# Examining Diurnal Patterns in the Vocal Activity of Southern Resident Killer Whales (*Orcinus orca*)

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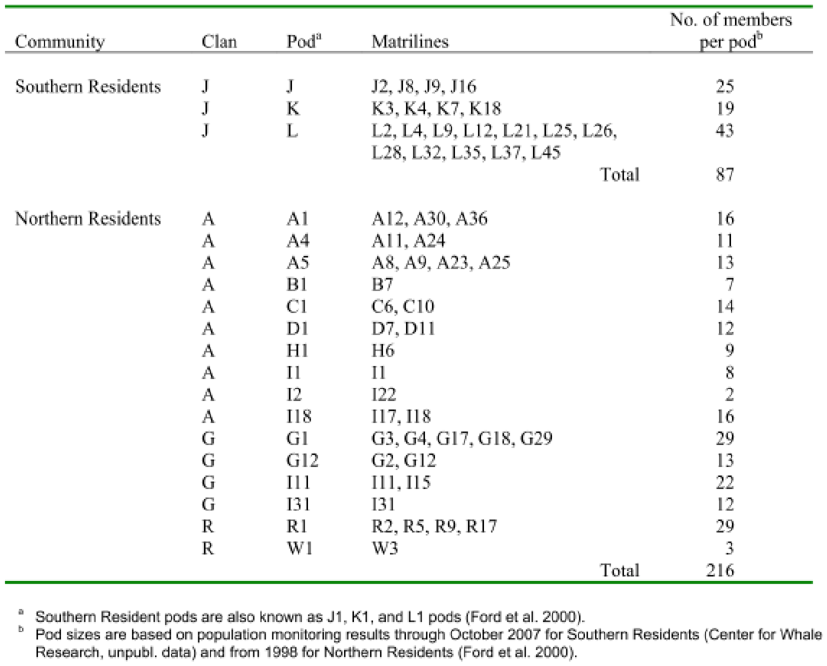
Recent studies have demonstrated that aquatic environments dramatically change the intensity and spectral composition of incident light (Downing 2001). Rapid attenuation of light with depth is common. To compensate for this, numerous marine species have evolved to rely on sound as their primary method of communication. Cetaceans, such as killer whales (*Orcinus orca*) are thought to use sound to maintain group cohesion during certain behavioural states. Regarded as a highly social species, killer whales live in close knit family units that are considered some of the most complex and stable social structures of any animal species. Three different ecotypes exist in the Pacific Northwest; residents, transients (Bigg's killer whales), and offshores (Thomsen, Franck, and Ford 2000). Residents, composing around 75% of the population (Ford 1990), are found throughout the year but are more common during June-October. Unlike northern residents that occupy the inland waters of Vancouver Island, southern residents reside in the Salish sea; a region that encompasses the water south of Vancouver Island (Bigg et al. 1987).

Resident killer whales have a diverse repertoire, and have a hearing range from 1 to 100 kHz (Szymanski et al. 1999). Because of the long-term stability of the social structure in southern residents, studies have examined vocal behaviour in much more detail than other ecotypes (Ford 1991). Three different types of vocalizations have been identified for the southern residents; echolocation clicks, tonal whistles, and pulsed calls (Ford 1989). Vocalizations can vary in multiple parameters, such as call rate, frequency, amplitude, or duration, and these parameters can change for many reasons (Wieland, Jones, and Renn 2009). Ford (1989) proposed that pulsed calls be classified as either discrete, variable, or aberrant. Discrete calls are stereotyped, repetitive and conform to a fundamental structure. Not only are discrete calls distinctive in structure, they appear to be population specific (Ford 1987, 1989). In both northern and southern resident communities, discrete calls are most frequent during vocal exchanges, and thus serve to signify group affiliation (Ford 1991).

Northern and southern residents are not only regionally distinct, but, also demonstrate differing types of calls. The differing call types separate the resident whales into groups called clans.

Clans are groups of pods that are united by the calls in their vocal repertoires (Ford 1987). The southern residents have only one clan (J), and this is composed of the three southern resident pods J,K and L. This study will focus on the calls produced by the southern residents which, as of 2012, was thought to be comprised of 86 members (The Whale Museum, Friday Harbor).



| Community | Clan | Pod[a] | Matrilines | No. of members per pod[b] |
|---|---|---|---|---|
| Southern Residents | J | J | J2, J8, J9, J16 | 25 |
| | J | K | K3, K4, K7, K18 | 19 |
| | J | L | L2, L4, L9, L12, L21, L25, L26, L28, L32, L35, L37, L45 | 43 |
| | | | Total | 87 |
| Northern Residents | A | A1 | A12, A30, A36 | 16 |
| | A | A4 | A11, A24 | 11 |
| | A | A5 | A8, A9, A23, A25 | 13 |
| | A | B1 | B7 | 7 |
| | A | C1 | C6, C10 | 14 |
| | A | D1 | D7, D11 | 12 |
| | A | H1 | H6 | 9 |
| | A | I1 | I1 | 8 |
| | A | I2 | I22 | 2 |
| | A | I18 | I17, I18 | 16 |
| | G | G1 | G3, G4, G17, G18, G29 | 29 |
| | G | G12 | G2, G12 | 13 |
| | G | I11 | I11, I15 | 22 |
| | G | I31 | I31 | 12 |
| | R | R1 | R2, R5, R9, R17 | 29 |
| | R | W1 | W3 | 3 |
| | | | Total | 216 |

[a] Southern Resident pods are also known as J1, K1, and L1 pods (Ford et al. 2000).

[b] Pod sizes are based on population monitoring results through October 2007 for Southern Residents (Center for Whale Research, unpubl. data) and from 1998 for Northern Residents (Ford et al. 2000).

Figure 1: Social hierarchy and pod sizes of Southern and Northern Resident Killer Whales in Washington and British Columbia (Thomsen, Franck, and Ford 2000; Centre for Whale Research, unpubl. Data).

Until relatively recently, it was assumed that cetaceans had excellent hearing and echolocation, despite having poor vision. This assumption was made on the basis that sight would play a minimal role in the ocean environment. Although developed auditory capabilities are key to survival, other forms of communication, for example vision, should not be overlooked. In Southern resident habitat, human divers reported an underwater visual range of 3-15 metres (Peninngton 2012). Throughout the last thirty years, behavioural investigations of visual capabilities, through captive research, suggests that the visual system of most cetaceans is highly-developed, and thus well adapted to both aquatic and aerial media (Basin and Mammal 1995).

By a method known as retinal topography mapping Mass and Supin (1997) were able to show that unlike the retina of terrestrial mammals, which contains a single area of high ganglion cell density, the retina of whales contains two; one in the temporal part and the other in the nasal part of the retina. These two areas are likely involved in vision both inside and outside of a water medium. Underwater, cetaceans, regardless of their suborder, rely on both areas of the retina. This provides a wide field of monocular vision. Out of the water, however, it is suspected that only one area of the retina is utilized ( M. Mass 2002). Bottlenose dolphins have demonstrated that they are capable of visually recognizing an array of arbitrarily shaped figures, in two and three dimensions underwater (Herman et al. 1989). From these studies, one could infer that the ability to see underwater is essential for predator avoidance, successful capture of prey, as well as social interactions and orientation. Antarctic Type B Killer Whales, that show preference for Weddell seals, have been recorded spy hopping around ice floes looking for seals resting on the ice (Pitman; American Cetacean Society 2011). By using sight, they are able to discriminate between the different seal species. Other forms of communication in the marine environment include tactile communication, and producing chemical signals. These however, unlike sound, sight, and echolocation, are not effective over large distances.

