Determining the correlation between call rate and group distribution in Southern Resident killer whales (*Orcinus orca*)

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Introduction:

It is well established that different animals use discrete calls to keep in contact. In the past decade, many species including elephants, dolphins, and birds have been identified using a unique contact or "cohesion" call to communicate with their group when they are beyond visual range (Janik and Slater, 1998; McComb et,al.,2001; Ford, 1991). A marine mammal that relies heavily on acoustic communication, yet has no scientifically identified contact call is *Orcinus orca*, or the killer whale. Studies of contact calls have been reported for the Bottlenose Dolphin (*Tursiops truncatus*), a close relative of the killer whale. Janik 1997, investigated unique signature whistle use as a way for a dolphin to keep in contact with its group and observed that a dolphin isolated from its group displayed an increased frequency of signature whistle use (Figure 1). Interestingly, all dolphins in the group increased their signature whistle use when one member was separated from the group, not just the isolated individual (Janik et al., 1997). These findings support the notion that a cohesion call is a valid and tested method of communication among different species.

Killer whales have a wide range of vocalizations and a very diverse population. Killer whales are classified into three ecotypes distinguishable by vocalizations, physical characteristics, diet, habitat, and behavior (Ford, 1989). The primary focus of this study are the resident killer whales, which are classified into two communities, the Northern Residents and the Southern Residents. The

Southern Resident Killer Whales (SRKW) include three pods J, K, and L which total to 86 whales. The SRKWs are an unique population that although genetically indistinguishable from other killer whale populations, are considered a distinct subpopulation within the species (NFMS, 2008). The SRKWs were listed as endangered under the Endangered Species Act of 1973 in 2005, due in part by their definition as a subpopulation distinguished by unique behaviors and vocalizations. This study reports the observations the SRKWs, which inhabit the southern tip of Vancouver Island and the coastal waters ranging from Washington to California (Center for Whale Research 2006).

SRKWs have the ability to produce a variety of vocalizations that can be classified into three different sounds: clicks, whistles and pulsed calls (Ford 1989). Clicks are typically employed in echolocation and are characterized as a brief series of pulses. The pulses can vary in structure with frequencies as high as 85kHz. Whistles feature either a nonpulsed or continuous waveform and can vary in frequency from 1.5 to18 kHz (Ford, 1989). The most profusely used killer whale sounds are the pulsed calls. Pulsed calls are classified as discrete, variable, and aberrant (Ford, 1989). A discrete call is repetitive in occurrence and has a characteristic fundamental structure. A variable call lacks repetition and fails to fall into a structured category. This study will focus the on use of discrete calls in killer whale communication.

A defining characteristic of the SRKWs that illustrates their variable sound range is a specific vocal repertoire that is unique to, and shared among individuals of a particular pod (Ford, 1989, 1991). A matriline which is composed of a mother and all her offspring, and her daughter's offspring (Wieland, 2007), is the smallest unit of hierarchical organization within the pod. Each matrilines within a pod is highly vocal and exhibits group specific dialects. These different family dialects reiterate the importance of intra-group communication. It has been suggested that having a collective repertoire is of great significance. By having multiple shared discrete calls killer whales can increase the efficiency of communication within the pod (Ford, 1989). Living in a stable matrilineal group, a killer whale will often travel with its mother its entire life (Bigg et al., 1990). This makes for a strong mother-offspring bond, and even as adults, offspring can be seen swimming next to their mothers. Contact calls are typically exhibited in animals with strong highly evolved family bonds, such as dolphins and elephants (Janik and Slater, 1998; Maccomb et,al.,2001). The killer whale behaviors of shared repertoires and staying close together emphasize the strong bonds among related whales and support the premise that forming close groups provides the species with a selective advantage. The shared repertoires provide an effective and reliable way for such groups to stay in contact when our of visual range.

Wieland (2007) explored the repertoire usage in the SRKWs, using hydrophones to record the current repertoire usage in all three of the SRKW pods. The results yielded a detailed spread of the types, frequency, and duration of calls used by the pods (Figure 2). She then compared her findings to those of Ford's (1989), which revealed that the discrete call S1 has been J-Pod's dominant call since at least the 1970's.

Based on previous data that this call is used solely by J-Pod, the S1 call likely serves as a contact call for the pod. A key aspect of a contact call it that it is unique and identifiable by those who use it. In the African elephant, *Loxodonta Africana,* the primary social unit, like killer whales, is matrilineal and composed of related adult females and their offspring (McComb et,al.,2001). Female African elephants recognize a contact call as belonging to a family member from distances as far as 2.5km (Poole, 1988). There have been many recorded instances of separated family members using contact calls back and forth for several hours in an attempt to relocate each other (McCombet,al.,2001; Poole,1988). This emphasizes that a contact call can help maintain group cohesion and coordination among family members. If the main purpose of a contact call is to stay in communication, then it is reasonable to speculate that the use of such a call would increase when the animals are separated or beyond visual range. As this concept applies to other social mammals, such as dolphins and elephants, it is highly likely that this model applies to whales who live in the marine environment where light is attenuated but acoustic signals rapidly travel long distances. This study will seek to determine whether J-Pod uses the discrete call S1 as a contact call to maintain group cohesion and whether this call is used more frequently when they are separated from one another.

Methods:

Sampling

To investigate the use of a contact call in killer whales, SRKWs in the Salish Sea were observed and recorded from mid April to late May 2011. A hydrophone array was used to record the killer whales acoustic communication. All recordings were made from the 42–foot hybrid electric-biodiesel catamaran, the *Gato Verde*, equipped with a battery pack that allows it to motor silently for as long as 3 hours continuously. The *Gato Verde* also has a biodiesel generator that can supply electricity to the electric motors, should an extended period of motoring prove necessary. This allowed recordings to be taken without disturbing the whales or disrupting our hydrophones.

For this study, data was collected only from the Southern Resident J-Pod. Specifically, we searched for S1 calls as they were recorded via the hydrophones (Figure 3). Simultaneously, the killer whales' degree of distribution was measured by taking wide angle photos of the whales when they surfaced for air. The distribution was assessed with respect to call rate, as well as call density. Call density is defined as the number of calls per minute, per group size.

Recording

To record the killer whales, a hydrophone array of 4 LAB-core hydrophones was towed in a strait line behind the boat. The LAB-core hydrophones exhibit peak sensitivity at 5,000Hz and decrease 30dB at 200Hz and 10,5000Hz. The sampling rate was set to 44,000 samples/sec and the gain setting was adjusted to 37dB. The hydrophones were distanced by 10m increments. To keep the hydrophones parallel to the surface and below the upper layer turbulence, we attached an 8lb weight to sink the array to a depth of about 5m. We also noted the date, file name, and time of each recording made.

Killer Whale Visibility

To supplement my data, I looked at J-Pod's call rate as it varied for day and night. To determine whether or not a decrease in visibility correlated to an increase in killer whale vocalization, killer whale calls for day and night were analyzed. If the killer whales used discrete calls more when they were out of visual range, the limited visibility of night may have influenced their call rate. This portion of the experiment utilized archived data because the *Gato Verde* was not equipped to follow the whales at night. Data was gathered from the five OrcaSound hydrophones located throughout the San Juan Islands. Subsets of the data analyzed were created using the SQLShare database (Howe et. al). By choosing to query the dataset for human detected recordings made by SRKWs, the uncertainty of the auto detectors was avoided and a large sample size was obtained for the day and night comparison.

The auto detections were unreliable because they are not very sensitive and often miss or don't record SRKW calls. Human detected recordings were reliable because it was a conscious being that heard and recorded the whale vocalizations. Joining the human detected query to one table that had all the times of sunrise and sunset for all the days recordings were detected. Night was defined as the hours after the sun set and before sun rose. Day was defined as all the hours between the sunrise and sun set. Joining these tables, I accounted for the day length as it varied with season. Specifically, I determined when J-Pod was most vocal by looking at the percentage of calls for the different bouts during day and night.

Image Analysis

From the photos taken in the field, there was a very selective set of criteria for measurement. For a photo to be analyzed, it must have had more than one whale in the frame and had at least one whale's full dorsal fin exposed. I used the known average male or female dorsal fin length,(1.5m and .61m, respectively) the fin was used as a control to calculate how far apart the whales were from each other in the photo. A ratio of the dorsal fin pixel length to the known dorsal fin length in meters was used to measure the distance between the whales. Image analysis began by measuring the control dorsal fin length in pixels using ImageJ64 (Rasbad)(figure 4a). After the dorsal fin was measured, the distance between the whales was measured with a horizontal line. For photos with only two whales in the frame, the distance between whales was measured from the fin tip of the shortest fin in the water to the closest edge of the fin of the other whale (figure 4b). In photos with more than two whales in the frame, horizontal distance between the furthest two whales and two closest whales was measured and the values were averaged (figure 5). Due to the different measurement tactics for two whales and more than two whales, the whales were grouped the two into separate categories for analysis.

Photos where depth of field played an influential factor in the distance measurement were noted but not measured. Only photos with whales in the same horizontal plane were used for measurement to account for the issue of depth between whale fins (figure 6). This feature will allow is to assign a numerical value to the killer whale's distribution, which was compared to the S1 call rate.

Sound Analysis

Using Audacity 1.3.12 Beta (Audacity Team), a sound recording and analyzing program, we analyzed the S1 killer whale calls. Visual sound file analysis was performed via spectrogram examination. Audible sound file analysis was conducted by listening and identifying the S1 call as recorded by the hydrophones. To be classified as a discrete S1 call, the call must be a clearly audible S1 and display the fundamental characteristics found in a S1 call (see Figure 3). A characteristic S1 has an average start frequency of 9 Hz, peak of 1224Hz, and end frequency of roughly 717 Hz (Ford, 1989).

