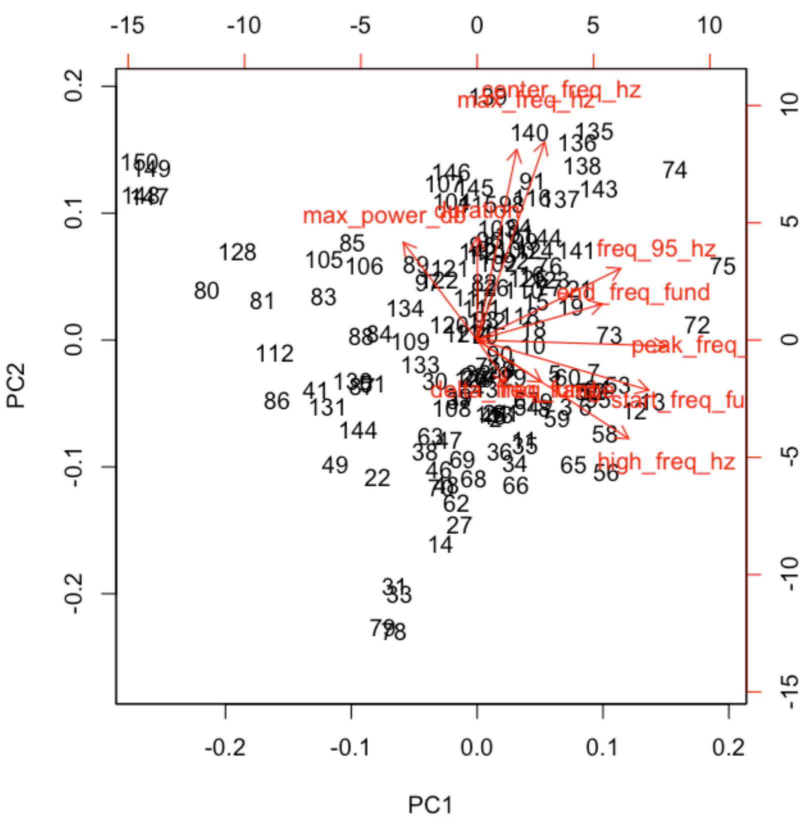
PCA analysis for S1 data

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
high_freq_hz	0.4030696178	-0.28689482	0.19398230	-0.2545596	0.0003439997	-0.27142235	0.02666341	0.57500200	-0.45603481	0.19914293	0.012744528
freq_range	0.1708863059	-0.12152440	0.45001871	-0.4902048	0.0663801755	-0.17892194	0.39592665	-0.28163922	0.48818398	0.04857754	-0.005546791
duration	0.0006488998	0.30086578	0.04488629	0.1996665	0.8772762758	-0.07542410	0.14871419	0.23952380	0.09892253	0.05469574	-0.005528755
center_freq_hz	0.1797479716	0.57688758	0.04286641	-0.0781149	-0.2096259231	0.15314919	-0.14639809	0.02861487	0.11101586	0.72362852	0.036609466
freq_95_hz	0.3821082530	0.20872185	0.26559148	-0.2437174	0.1910683740	0.13796718	-0.64286566	-0.23084780	-0.12101850	-0.37889118	-0.013357559
max_freq_hz	0.1051234419	0.55480942	0.04917072	-0.0889056	-0.2885766883	0.14508232	0.43222128	0.33755009	-0.04589351	-0.51295106	-0.022536916
max_power_db	-0.1967994545	0.28467870	0.32001022	0.2856925	-0.1758757484	-0.78760801	-0.12469521	-0.12770448	-0.10020467	-0.05510087	-0.002861511
start_freq_fund	0.4563229784	-0.14561952	-0.12250203	0.3838785	-0.1578280811	-0.13234796	-0.21048724	0.31378027	0.63822028	-0.11690892	-0.044871199
peak_freq_fund	0.5051331145	-0.01716290	-0.03952607	0.3710133	0.0112675269	0.02671063	0.31485065	-0.40035923	-0.24595458	0.01850167	0.533139756
end_freq_fund	0.3329288112	0.10501330	-0.51877213	-0.1153360	0.0569138290	-0.26949377	0.15134076	-0.29043640	-0.13390739	0.01979931	-0.627898948
delta_freq_fund	0.0774829123	-0.12106204	0.54308840	0.4491007	-0.0551825194	0.33750089	0.13039409	-0.07227387	-0.13804290	0.08507064	-0.563234367