Focusing on the southern residents specifically, approximately 25 discrete calls have been recorded (Ford 1987). The predominant call types for southern residents are S1 in J pod, S16 in K pod, and S2iii and S19 in L pod during directional travel (Foote and Nystuen 2008). It has been suggested that these calls could be a contact call, but, this is not an established phenomenon nor is it supported by any available data. A contact call is primarily used to establish the location of other pod members during certain behavioural states (Ford and Fisher 1983). Foraging, for example, generally involves moderately sized subgroups travelling quickly, spread out in flank formation with an average distance of about 400m between groups (Hoelzel 1993). In the terrestrial world, contact calls are widespread among primates, other social mammals and birds (Rendall, Cheney, and Seyfarth 2000). For example, in Chacma baboons (*Papio cynocephalus ursinus*) loud calls are given periodically by separated individuals whilst participating in activities with a high risk of separation such as foraging (Rendall, Cheney, and Seyfarth 2000).

Through captive experiments, White et al. (1971) estimated that the underwater visual acuity of the killer whale to be at least 5.5 min of arc within a stimulus range of 10-20ft (3-6m). In the wild, closely related killer whales have been observed travelling within 1-10 metres of each other, and 10-100 metres for matriline members (NOAA-NMFS 2004). This would suggest that they often travel beyond visual sight of one another. At night, and times of the day where light penetration is at its lowest, distances at which killer whales can effectively see will be compromised. To date, there have been no studies conducted investigating how killer whales behave at night. Given S1, S16, and S19 are thought to be contact calls produced when group members are beyond visual range of one another, it is hypothesized that at night and times of day when underwater visibility is compromised, the whales will increase their 'contact call' relative to all other calls. There are two ways to investigate this; conduct a day/night call comparison, and to plot the variation of visibility over the course of a day.

## **Methods**

### Data Collection

The southern residents were observed and recorded in the Salish Sea for a study period lasting three weeks from 30th April to 24th May 2012. All observations and acoustic recordings were made from a 42ft hybrid electric-biodiesel catamaran called the Gato Verde. This vessel has the potential to operate on a battery pack, if needed, allowing for at least three hours of 'silent' travel. This was beneficial when studying the whales because it not only reduced the vessel's presence, but, enabled sounds to be more easily detected by any hydrophones used. A four hydrophone array (Labcore 40's Array with peak sensitivity at 5 kHz), was deployed from the stern when a whale encounter was anticipated. The hydrophones on the array were located in line on a single cable and spaced 10 metres apart. The array was weighted to a depth of 5 metres below the surface to reduce flow noise. The Gato then towed the hydrophone array, at a steady speed, for the duration of the interaction. Onboard, dual time- synchronized recorders (Sound Devices 702 model) automatically assigned a file name, in addition to recording the date and time of each sample. For every five minutes of recording, a sub sample of one minute was brought into Audacity 2.0.0, and examined for S1, S16 and S19 calls.

### Call Density

Discrete calls are easily differentiated by the human ear and can also be visualized by a unique spectrographic structure. However, Ford et al. (1999) found variation in how humans perceive sound. Therefore in order to remove bias from the study, specifically on occasions where overlapping calls made distinguishing between them challenging, two or more people counted the calls and the average score was used. Calls were categorized as S1, S16 or S19 based on visual parameters outlined in the call catalogue (Ford 1987). Any calls made, that were not considered contact calls, were classified as "other calls". These counts were then totalled and used to calculate call density. For the purposes of this study, 'call density' was defined as the number of S1, 16, S19 or other calls per minute relative to the total number of calls. The call density of these calls could then be calculated by the following equation;

$$\frac{\textbf{\# of S1, or S16, or S19, or "other calls" per minute}}{\textbf{Total number of calls per minute}}$$

Night time data was collected from the research vessel, when it was safe to do so. In addition, at times when whales were anticipated, continuous night recordings were made from the Reson hydrophone at Lime Kiln using Ishmael software. To increase sample size further, 8 nights of archival data, made from Lime Kiln, were obtained from August/September 2010. Because length of day is known to vary through the season, only recordings made within midnight ± 2 hours (10pm-2am) were considered for analysis. This corresponded with a period of known darkness at this latitude. In total 213 minutes of night data were examined for calls.

## Group Density

Because S1, S16 and S19 calls are theorized to be contact calls, additional data such as group size and whale density were recorded with each interaction. Group density was calculated by using a calibrated photography method as follows. Photographs were taken of a human subject (166cm tall) at distances of 25m, 50m, 100m, and 200m using a Canon 1000D with an EFS 18-55mm zoom lens which was kept on the 55mm setting. The photographs were imported into ImageJ 1.45s(NIH). Height of the subject, and the total area in the field of view for each distance, was measured in pixels (Figure 2a). Pixels were then converted into metres squared.

In the presence of whales, distance from a focal group was judged by trained observers; each morning, observers practiced estimating distance over water by range finding off a buoy. Photographs were taken of the focal group as individuals surfaced. It proved challenging to capture each individual surfacing simultaneously, therefore a record of total number of individuals was also kept. If the area inside the field of view was known, individuals in the frame could be counted, and group density calculated.

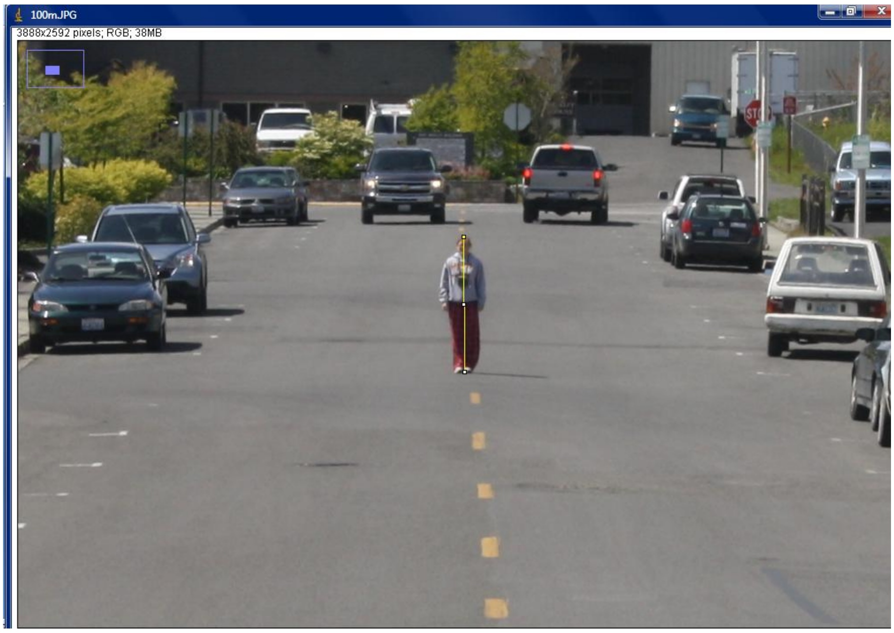


**Figure 2a: An example of the images used for the calibrated photography method**
A subject of known height was photographed at a variety of different distances. When the image was brought into ImageJ 1.45s the subject was measured. Knowing this measurement enabled field of view, in pixels, to be calculated.