Results:

Call Rate and Distribution

The measures of J-Pod distribution were grouped into three categories, two whales, more than two whales and all whales. A total of 129 photos were examined and analyzed for call rate. The two whales group had 92 usable photos and the more than two whales group had 37 usable photos. Two measures of distribution for these three categories were analyzed. For one measurement, the distribution was calculated based on the average of the minimum and maximum distance between the killer whales. This measurement was then normalized by taking the average distance and dividing it by number of whales in the image (see Table 1.1).

For the three raw (un-normalized) data categories, two whales, groups of more than two whales, and all groups of whales a linear regression model was constructed to assess the correlation between the call rate of the discrete call S1 and killer whale distribution (see figure 7). For the three un-normalized whale groups analyzed, all failed to reveal a linear regression model correlating whale distribution to the call rate of the discrete call S1 (see figure 7). Due in fact to the failure to generate a normally distributed graph, the log of the whale distribution was plotted against the call rate to see if the data could be manipulated in different ways The log graph revealed no correlation for any of the three un-normalized whale groups tested(figure 8). For the three normalized datasets, the same methods were employed and no significant correlation was found between killer whale distribution and S1 call rate. By manipulating the data in four different ways and finding no changes in the relationship between the variables measured, we can confidently state that within the parameters tested, the S1 call rate shows no direct correlation with killer whale distribution for groups of two whales, more than two whales, or for the combined set of all whales.

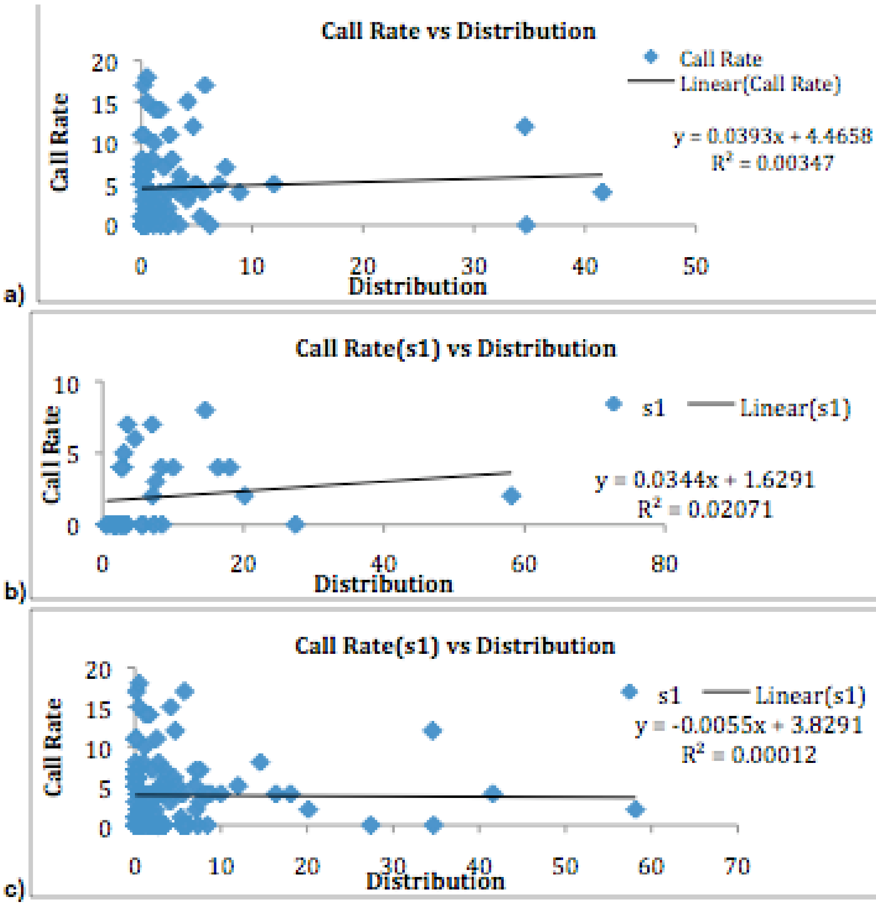


Figure 7 a)Call Rate vs. Distribution for groups of two whales raw distribution
b) Call Rate vs. Distribution for more than two whales raw distribution
c) Call Rate vs. Distribution for all groups of whales raw distribution

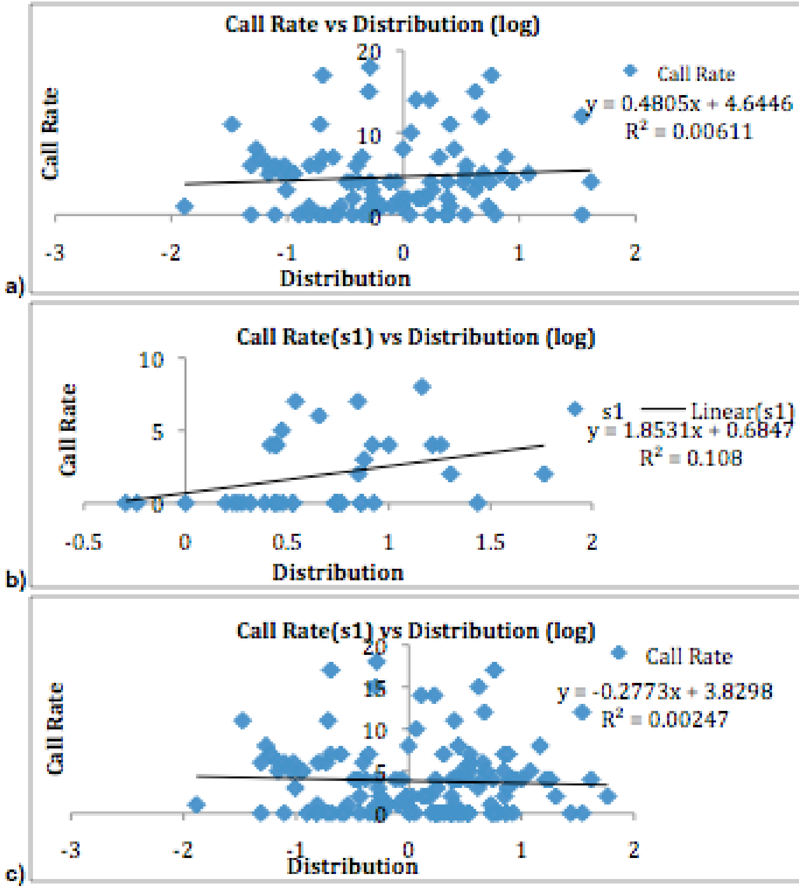


Figure 8 a) Log transformed data for groups of two whales
b) Log transformed data for groups of more than two whales
c) Log transformed data for all groups of whales

Distribution

Analysis Between Average and Normalized Data Sets

Information regarding the mean distribution, mean call rate, standard deviation for distribution and call rate can be found in Table 1.1. The average distribution for two killer whales for all the recorded days, was 2.8m for the average distribution data and 1.22m per whale for the normalized data (Table 1.1). Whale distribution was significantly different between the mean distribution of the average and normalized data for two whales resulted in a p-value of .04164, which revealed that there was a significant difference between means of the average and normalized data sets for the distribution of two whales (p=0.0416, Students t-test). Performing the same analysis for the average and normalized distribution of more than two whales yielded a p-value of .005881, which discloses a significant variation between the two data sets for more than two whales. Comparing the average and normalized distribution for all whales resulted in a p-value of .001047, meaning that there is a significant difference between the average and normalized values for the group of all whales. From these tests, we have established that there is a significant difference between the average distribution and the normalized distribution and can confidently measure the distribution in these two ways knowing that they are different techniques to measure the same data. Reflecting upon the comparison for the distribution for the average and normalized data showed that there was a significant difference between the normalized results and the average results which shows that normalizing the data by fin count yields a different result.

Comparing Two Whales to Groups of more than Two Whales

Average Distribution

Analyzing the data for the killer whale distribution as it varied between groups of two whales and more than two whales yielded interesting results. The histograms for the distribution and call rate of two whales were not normally distributed, however transforming the data to the log of the values produced a fairly normally distributed histogram (see Appendix B, 1c and 1d). Comparing this to a histogram of the theoretical normal distribution, the histogram displaying the two whales group spread appeared normally distributed. Following the same procedure for more than two whales, the histograms revealed a normal distribution for the log of the distribution and call rate data points.

A t-test was performed to see if there was a significant difference between the distribution and call rate for groups of two whales and groups of more than two whales. This is relevant because the number of whales in the group could affect how the group is distributed. The p-value for the t-test conducted between the distribution of two whales and more than two whales was 3.359e-5 (Table

1.2). The p-value for the call rate for two whales and more than two whales was 0.0118 (see table 1.2). Considering a p-value of <.05 to be statistically significant, this revealed that there was a significant difference between the distribution and call rate for groups of two whales and groups of more than two whales.

Normalized dataset

A histogram was made to compare the normalized groups of two whales to the normalized groups of more than two whales. The histogram for the normalized distribution of two whales, was not normally distributed, however the log of the distribution resulted in a normally distributed dataset (see Appendix B, 3a-d). When compared to a theoretical normal distribution histogram for this data (appendix B, 3e-f), the call rate and distribution displayed a roughly normal distribution. Using a t-test to see if the means of the two categories of distribution were different, revealed that the p-value for the distribution was .0686 which is not statistically significant (Table 1.2). However, the p-value of the call rate for the normalized dataset of two whales compared to the normalized dataset of more than two whales was .00092. This supports that the call rate was significantly different between two whales and groups of more than two whales for the normalized data (Table 1.2). From this comparison, there was no significant difference in the normalized killer whale distribution between two whales and groups of more than two whales, however the data supports that there was a significant difference in the call rate between the two groups compared.