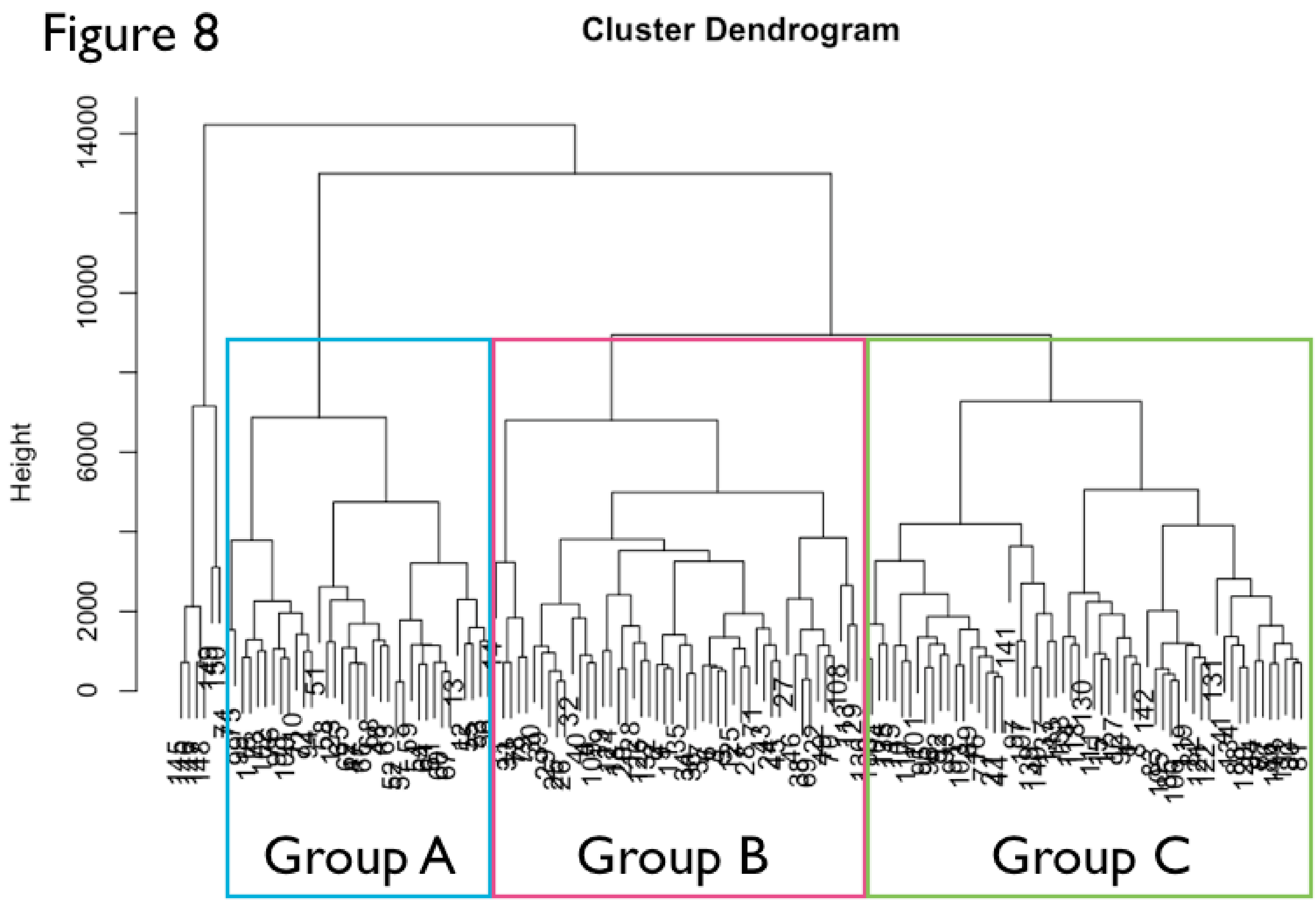


Upper is for Sea Sounds.



Lower is of 150 S1 calls

Figure 8



Hierarchical clustering in R broke the S1 data set into three major groups

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