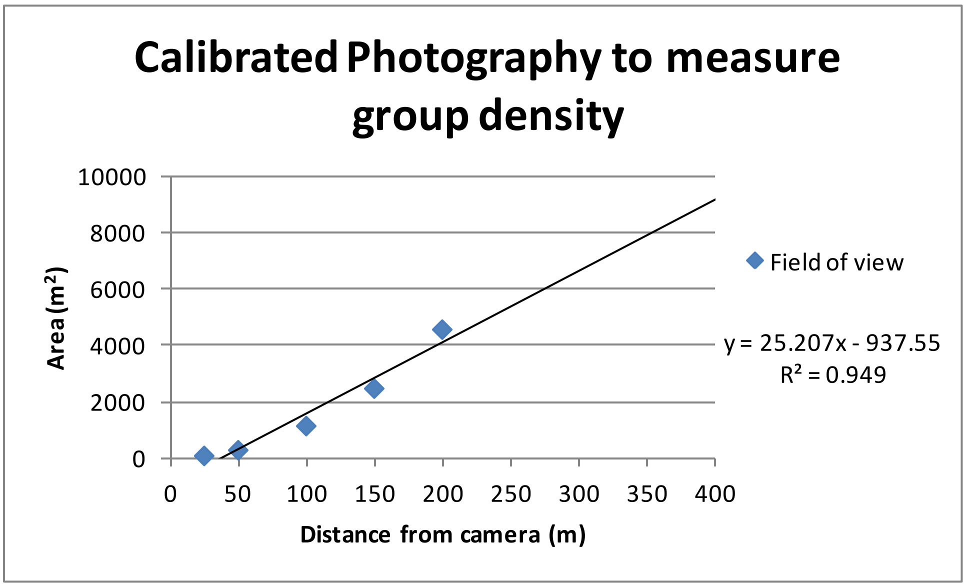


**Figure 2b: Graph showing how the field of view changes with distance**
Vertical and horizontal lengths of image were converted from pixels into $m^2$. The results were then extrapolated as shown.

## Day time Visibility

Day time water visibility was measured using a Secchi disk with a diameter of 8cm. Transparency measurements were made from lowering the Secchi disk from the shaded side of the research vessel wherever possible until the disk was no longer visible. Weights were used to ensure the descent was vertical. Two observers were present at the time of deployment in order to minimize any interpersonal differences in visual acuity. Because Secchi disk readings are dependent on available illumination, variables such as time of day, solar radiation, wind speed, currents and tides were considered. Solar radiation data was acquired through a weather station at the Friday Harobr Labs. Wind speed was obtained using an onboard anemometer when the research vessel was stationary. Current velocity and tide heights were acquired from daily predictions from Multi-Tide version 1.0.5. If the sample site fell between two or more tidal stations, the average tidal height was used. Predicted current velocity was compared to Washbourne's Table predictions to determine how accurate predictions were. A multivariate ANOVA was performed to test significant difference between variables, and a Tukey test was used to put confidence levels on the ANOVA. In total thirteen sites were sampled within the Salish sea.

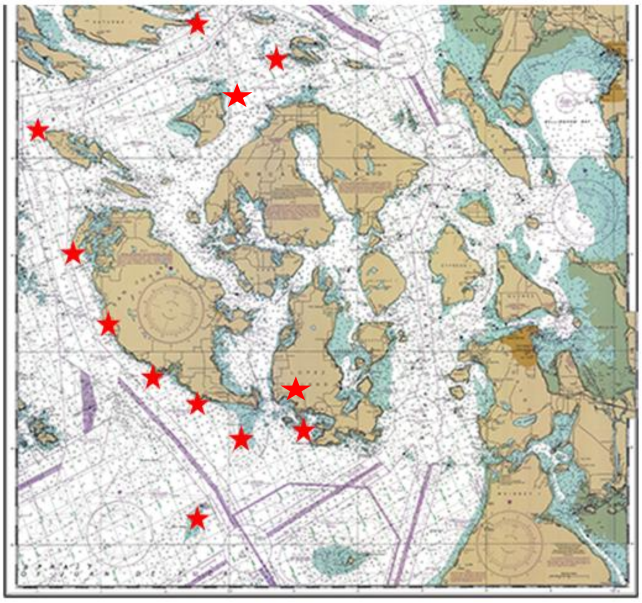


**Figure 3: Chart of sites where vertical Secchi disk measurements were taken in the Salish Sea**
Secchi disk measurements, represented by red stars, were made at thirteen locations within the Salish Sea between 30th April and 24th May 2012. Tsawwassen is not included on the above chart.

On 17th May 2012, a Secchi measurement was recorded each hour at the same way point in order to monitor the change in visibility over the course of a day at that given location. In addition to vertical measurements, horizontal Secchi recordings were also made. By submerging the Secchi disk perpendicular to the water, off the stern of the vessel, a horizontal measurement could be made by a swimmer, wearing diving goggles, swimming to a distance where the Secchi was no longer visible (figure 4). The swimmer remained consistent across the samples to remove bias. Data collected from Secchi disk measurements were cross checked with CTD data, in addition to the results from plankton tows of a concurrent project. The same statistical tests were performed on both the horizontal and vertical Secchi measurements. On days when whales were present, vertical Secchi measurements were collected within twenty minutes following a whale encounter.

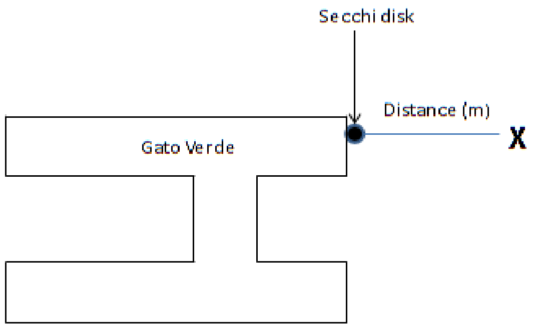


**Figure 4: Diagram of horizontal Secchi disk measurements taken from the Gato Verde.**
The swimmer, represented by the X, moves away from the research vessel until the Secchi disk can no longer be seen. One end of a line is attached to the Secchi disk while the other is held by the swimmer. Equally spaced knots along the line help determine distance.

## Results

### *Visibility*

Vertical Secchi measurements were taken at thirteen sites throughout the Salish Sea. Some sites, such as Kellett Bluff, Lime Kiln, Turn Point, among others were sampled on more than one occasion. In total, 42 vertical Secchi deployments were made over a three week period. During this time, the maximum measurement recorded was 8.5m (Boundary Pass and Salmon Bank). The minimum score was made at East Point and was 1.5m. Vertical results were made into a box plot so that a comparison could be made. The box plot (figure 5) shows that the visibility at each site remained relatively consistent. A one way ANOVA was performed on sites where there were replicates. The ANOVA confirmed that these locations were not statistically significantly different from one another (df=1, p=0.09).

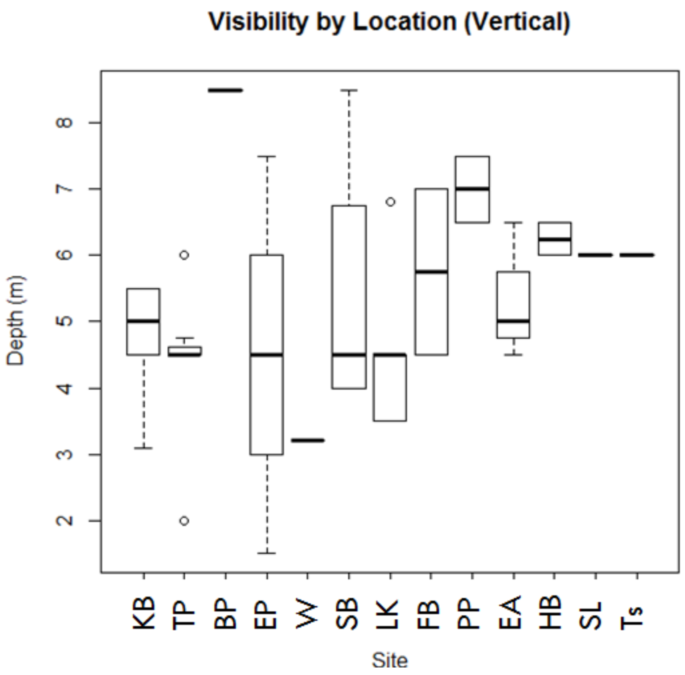


**Figure 5: A series of box plots showing the spread of vertical Secchi depths by location** Vertical Secchi measurements were taken at 13 sites around the Salish Sea between 5/2/12 and 5/23/12. The Secchi disk was deployed over the shadier side of the research vessel, wherever possible, consistent with the methodology outlined in Preisendorfer

Horizontal Secchi measurements were limited to 6 sites; Kellett Bluff, Turn Point, Salmon Bank, Eagle Point, East Point, and Lime Kiln. Three of these sites (Turn Point, East Point, and Kellett Bluff) were sampled more than once. The maximum distance at which the Secchi disk could no longer be seen was 9m. This measurement was recorded twice, once at Eagle Point and once at Kellett Bluff. A minimum measurement of 2m was measured at Kellett Bluff and East Point. A one way ANOVA was then performed in R on the horizontal Secchi sites. The results from the analysis suggest that these sites are not significantly different from one another with respect to depth observed (df=1, p=0.1289).