Visibility

Data from the five OrcaSound hydrophones located throughout the San Juan Islands was uploaded into SQLShare (Howe, Bill) and queried for killer whales call rates during the day time hours and night time hours to get a table of day and night call rate comparisons. Subsets of the data analyzed were created by querying for resident killer whales only and human detected recordings.

Choosing to query my dataset for human detected recordings made by SRKW'S, I was able to get a large sample size for the day and night comparison and avoid the uncertainty of the auto detections. The bar graph constructed (figure 10) reveals that for the 1209 calls analyzed during the day time, the whales peak vocal hour was 2:00pm. For the 164 night time calls analyzed, it was found that the killer whale's peak vocal period for this dataset was around 1:00am with 109 calls. Using a t-test to compare the mean call rates for day and night investigates the possibility of a significant difference between the mean call rates for day and night. The t-test revealed the p-value for the call rate (calls per hour) during the daytime compared to the call rate during the night time was 0.3641. This means that there is no significant difference between the call rate during the day and call rate during the night . These results suggest that there is no difference between the mean of the two call rates and therefore, from this data we can state that killer whale vocalization are not influenced by diurnal factors.

a) b)

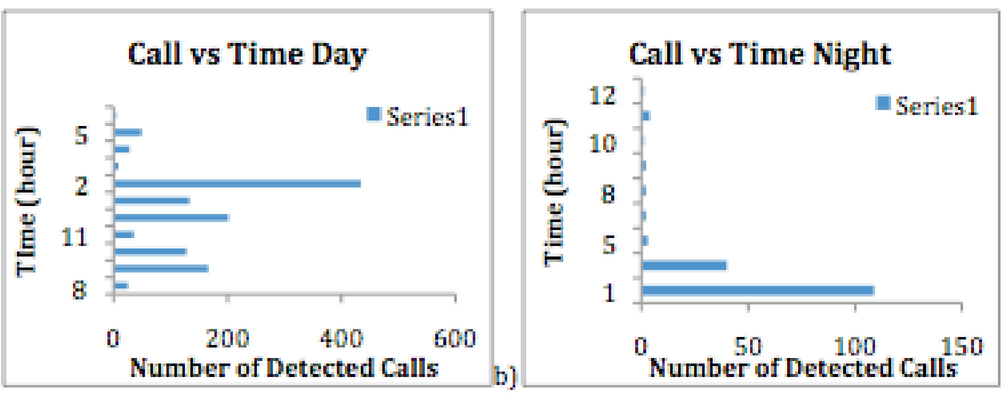


Figure 10 a) Bar plot for day time call rate

b) Bar plot for night time call rate

Discussion:

In the context of S1 call rate and killer whale distribution, these results found that there was no direct significant correlation between S1 call rate and killer whale distribution. Although my data fails to support a relationship between

S1 call rate and killer whale distribution, this does not mean that none exist. It is possible that the relationship between call rate and distribution is complex and may be influenced by many external variables that were not measured in this study. Perhaps the S1 call is a contact call but instead of being influenced by distribution it is dependent on another variable, such as the number of whales. With marine mammals, knowledge is limited to what was see above the surface and can confidently measure, it is highly possible that there are many influential factors exist that we were unaware of. It is also possible, that J-Pod's discrete call, S1 is not used as a contact call to maintain group cohesion. One influential point to consider, is the method of whale distribution measurement. A sound method for whale distribution measurement can be complicated and different measurement techniques may yield different results. A limiting factor for distribution measurement in this study, was the restriction to measuring solely the whales in the photo, leaving whales not in the frame out of consideration. If this study were repeated, it would be highly beneficial to the dataset to develop a method for single whale distribution measurement. This study rejected photos with only one whale in the frame and this may have been an important aspect in the whale distribution measurement. Another different distribution measurement technique would be to classify the photos into a predetermined category reflecting their degrees of separation. Having average and normalized distribution was important in analyzing killer whale distribution because according to the t-test, the two methods for calculating distribution produced significantly different results.

As the data failed to find a linear relationship between S1 call rate and distribution, there was a significant difference between the distribution and call rate for two whales and groups of more than two whales. The data suggests that killer whale distribution and call rate differs with the group size. My data shows that the smaller the group size, the higher the call rate. The mean distribution for groups of two whales was 2.8m with a mean call rate of 4.6 calls per minute while the mean distribution for groups of more than two whales was 7.6m and the mean call rate was 1.9 calls per minute (Table 1.1). Similar results can be seen in table 1.1 for the normalized dataset as well. This could be a contribution of a number or external variables, influenced by factors varying from killer whale social dynamics to geographic bathymetry. Kinship may play a role in the killer whale distribution, seeing as killer whales of all ages are often found swimming next their mothers or closely related family members (Wieland, 2007). There may be some cooperative hunting strategy or cost benefit analysis driving the differing distribution. Group hunting in mammals is very common and exhibited in hyaenas, lions, wolves and wild dogs, all highly social animals(Kruuk, 1972; Schaller,1972; Estes & Goddard 1967). It has been documented in Tai chimpanzees, that it pays for individual chimpanzees to hunt in groups of 3-4 rather than in pairs or alone (Boesch,1993). However for Gombe chimpanzees, the success rate is higher for single hunters (Boesch,1993). . As group size plays a role in hunting, perhaps there are other variables contributing to the differing group spread in killer whales. This study strongly implies that the discrete call S1 is used independently of killer whale distribution but is influenced by the number of whales in the area.

Although the results failed to reveal any significant difference between the call rate per hour for day and night, there are still many interesting conclusions that can be drawn from the results. Looking at the night time call rate, 66% of the night time calls were made during the hour of 1:00a.m. The visibility data presented in this study only dealt with night vs. day measurements. These data may be confounded by behavioral changes throughout the day that are unrelated to visibility. Future studies can address this question more directly by taking water visibility measurements at the same time that photography and acoustic measurements are made.

Given more time, it would be interesting to localize the killer whale s1 calls that were recorded. Using the metadata documenting each whale's bearing, the individual whale making each S1 call can be determined. Using the computer program, Ishmael (Mellinger) the bearing of the vocalizing killer whales can be determined by analyzing the time of sound arrival differences between pairs of hydrophones in the array. Looking at which whales made the call may shed light on how the call is used. If the bearings in Ishmael remain the same for the S1 calls and the observed whale groups were very spread out, then we could confidently say that there is only one group of whales making the S1 call. In comparison, if there are many different bearings for each S1, indicating that all of the individuals in the pod are using the call, this would support the notion that S1 is a contact call.

Conclusion

This observational study revealed that there was no significant direct correlation between killer whale distribution and S1 call rate. However, it was supported that there was a significant difference between the call rate and distribution for two whales and more than two whales in the average distribution data. The data fails to support my hypothesis, however further investigation is requires to confidently reject the hypothesis that the SRKWs use S1 as a contact call. It was supported the call rate and distribution was significantly different based on the number of whales in the group, which implies that the SRKW acoustic interactions and behavior are subject to a number of different variables.

Type	Mean Distribution	Distribution Standard Deviation	Mean Call Rate	Call Rate Standard Deviation
2 Whales	2.80314	6.707872	4.576	4.482527
3 Whales	7.645669	10.434434	1.891892	2.492029
All whales	4.19208	8.212497	3.806	4.185312
2 Whales Normalized	1.222826	2.835417	3.85	3.558196
3 Whales Normalized	2.4182	3.413446	1.892	2.492029
All Whales Normalized	1.600857	3.066416	3.231	3.374306

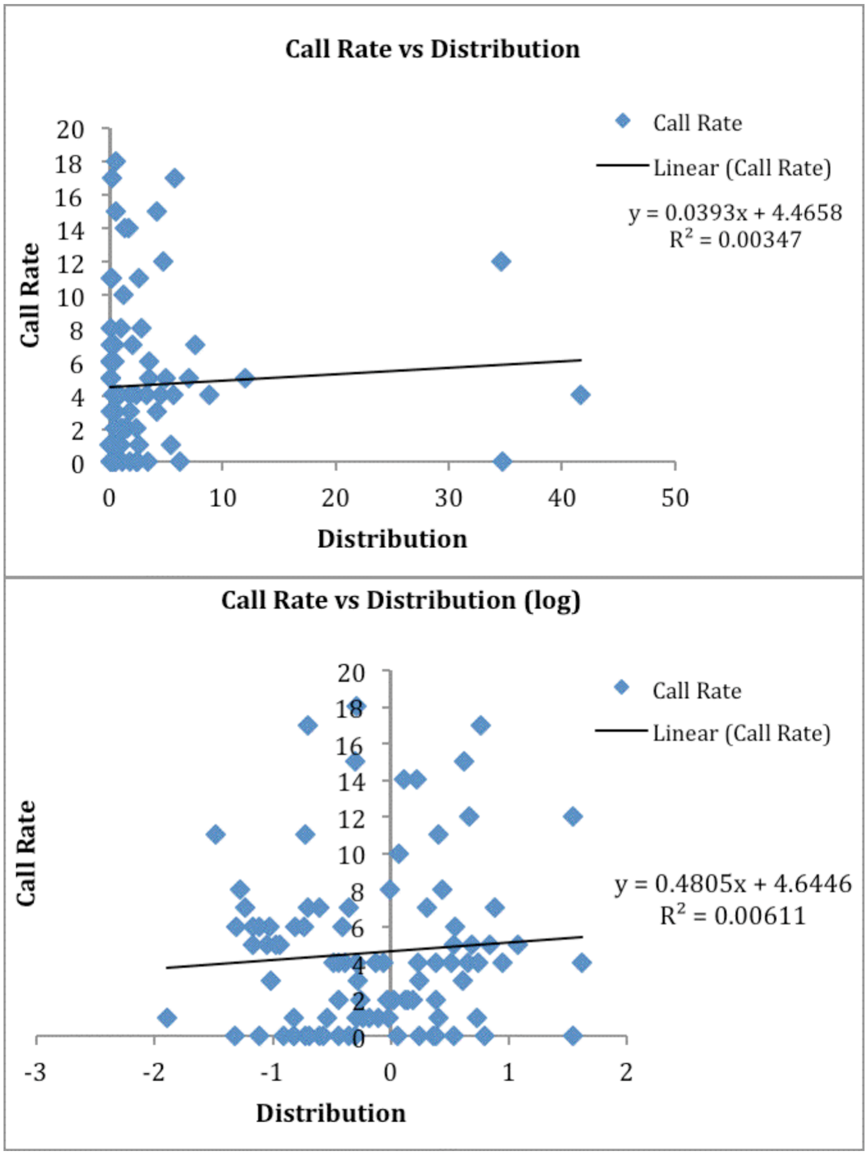
Table 1.1

T-test, p-value		
Type	Distribution	Call Rate
2 Whales to 3+ Whales	0.0119	3.36E-05
2 Whales Normalized to 3+ Whales Normalized	0.06856	0.00092
2 Whales to 2 Whales Normalized	0.04164	0.2384
3 Whales to 3 Whales Normalized	0.005881	1
All Whales to All Whales Normalized	0.001047	0.2345