On May 17th 2012, Kellett Bluff was sampled over a 7 hour period from 10:00am-16:36pm. The site was chosen, in part, due to its proximity to Snug Harbor, in addition to meeting the groups scientific goals. On this day, vertical Secchi measurements were taken every hour beginning 10:00am, and horizontal recordings were made every hour beginning at 10:36am. The results of these Secchi experiments can be seen in Appendix A.

Variation in both vertical and horizontal visibility was plotted over the course of a day (Appendix A). The same observer remained consistent across all samples. The horizontal Secchi measurements appeared to follow a trend despite showing great variation over the course of a day. The maximum visibility in which the instrument could still be seen was 9m. On the other hand, the minimum recording for that day made was 3.5m in the horizontal plane. Contrastingly, vertical Secchi measurements showed little variation across the 7 hour period (min=4.5m, max=5.5m). Interestingly the minimum horizontal measurement corresponded with a small dip in the vertical visibility. This dip occurred around hour 4 (13:00pm).

As Secchi measurements, both vertical and horizontal, were taken at each location, variables such as time of day, tide height, current speed, current direction, wind speed, wind direction, solar radiation, and phytoplankton density were taken into account. These factors were noted in order to develop a broad sense of how physical factors may affect underwater acuity. A principle component analysis (PCA) was then performed in R to isolate the variable which contributed most to the decrease in visibility. From the principle component analysis, phytoplankton density appeared to have the greatest influence over visibility followed by solar radiation. These results concurred with other studies conducted during the study period. During the sampling period, a phytoplankton bloom was observed. Phytoplankton samples were fixed and refrigerated before being transferred to a counting chamber. Ten microlitre squares were inspected under a microscope before being photographed for counting. Specifically looking at the samples taken at Kellett Bluff (5/17/12), the average relative species abundance for each time period was recorded. Due to time restraints, however, the observer later switched to counting from a total of 10 squares to a subsample of 5 squares. In addition to the relative abundance, the average total number of phytoplankton for each hour was also noted. The results of this count are as follows.

| Time | Total Av. Phytoplankton |
|---|---|
| 10:31 | 215 |
| 11:00 | 203 |
| 12:25 | 471 |
| 13:32 | 619 |
| 14:29 | 354 |
| 15:26 | 222 |
| 16:25 | 165 |

**Figure 6: Average phytoplankton counts sampled each hour at Kellett Bluff (5/17/12)**
Twenty metre phtyotplankton tows were conducted each hour for a total of 7 hours. The phyotoplankton was then photograph through a microscope using a canon digital camera. Total species were counted and averaged per time period.

The results from the phytoplankton tows (5/17/12) showed that the time with the highest density of phytoplankton was 13:32. In equating the relative abundance of species, *Skeletonema* was revealed to be the dominant species in each of the samples (Figure 7). When the number of *Skeletonema* in each sample was averaged and plotted against the vertical distance observed, the plot looked almost identical to the graph showing total number of phytoplankton (figure 8). This suggests that *Skeletonema* was the variable most responsible, in this particular study, for influencing visibility in both the horizontal and vertical plane.

|  | Squares |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KB_05_17_12 (10:31am) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average |
| Skeletonema | 245 | 228 | 202 | 234 | 129 | 157 | 250 | 254 | 282 | 98 | 207.9 |
| Chaetoceros | 14 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Detonula | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.6 |
| Thalassiosira | 0 | 0 | 3 | 3 | 4 | 0 | 0 | 2 | 0 | 8 | 2 |
| Thalassionema3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.3 |
| Stephanopyxis | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.8 |
| Dinophysis | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0.1 |
| Unidentified | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0.1 |
| Actinoptychus | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0.1 |
| Unidentified | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unidentified dino | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| Total | 267 | 228 | 221 | 243 | 134 | 158 | 251 | 256 | 282 | 110 | 215 |

**Figure 7: Relative abundance of species collected at Kellett Bluff 10:31am.**
Phytoplankton was sampled each hour for a 7 hour period on 05/17/12. The table shows the relative abundance of species. From these results it is clear that a *Skeletonema* bloom was occurring

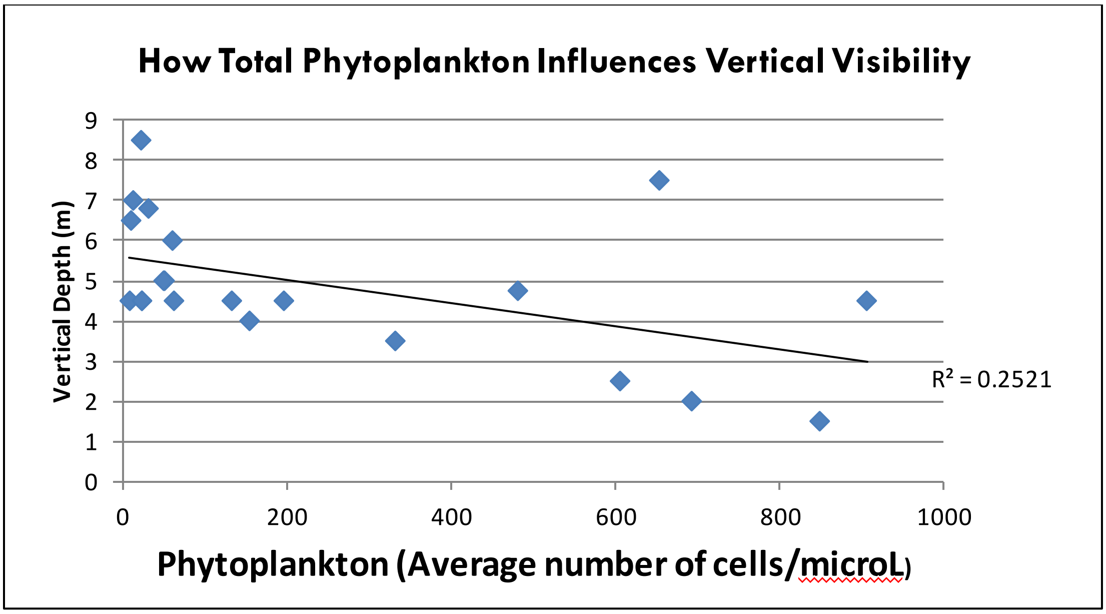
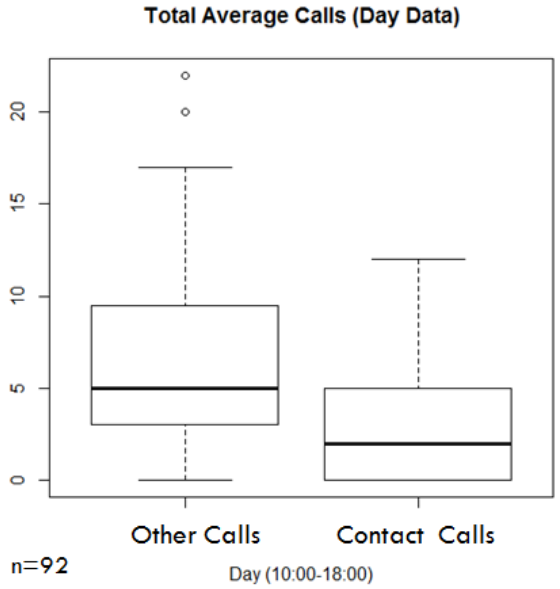


**Figure 8: A regression of the vertical Secchi measurements with corresponding plankton data**
A total of 21 measurements had phytoplankton counterparts and thus were able to be graphed. When phytoplankton was at its lowest, vertical visibility was at its highest. The converse was true of times with high phytoplankton density.