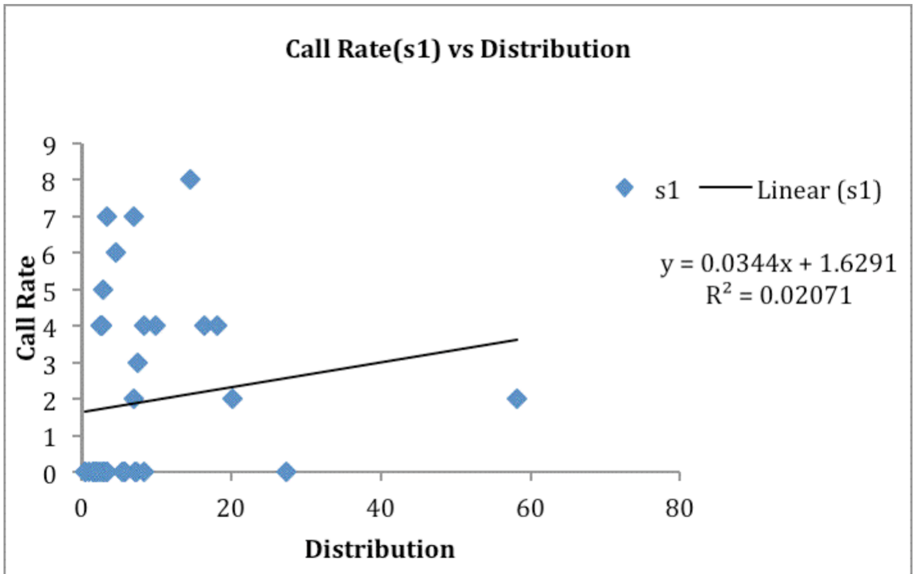
Table 1.2

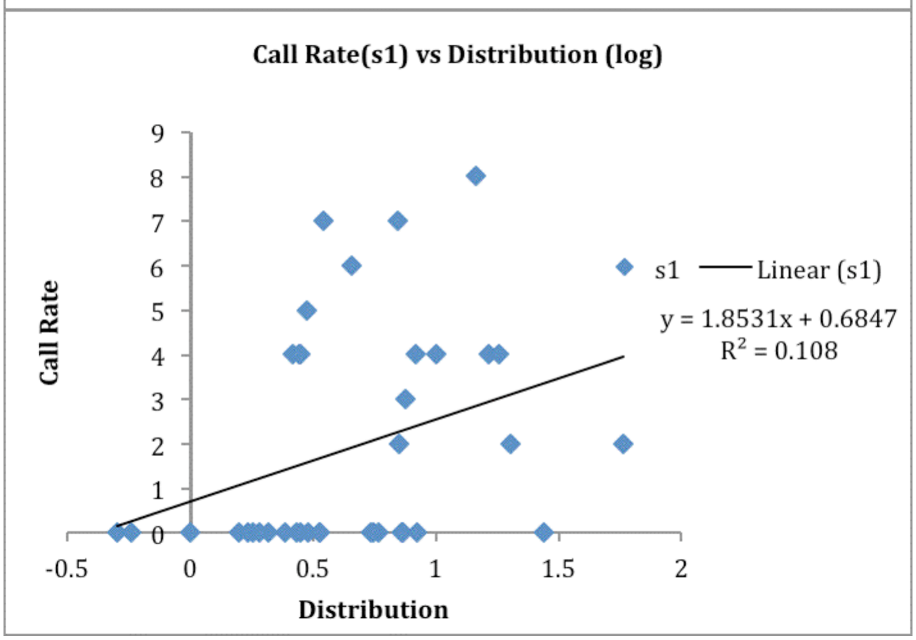
Appendix

Appendix A

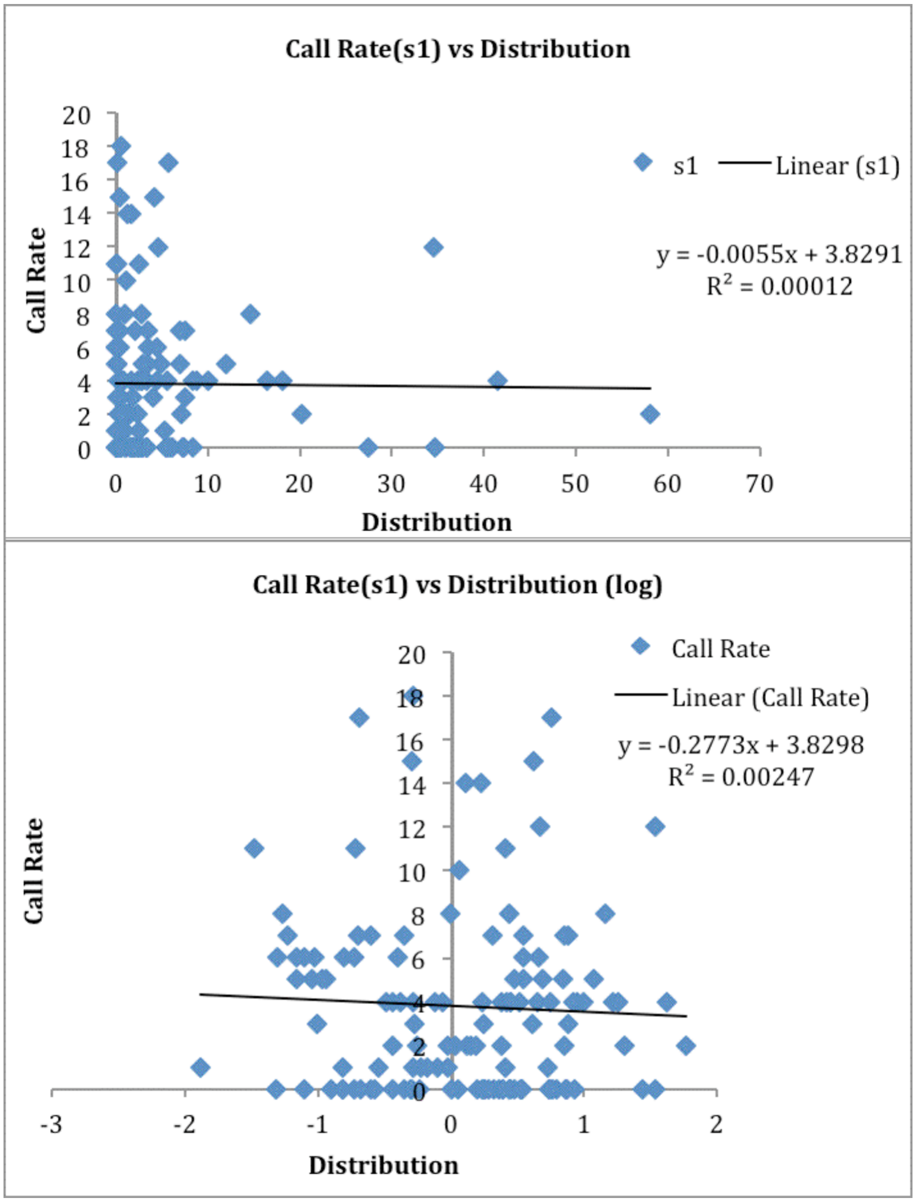


a) Call Rate vs. Distribution for groups of two whales top is average data, bottom is log transformed data

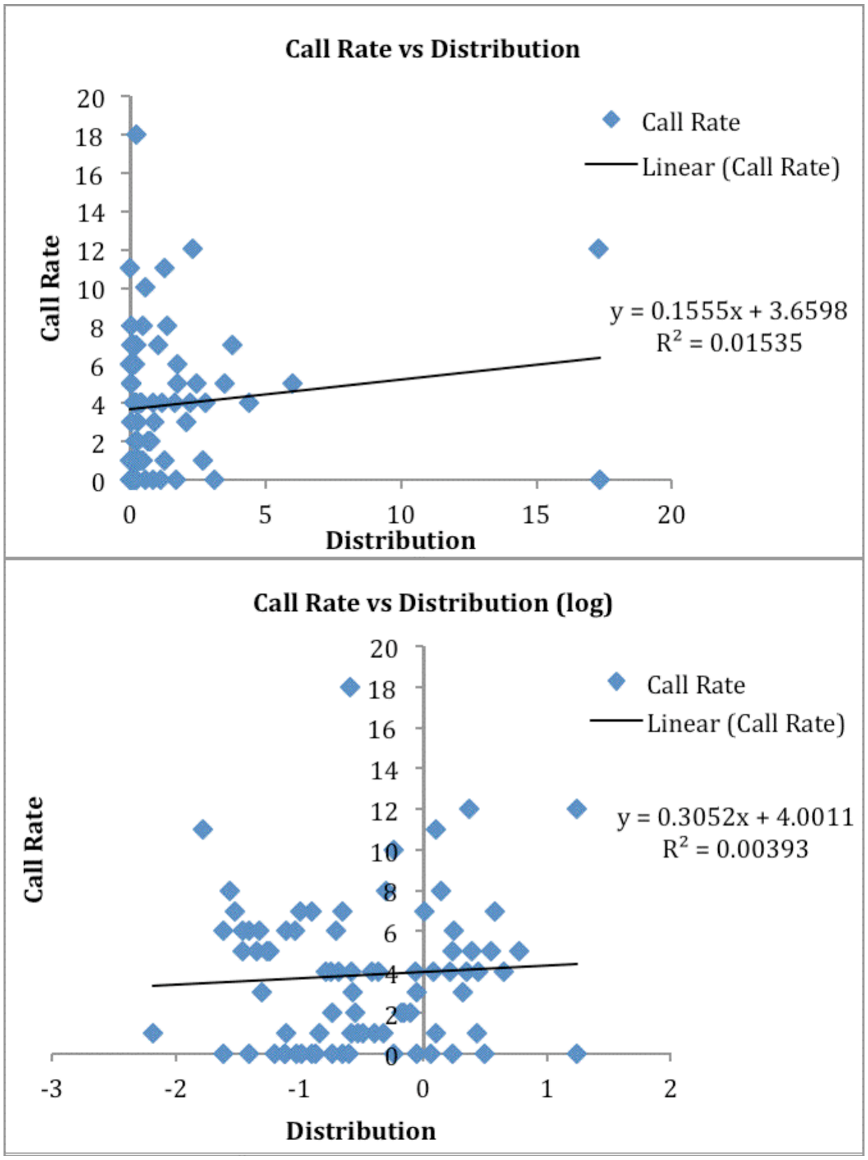




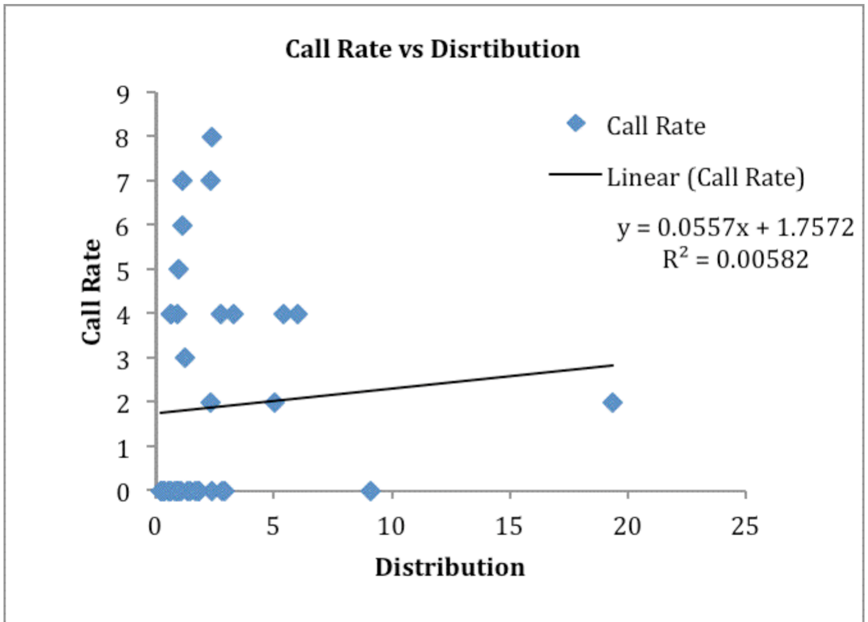
b) Call Rate vs. Distribution for groups of more than two whales top is average data, bottom is log transformed data

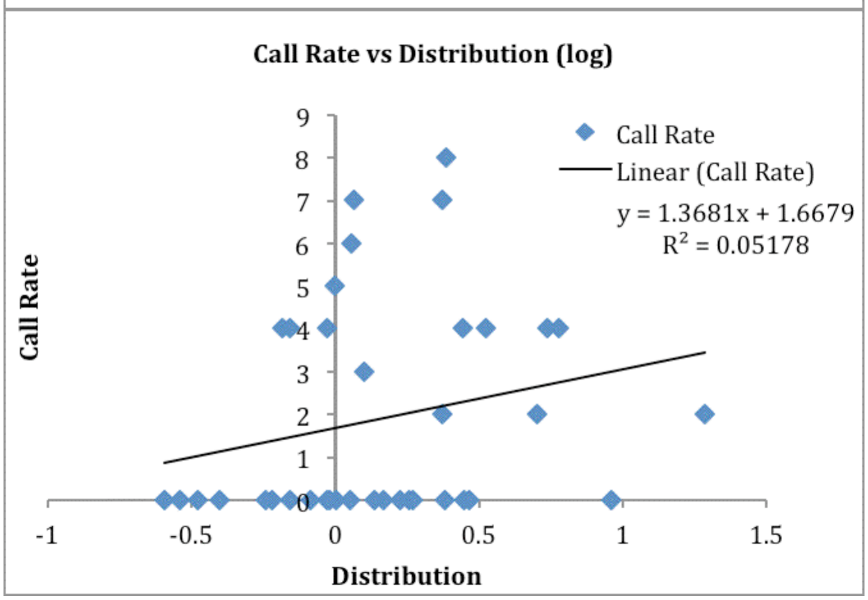


c) Call Rate vs. Distribution for groups all groups dataset top is average data, bottom is log transformed data

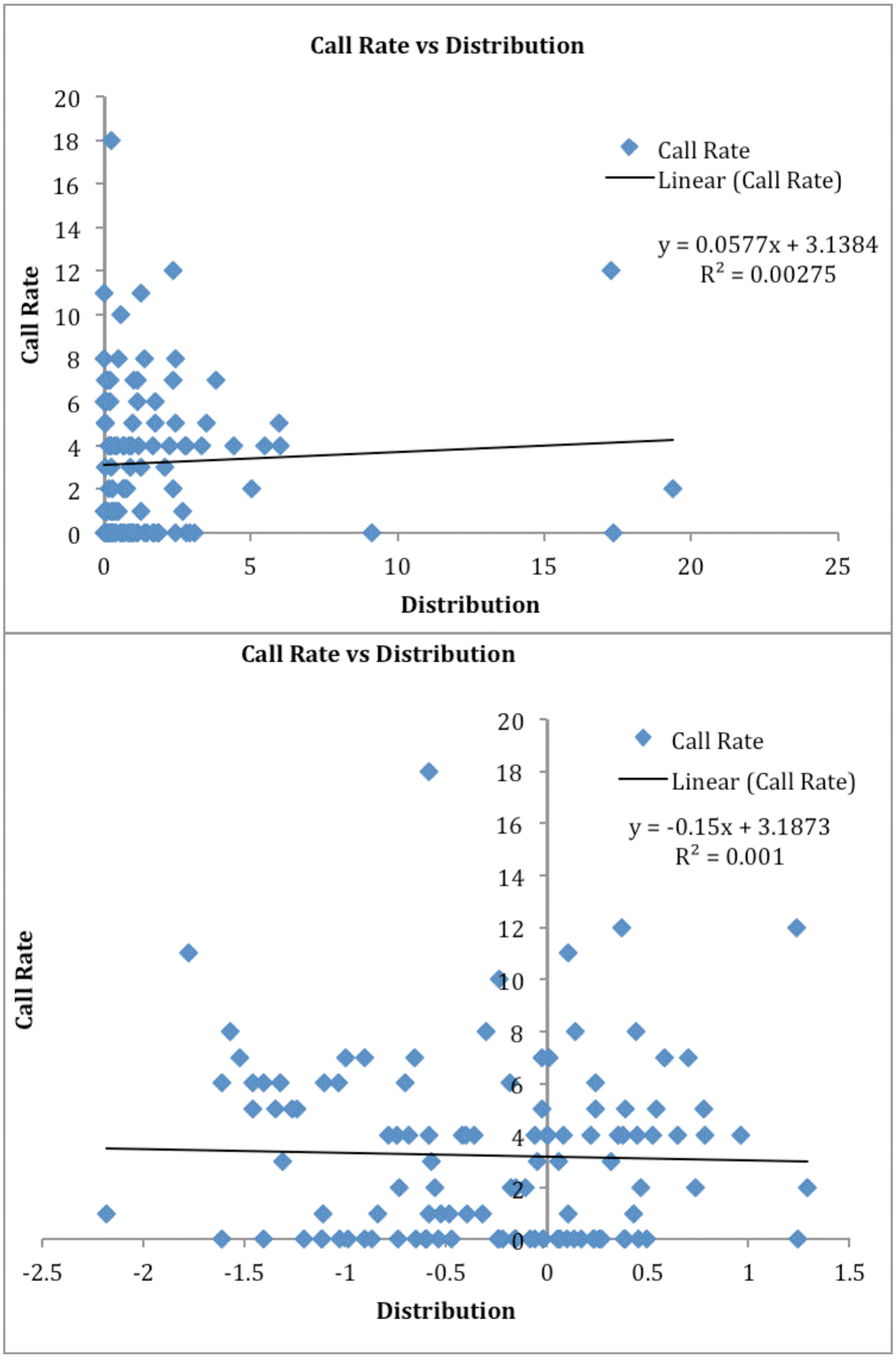


d) Call Rate vs. Distribution for two whales normalized top is average data, bottom is log transformed data