*Acoustics*

In total 213 minutes of night recordings and 100 minutes of day recordings were listened to using Audacity software. Initially every ten minutes were sampled during night time recordings, but, this was later increased to every 5 minutes to obtain a larger sample size. Alternatively, recordings made during the day were sampled every minute. This was again to increase sample size as only the minutes with calls heard were used in the final analysis. This allowed for a subsample of 92 minutes of day time data, and 97 minutes of night time data to be analyzed. The total average number of contact calls and other calls were graphed for both day and night data (figure 9a(b)). Box plots showed that the interquartile ranges were reasonably similar; however, the overall range of the data set was greater for "other calls" in both cases. Because the data was non parametric, a Kruskal Wallis rank sum test was performed on both night and day recordings. The test showed that, in both cases, the data was not statistically different (df=17, p=0.371, df=12, p=0.04122 respectively).

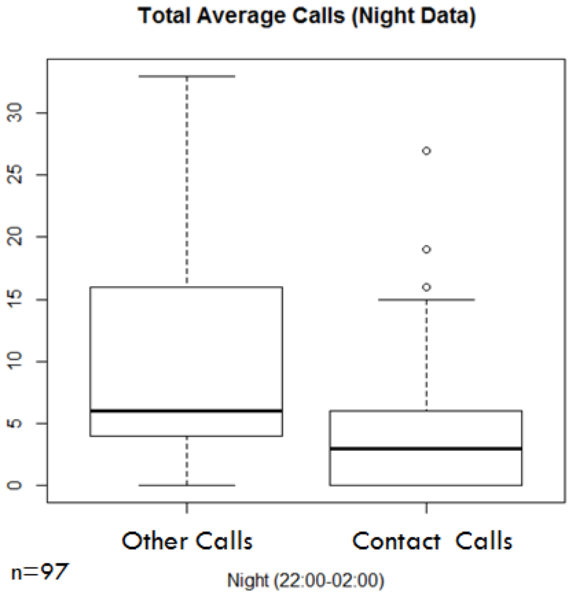
9a)



| Type of Call | Total |
|---|---|
| S1 Calls | 254 |
| S16 Calls | 10 |
| S19 Calls | 0 |
| Other Calls | 681 |
| Total Calls | 945 |

**Figure 9(a)(b):Comparing the total average of other calls with the total average of contact calls heard during day and night recordings.**
S1, S16, and S19 were grouped and the average was taken. The circles featured in the box plot represent outliers.

9b)



| Type of Call | Total |
|---|---|
| S1 Calls | 379 |
| S16 Calls | 56 |
| S19 Calls | 68 |
| Other Calls | 1171 |
| Total Calls | 1674 |

Relative to other contact calls, J pod's S1 was heard the most frequently during this study. In total, S1 was counted 633 times. Contrastingly, S16 and S19 were heard only 66 and 68 times respectively. The recording with the greatest amount of total calls was produced by the Lime Kiln Reson hydrophone on the night of 8/13/2010 at 22:25pm. At this time, 37 calls were heard.

A night recording from 5/20/2012 (Reson hydrophone at Lime Kiln) was compared to a corresponding day recording from the Gato Verde (5/22/12) in order to see how the relative proportion of calls changed. Although there was a two day separation period between the two recordings it was suggested that the same animals remained in the area during this time. Photographic identification was conducted on the animals encountered. From the photographs, J26, J8, J2, L87 among others were identified. In addition, further photographs were taken to calculate group density as a proxy for group spread. There were six usable densities (figure 10).When the acoustic recording 5/20/12 was examined for calls, the proportions of each contact call relative to total amount of calls was recorded and compared to 5/22/12 (figure 11). For a sample size of 39 minutes, “Other calls” contributed to 49%, followed by S1 (46%) and S19 (4%). In this particular night sub sample, no S16’s were detected. When analyzing the day data (n=47) S1 made up 34% of the recording with the remaining 66% composed of “Other” calls (figure 12).

| Start Time | Whales | Distance | Density | File |
|---|---|---|---|---|
| 13:01 | 2 | 300 | 2 per 6500m^2 | IMG_2406 |
| 13:02 | 1 | 200 | 1 per 4500m^2 | IMG_2409 |
| 13:03 | 1 | 50 | 1 per 300m^2 | IMG_2413 |
| 13:04 | 1 | 300 | 1 per 6500m^2 | IMG_2414 |
| 13:12 | 2 | 300 | 2 per 6500m^2 | IMG_2416 |
| 13:13 | 3 | 200 | 3 per 4500m^2 | IMG_2418 |

**Figure 10: Group Density Table**
Group densities were determined after minutes were analyzed in audacity. Using behavioural data sheets, the area within a photo frame could be calculated. Group density is equal to number of animals per area

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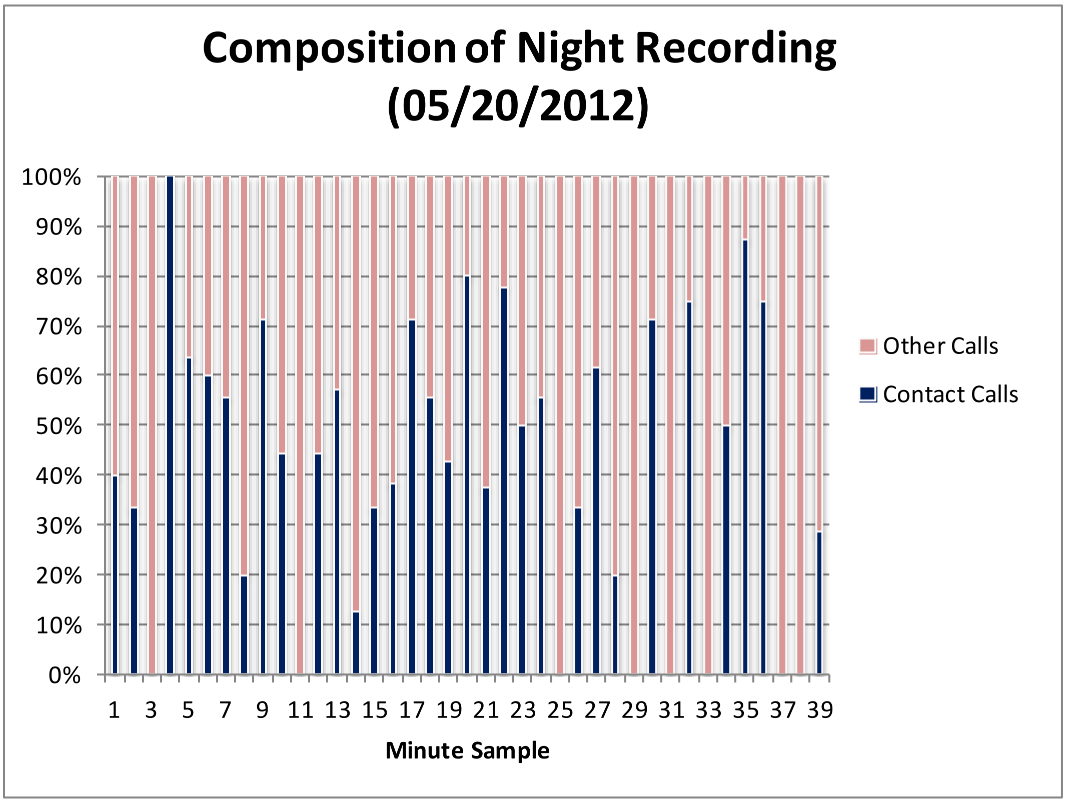

**Figure 11:The proportion of contact calls relative to all other calls in a night recording (5/20/12)** Night time data was collected from the Reson hydrophone at Lime Kiln when whales were anticipated during the study period.

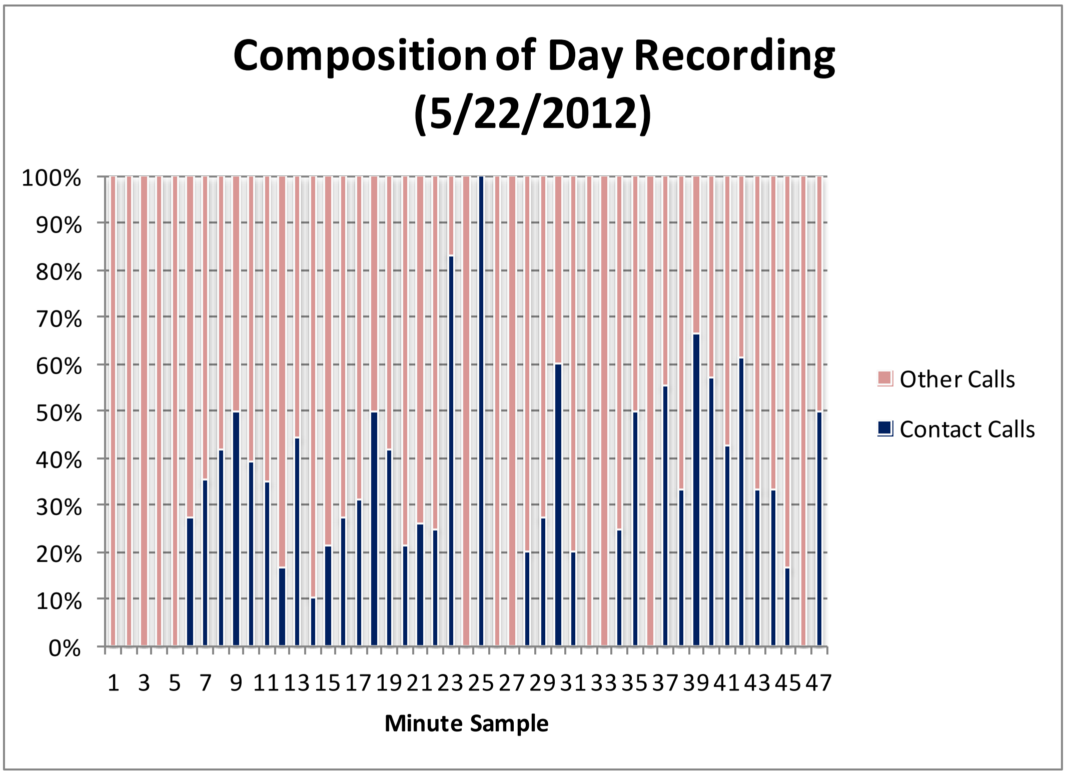

**Figure 12:The proportion of contact calls relative to all other calls in a day recording (5/22/12)** Day time acoustic recordings were collected using a hydrophone array off the stern of the Gato Verde in the presence of whales. Behavioural data was also taken during this time

A small comparison was also made between the night data collected from Lime Kiln during May 2012 with the night recordings made from August/September 2010. A different proportion of contact calls relative to other calls were observed. In 2010, the samples were 79% dominated by other calls whereas in 2012 this percentage had lowered to 58%.

## Discussion

### *Visibility*

The various sites sampled around the Salish Sea showed no significant statistical difference between locations when measured against vertical and horizontal Secchi measurements. This result was expected given the majority of way points sampled were within a relatively small sample area. In addition, over the three week period, a small sample size was collected. With a greater sample size, more conclusive results may emerge. Replicate Secchi measurements at individual sites also showed little variation when an Anova was performed. The principle component analysis revealed that phytoplankton was the main factor limiting the distance at which the Secchi disk could be seen in both the horizontal and vertical plain. Prior studies have suggested that beam attenuation is correlated with suspended particle mass. Durand (1996) found that diel variations in light scattering of phytoplankton exist primarily due to cell growth as the cells photosynthesize. During the study period, the onset of a *Skeletonema* bloom occurred. When examining phytoplankton samples under a microscope it was evident, from the long chains observed, that *Skeletonema* dominated. When *Skeletonema* was plotted against vertical Secchi measurements there was little change when compared to when total phytoplankton was graphed. This confirmed that *Skeletonema*, at this time of year at least, was having a negative effect on underwater visibility. In order to see if this trend is seasonal, phytoplankton counts and visual measurements would need to be recorded over a larger portion of the year. Deeper samples would also be beneficial for determining trends, and seeing whether layers exist within the ocean.

Sampling at Kellett Bluff allowed visibility, both horizontal and vertical, to be plotted over the course of a day. This method of sampling was the first of its kind and produced interesting results. Although patterns emerged from this day of sampling, additional data points would have strengthened any conclusions drawn. If this study were to be recreated, recordings would ideally begin with first light and end around sunset. This would expose patterns over a longer time frame in order to see how uniform the trend remains. In this preliminary study, horizontal visibility varied across the course of the day, whereas the vertical visibility remained relatively constant. It is unclear, however, whether this result is true of all locations or exclusively to Kellett Bluff. Further day samples at numerous locations, including Kellett Bluff again, would contribute to a stronger data set. Across sites, all horizontal measurements were made within the top 30cm of the water. This could have been influential as productivity, especially at the ocean surface, is linked to important climate variables such as sea-level pressure, surface winds, sea surface temperature, surface air temperature, and cloudiness (Behrenfeld et al. 2006). At the time of sampling, it was noted that surface waves were causing light attenuation to fluctuate. These surface waves, driven by winds and current, affected the distance at which the horizontal Secchi could be seen. In addition, strong currents often made the observer drift. Fighting the current was tiring, and likely influenced Secchi readings. Looking at the results of the horizontal Secchi from Kellett Bluff (5/17/12), the furthest distance recorded was at 9m whilst the minimum distance was recorded at 3.5m. Tidal height changed during this period, as did current speed. Haro Strait is known for its microclimates, unpredictable current, and a diverse tidal range (Mofjeld 1984). Tides and currents are thought to churn sediment and particles in the water. This type of mixing can lead to reduced underwater visibility. The furthest recorded horizontal Secchi distance aligned with a period when the tide was slack, currents were slow, and phytoplankton density was at its lowest. Little mixing of particles would have happened at this time. Contrastingly a lot of mixing would have occurred during a higher tide when the currents were stronger. Some phytoplankton species are particularly susceptible to tidal movements. *Skeletonema,* for example, is a species that cannot swim, and instead relies ocean mixing. Given this, it is not surprising that the highest levels of phytoplankton sampled were observed during a period of predicted high mixing. If samples were taken at alternative times of the year, during a period when the bloom was not driven by *Skeletonema*, one could still expect visibility to correlate with the vertical migration of phytoplankton species.

When comparing the horizontal and vertical Secchi measurements, it is important to note that different mediums, in which the Secchi is viewed, influence the attenuation of light differently. Light travels through water much slower than it does in air due to the rate at which light particles are absorbed. Throughout this study, vertical Secchi measurements required an observer to look through two mediums, water and air, whereas the swimmer in the horizontal experiment looked through water and a diving mask. In addition to this, it is important to remember that these experiments were conducted with a human observer, and thus does not necessarily reflect what a whale could see. Killer whales, like other odontocetes, are thought to have strong vision in water, whereas human vision is relatively restricted (Dral 1975). In air, however, the human eye is better adapted.