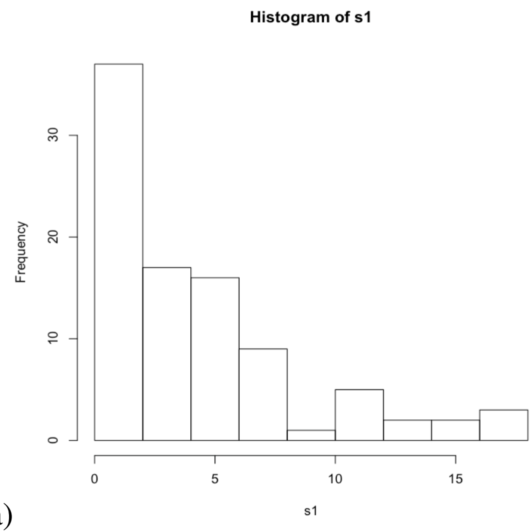
e) Call Rate vs. Distribution for more than two whales normalized top is average data, bottom is log transformed data



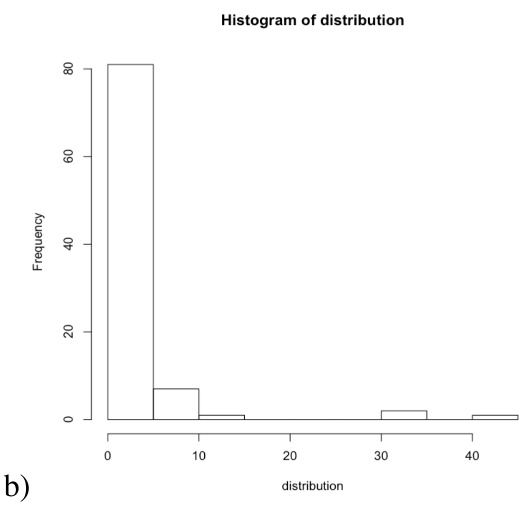
f) Call Rate vs. Distribution for all groups normalized dataset top is average data, bottom is log transformed data

Appendix B

1) Analysis for group of two whales:

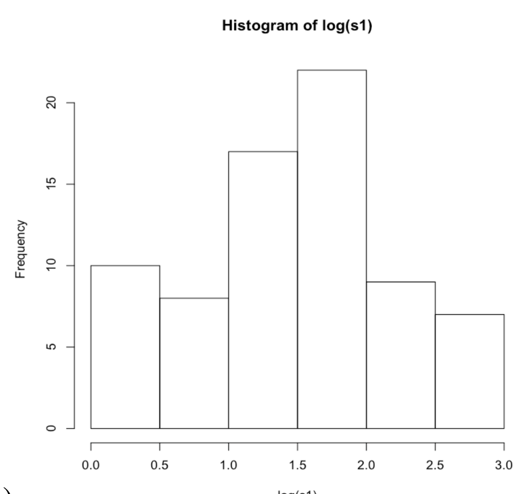


a)

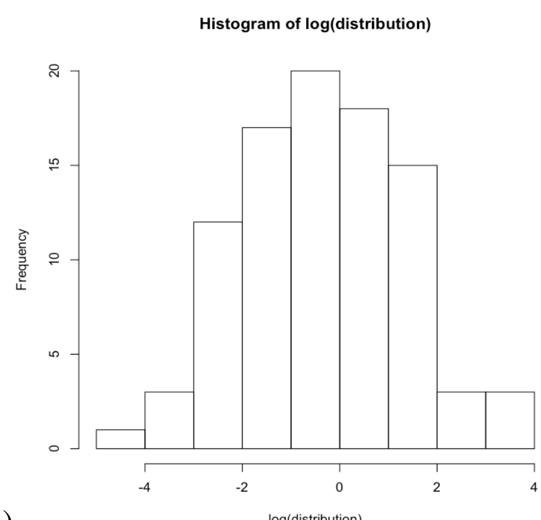


b)

Histograms of S1 call rate(a) and distribution for groups of two whales(b)

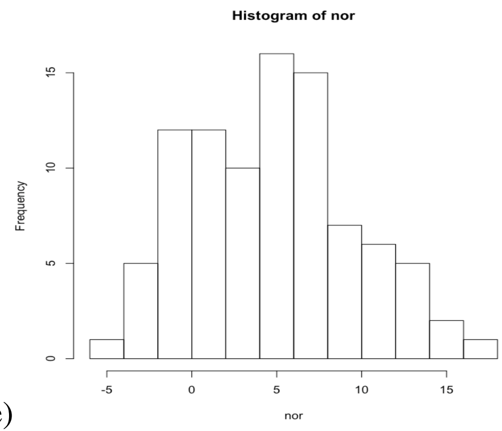


c)

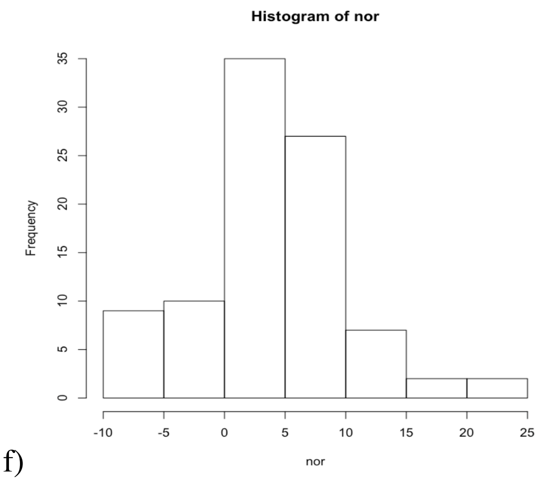


d)

Log histograms of S1 call rate (c) and distribution for groups of two whales (d)



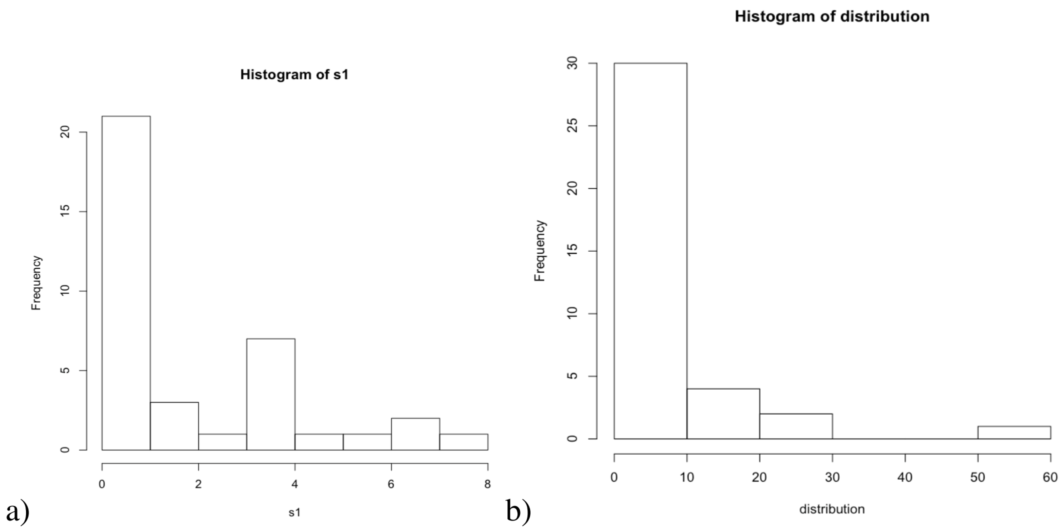
e)



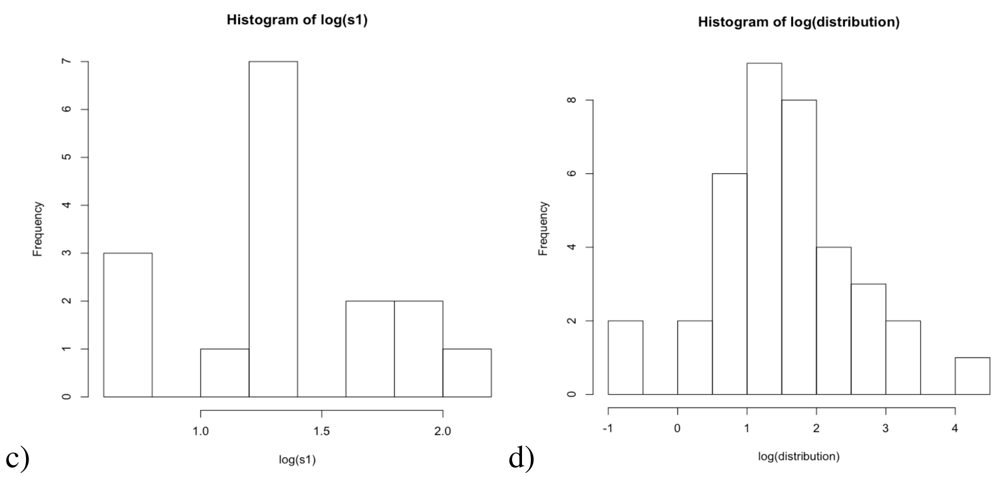
f)

Normal histograms of S1 call rate (e) and theoretical distribution for groups of two whales (f)

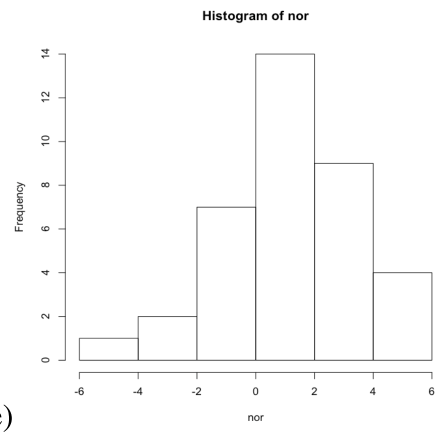
2)<u>Analysis for group of more than two whales:</u>