*Acoustics*

This study was conducted on the assumption that different contact calls, S1, S16, and S19 exist for Southern Resident Killer Whales. This theory however is speculative and not supported by any current data. The three calls examined in this study have been deemed contact calls due to the frequency of which they are heard in the presence of pod members. L pod is also thought to have an additional contact call S2iii, however, it was not included in this study due its complexity. Studies on terrestrial animals (Rendall 2000; Poole 1988) have suggested that the proportion of contact calls is dependent on the behavioural state of the animals. It proves challenging however to correlate acoustic signals to behaviour. During the times sampled, all suggested contact calls were heard at least once. S1 was the contact call heard most frequently. This call is associated with J pod, however, k pod members have, on occasion, been heard replicating the call. Based on past reports and local knowledge, members of J pod are usually the most frequently encountered residents during the Spring. In the few instances where whales were observed from the research vessel, members of J,K, and L pods were present. Members of the different pods were sometimes seen travelling together. For example "Onyx" L87 was regularly seen with K-pod. Whether L87 now uses S16 as a contact call instead of S19 is unknown.

When day recordings were made on the Gato Verde, using the hydrophone array, it was not possible to isolate the sounds to particular individuals. There were numerous focal groups that were often spread across relatively far distances. This made it difficult to determine whether the whales were indeed beyond visual contact of one another. Group density, calculated by calibrated photographs, served as a proxy for group spread. This method was not without its limitations. In addition, ambient noise generated by nearby whale watching boats, and passing ships, was heard over the hydrophones. On more than one occasion potential calls, regardless of whether they were thought to be contact or other, were discounted due to the amount of distortion caused by ambient noise. This study was conducted during May at a time prior to the start of 'tourist season' in the San Juan Islands. If this study was extended into the summer season, more calls would have been discounted due to the increasing levels of ambient noise.

Night was defined in this study as midnight ± 2 hours which took in to account the seasonal variation in daylight hours. In the archived night recordings available, many calls were detected outside of this time bin and thus were not included in the study. For example, 21:00-22:00 proved a strong hour for calls on multiple occasions. The majority of contact calls, however, were made between 22:00-23:00pm. If this study were replicated, time of sunset could be researched. This would increase sample size further, and provide insight into a period of known darkness. If this protocol was followed, the same study could be conducted at a more northerly location. It would be interesting to see how relative call rates from future studies would compare to this preliminary study.

By examining the recordings exclusively for discrete calls, the study was limited in that it did not take into consideration whistles and clicks. Killer whales are thought to use echolocation in a variety of behavioural states and thus future studies should monitor for clicks in addition to calls. Although no significant statistical differences were found when comparing night and day time data in this study, suggesting southern residents do not necessarily produce contact calls more frequently in the absence of light relative to other calls, a larger data set is needed to strengthen any findings.

## **Conclusion**

Many predictable diurnal patterns exist within the natural world in both terrestrial and marine environments. Observer effort around the Salish Sea has ensured that the southern resident behaviour occurring within daylight hours, at least what can be observed from the surface, is well documented. Night behaviour on the other hand still remains relatively unexplored. This project examined one of the many gaps in this area, and would benefit from further assessment. The results of this particular study suggest that no statistical significance exists between day and night acoustic behaviour. The scope of this project also enabled visibility across locations within the Salish Sea to be studied. No clear patterns emerged when comparing multiple sites to one another. Sampling at the same site over the course of a day, however, suggested that visibility in the horizontal plane is not necessarily reflective of the vertical plane. This may, or may not have been, related to sampling during a phytoplankton bloom. Phytoplankton was found in this study to be the factor that limited daylight visibility the most. Future studies should use this preliminary study as insight into the diurnal behaviour of the southern residents. Further data, however, is needed on each analysis to obtain stronger and more conclusive results.

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## Appendix A

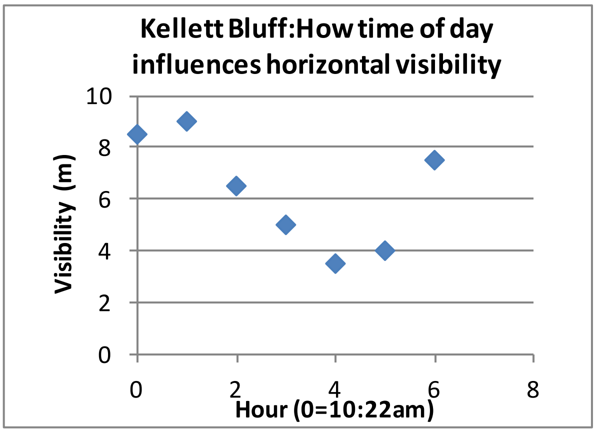


Figure 14a:The variability in the horizontal distance recorded over the course of a day at a single site (Kellett Bluff).

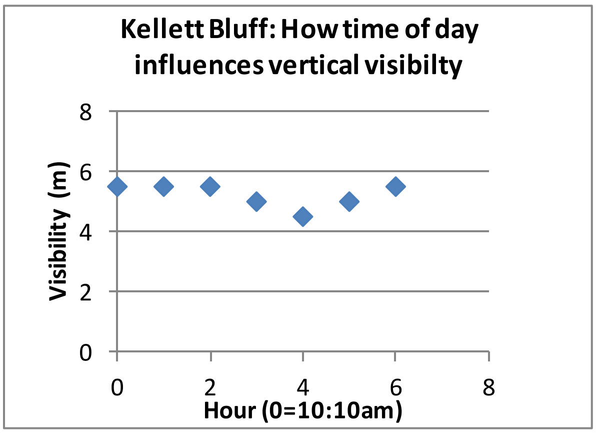


Figure 14b:How vertical visibility varied over the course of a given day (05/17/2012) at a single site (Kellett Bluff).

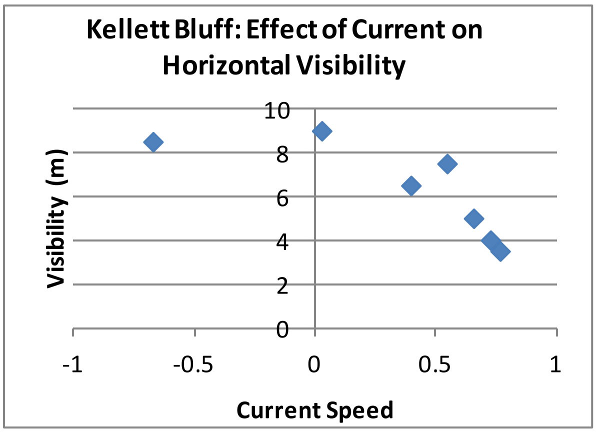


Figure 14c: How the speed of the current affected horizontal Secchi readings on 5/17/2012 at Kellett Bluff

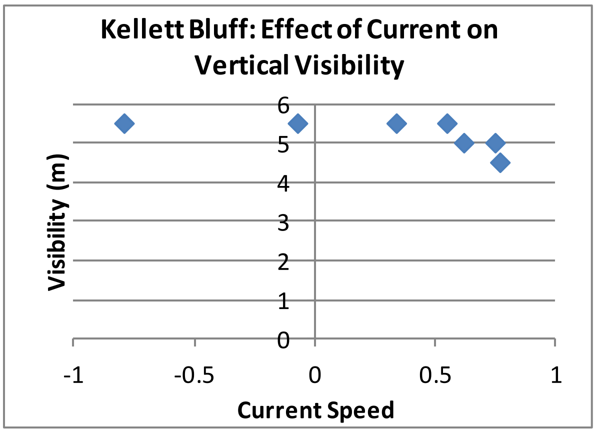


Figure 14d: How the speed of the current affected vertical Secchi readings on 5/17/2012 at Kellett Bluff