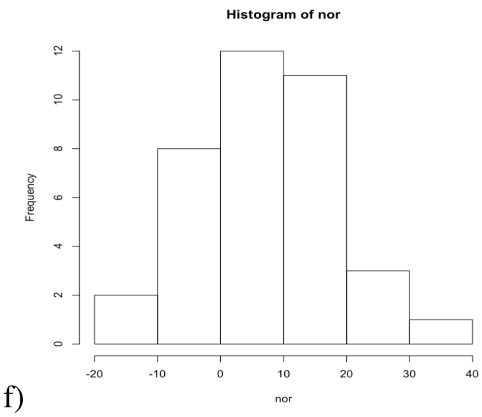
Histograms of S1 call rate(a) and distribution for groups of two whales(b)



Log histograms of S1 call rate (c) and distribution for groups of two whales (d)



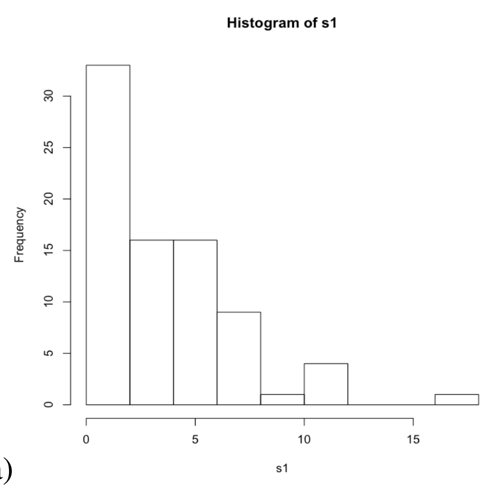
e)



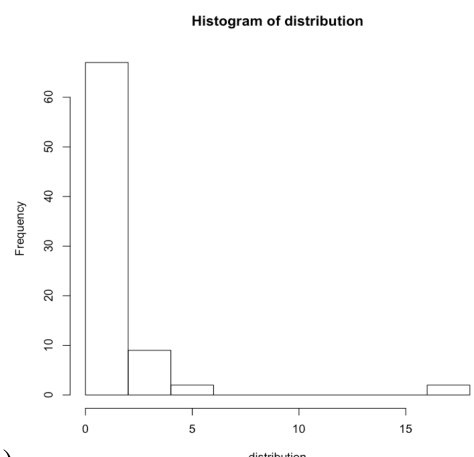
f)

Normal histograms of S1 call rate (e)and theoretical distribution for groups of two whales (f)

3)<u>Analysis for Normalized group of two whales:</u>

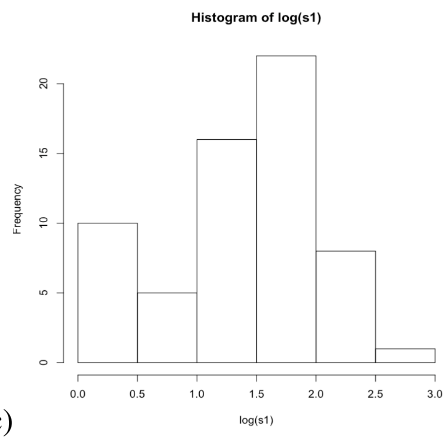


a)

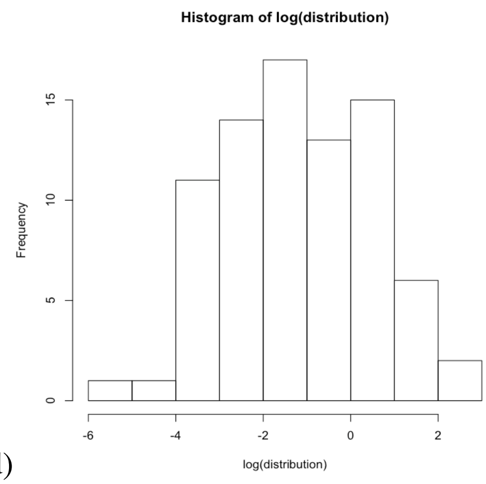


b)

Histograms of S1 call rate(a) and distribution for groups of two whales(b)

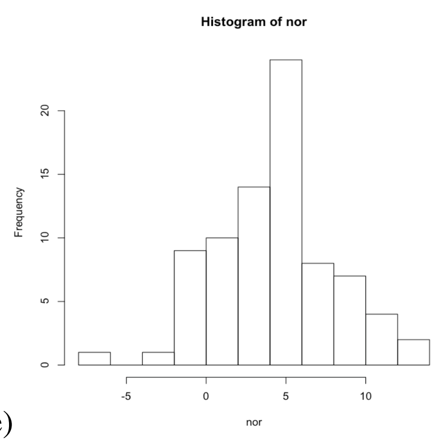


c)

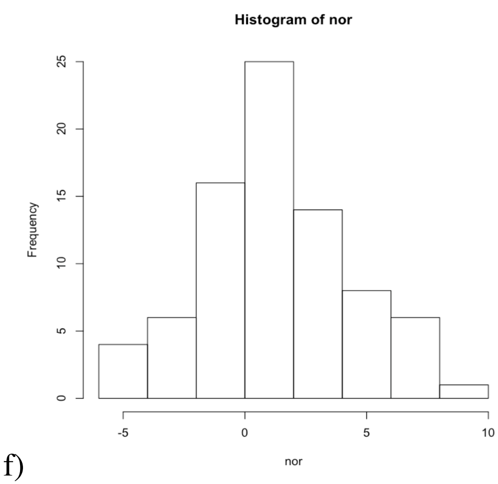


d)

Log histograms of S1 call rate (c) and distribution for groups of two whales (d)



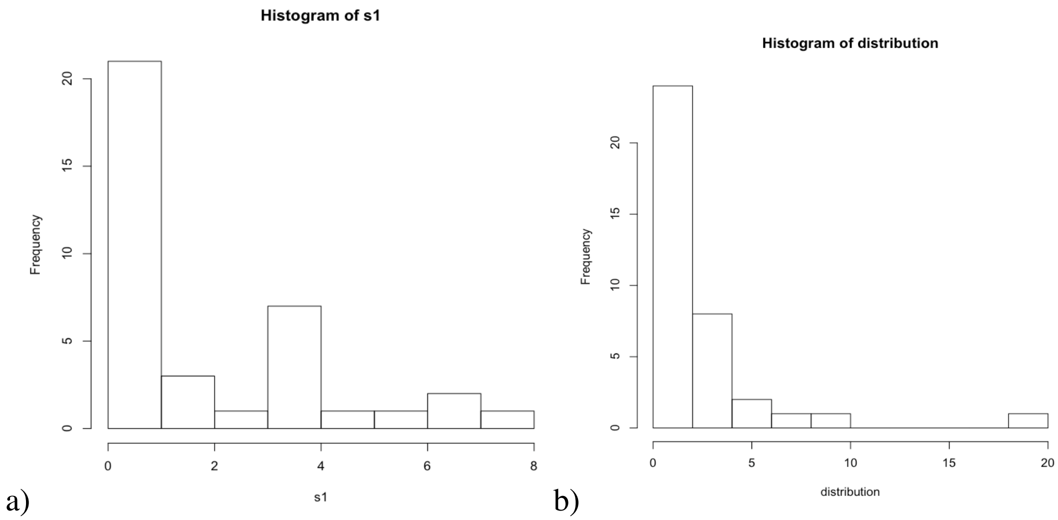
e)



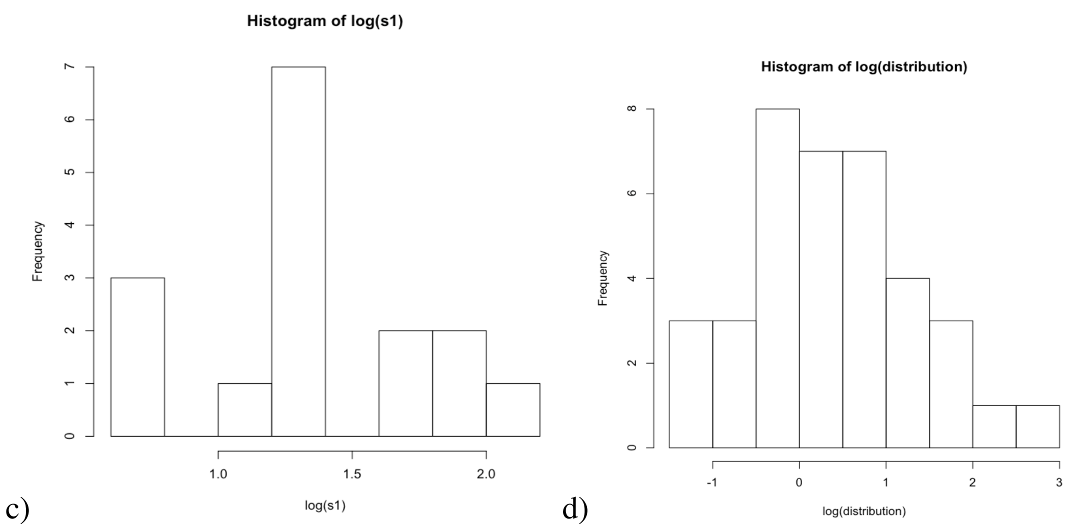
f)

Normal histograms of S1 call rate (e) and theoretical distribution for groups of two whales (f)