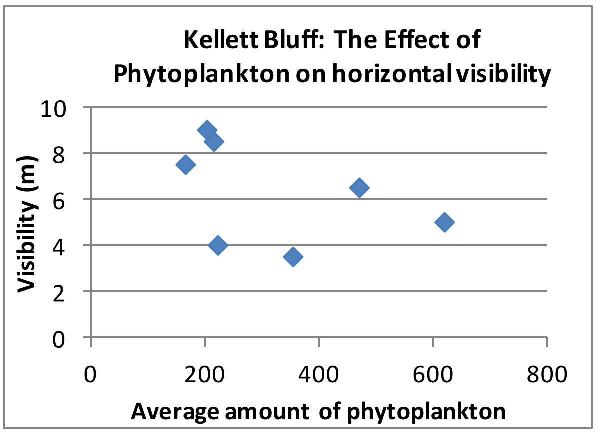


Figure 14e: Looking at the relationship between phytoplankton density and horizontal Secchi measurements at Kellett Bluff 5/17/12

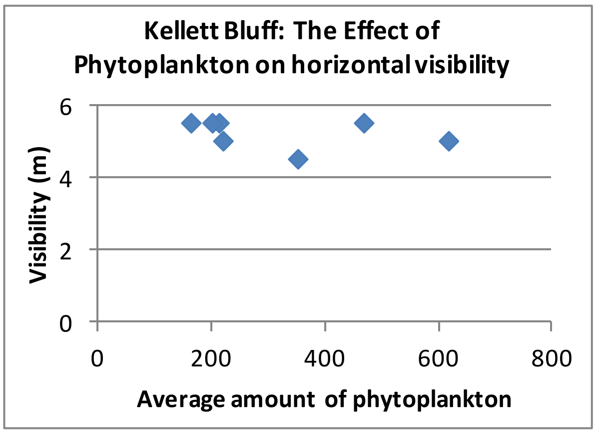
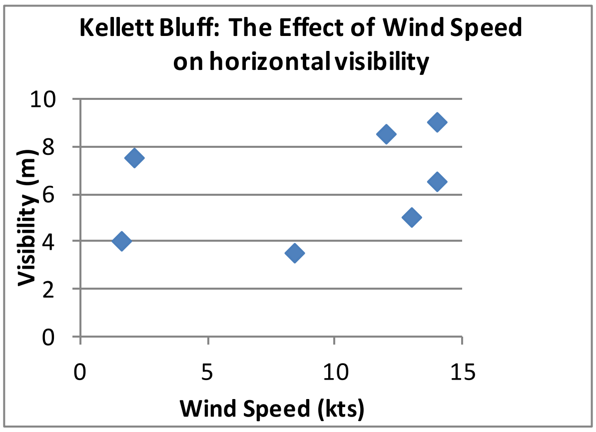


Figure 14f: Looking at the relationship between phytoplankton density and vertical Secchi measurements at Kellett Bluff 5/17/12



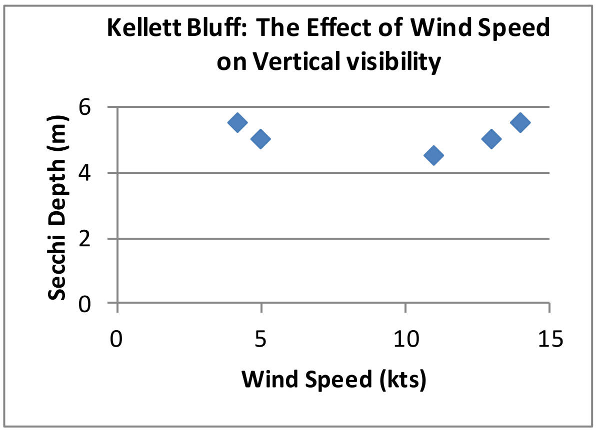
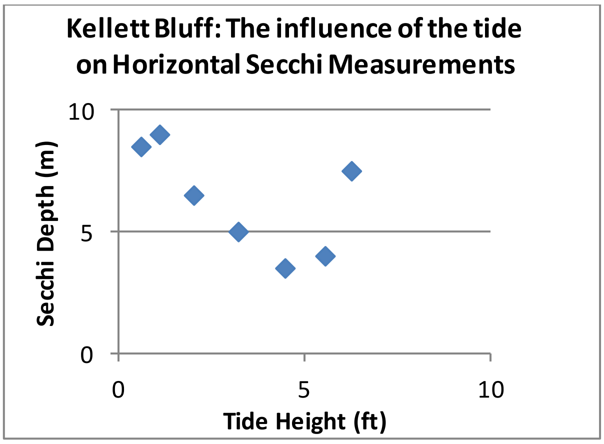


Figure 14g: The relationship between wind and the horizontal Secchi distances measured on 5/17/12

Figure 14h: The relationship between wind and the vertical Secchi depths measured on 5/17/12



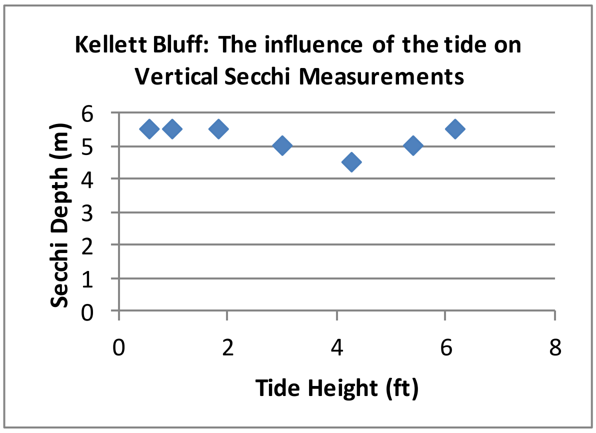
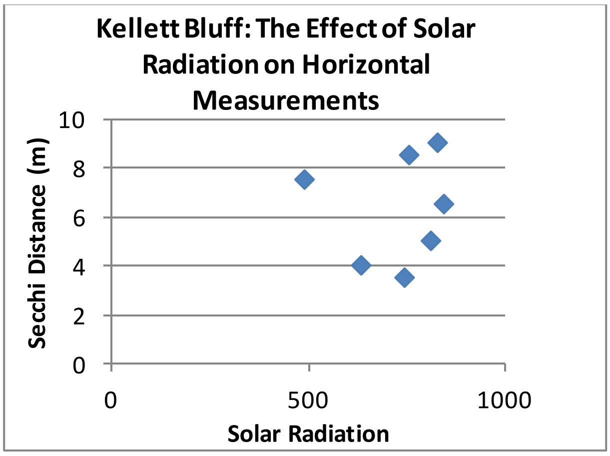


Figure 14i: How tidal height influences horizontal Secchi depth at Kellett Bluff

Figure 14j: How tidal height influences vertical Secchi depth at Kellet Bluff



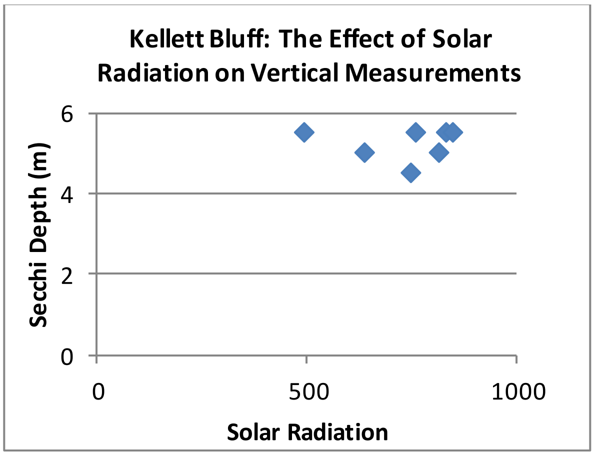


Figure 14k: The relationship between solar radiation and horizontal Secchi distance

Figure 14l: The relationship between solar radiation and vertical Secchi distance