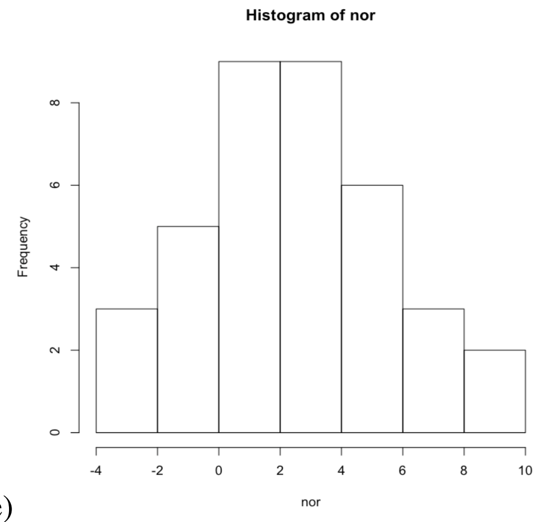
4)<u>Analysis for Normalized group of more than two whales:</u>



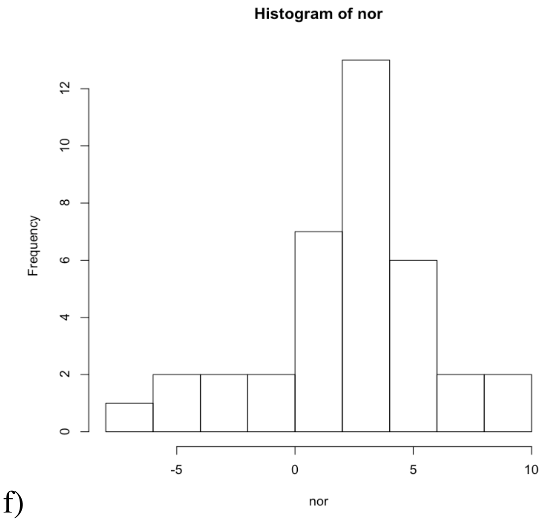
Histograms of S1 call rate(a) and distribution for groups of two whales(b)



Log histograms of S1 call rate (c) and distribution for groups of two whales (d)



e)

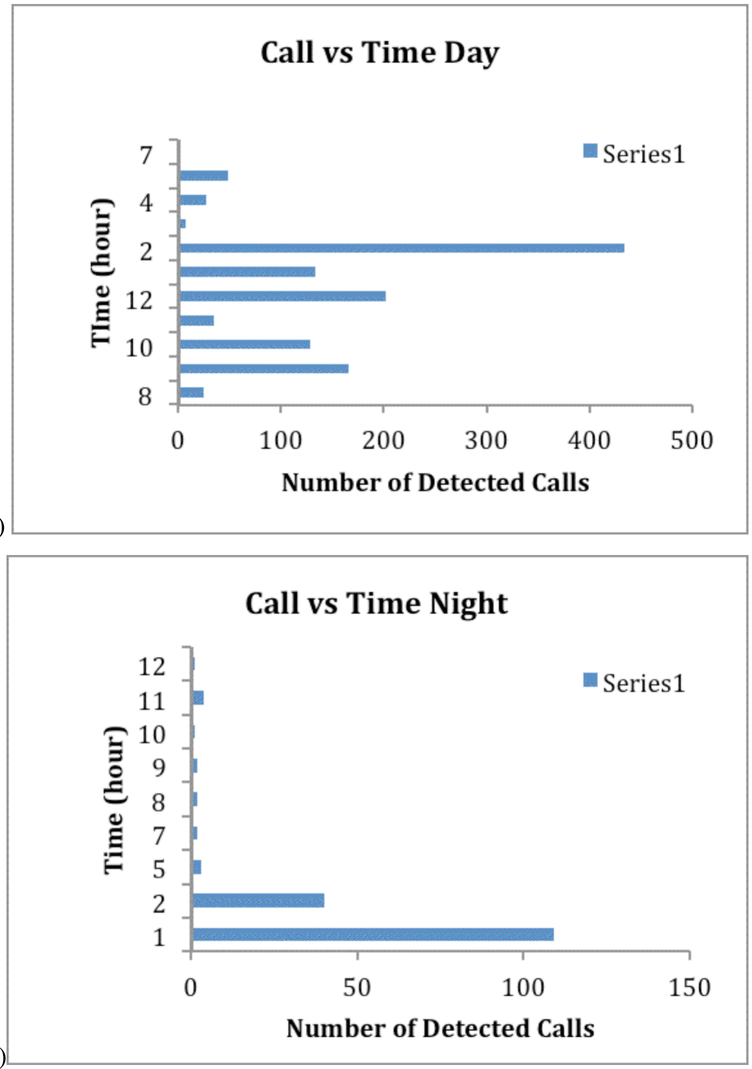


f)

Normal histograms of S1 call rate (e) and theoretical distribution for groups of two whales (f)

Appendix C

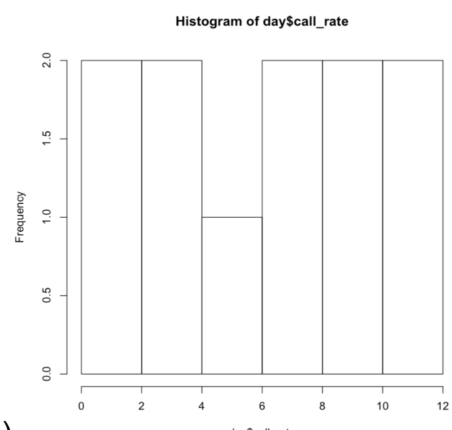
1) Visibility



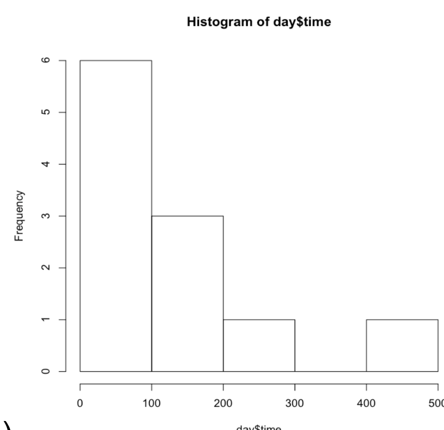
a)

b)

a) Bar plot for day time call rate b) Bar plot for night time call rate

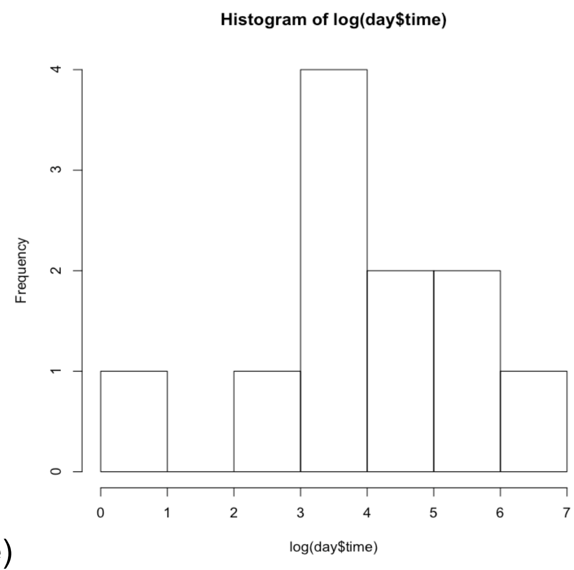


c)

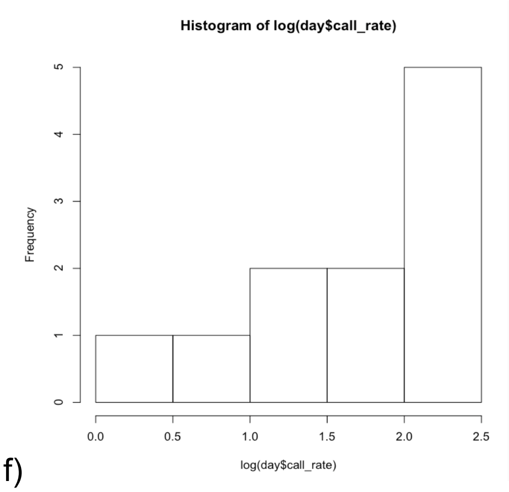


d)

Histogram of day time call rate(per hour) and time

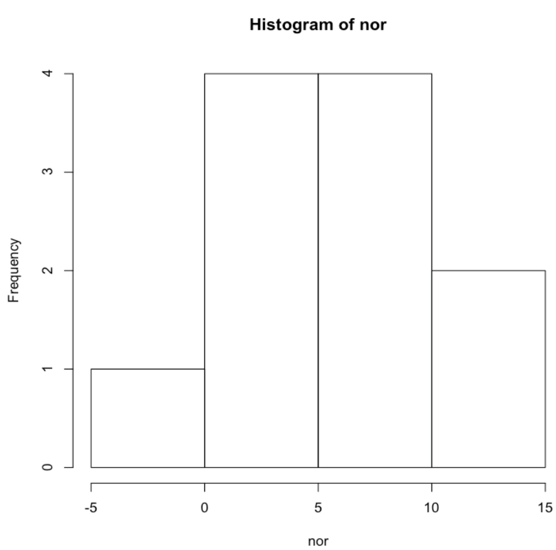


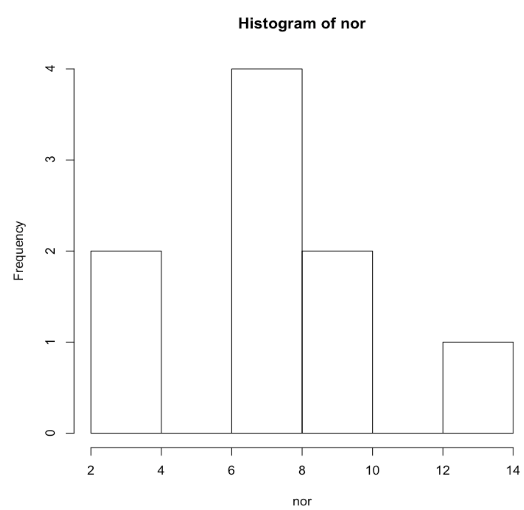
e)



f)

Log histograms of call rate (per hour) and time





Normal histogram distribution for call rate(per hour) and time

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