

**Killer Whale (*Orcinus Orca*) Call Rate in Relation to Visibility Indices of the Salish Sea**

Rachel Bramble

Beam Reach Marine Science and Sustainability School

Friday Harbor Labs, University of Washington

620 University Road, Washington 98250

## **Abstract:**

Killer Whales (*Orcinus orca*) are heavily reliant upon vocal communication as a means to maintain social cohesion and it has been suggested that these animals may also have adequate vision both in and out of the water. A relationship between call rate and visibility was sought through the collection and interpretation of killer whale call rate and the creation of two visibility index equations using various oceanographic data: fluorescence, transmissivity, secchi disk deployments, and phytoplankton abundance. The sample period occurred between April 16 and May 25, 2012, using SBE17plus CTD casts, 8cm diameter secchi disk deployments, and vertical plankton tows. Statistical analyses, in the forms of linear regressions and principle component analyses indicated there was not a significant relationship between call rate and visibility, further suggesting that killer whale call rate is not dependent upon their ability to see in the water.

Visibility Index Equation 1:  $S + T - F - P$ , where S = secchi disk reading, T = transmissivity, F = fluorescence from the presence of phytoplankton, and P = phytoplankton abundance, counted from ten, 1mL<sup>3</sup> squares under an *Olympus* microscope.

Visibility Index Equation 2:  $S+T - F$ , where S=secchi disk reading, T=transmissivity, and F=fluorescence from the presence of phytoplankton.

## **Introduction**

Social interaction in mammalian species plays an important role in the survival and function of cohesive family groups. For example, individual timber wolves (*Canis lupus*) have distinct howls which, along with olfactory senses, are effectively used to communicate when members are separated at great distances (Falls, 1967). Similarly, African elephants use very low frequency vocalizations to stay in contact with one another, their calls spanning over vast areas of land (Poole et al. 2012). This kind of social interaction ensures group cohesion and can not

only be found in terrestrial mammals, but also in marine mammals. Bottlenose dolphins produce signature whistles that enable individual recognition and are mainly used when individuals are at distant proximities (Sayigh et al. 2007).

Killer whales (*Orcinus orca*), the largest member of the *Delphinidae* family, are considered one of the most social mammals of the sea, using their vast repertoire of calls, whistles, and clicks to communicate during a number of different social behaviors such as foraging (Wieland 2007). Resident killer whale foraging behavior occurs mainly within the first thirty meters of the water column, as their food source, Chinook salmon, reside mostly within this range. Although it has been documented that killer whales have the ability to dive to a depth far beyond that of their prey, they are usually observed and studied within the first thirty meters of the water column (Baird, 2002). The southern resident killer whales of the Salish Sea are among the most extensively studied killer whales in the world. Their vocalizations have been intensely studied over the past few decades (Ford 1987), revealing the extent to which killer whales communicate with one another. Vocal communication is thought to be imperative for maintaining social cohesion and organizing activity within a pod of killer whales (Weiss et al. 2007).

The southern resident killer whales consist of three different pods, J, K and L, who share a common dialect and have a habitat ranging from as far south as central California, up to northern British Columbia. During the summer and fall months, the southern residents are usually found residing in the inland waters off the coast of northern Washington and southern British Columbia (Hanson et al. 2010). This area of the Pacific Ocean, the Salish Sea, is unique in its oceanographic diversity. The environment of the Salish Sea changes seasonally in respect to the content of the water. Influenced by tidal mixing and freshwater Fraser River runoff into the

Strait of Georgia, phytoplankton abundance can vary at different depths of the water column, creating a diverse biological community in the water (Dekshenieks et al. 2001). In addition to phytoplankton, 6.5 million tons of sediment runoff from surrounding rivers enters the Salish Sea on an annual basis, causing fluctuations in the content and makeup of the water (Czuba et al. 2011). The diversity of physical, chemical, and biological influences on the Salish Sea creates an unpredictable and ever-changing environment in which the southern resident killer whales live.

The southern resident pods that inhabit the Salish Sea are made up of various small family groups, often referred to as 'subpods' (Connor et al. 1998). Each subpod consists of up to four generations of immediately related individuals. The family structure of killer whales is matrilineal, meaning that offspring continue to travel with their mother throughout the duration of their lives. This matrilineal social structure of killer whales is considered to be among the most stable social structures of any mammalian species, and results in tight group cohesion (Weiß et al. 2006). Calls used in vocal interaction that are shared among the members of a matriline are called discrete calls. Because killer whales live together in groups consisting of a number of different matrilines, all closely related, they share an abundance of calls that make up their own dialect. The discrete calls that make up the dialect of a pod are thought to be important in the social cohesion of each pod (Weiß et al. 2006).

Of the three resident pods, the vocalizations of J Pod reveal a particularly interesting and common call, S1, which is easily identifiable and is theorized to be used as a contact call. It is thought that pods rely upon contact calls to maintain group cohesion, especially when traveling (Ford and Fisher, 1983). Assuming killer whales use S1 as a contact call implies that killer whales may rely intensely on vocal communication to remain in a cohesive group when they are

out of visual range. Therefore, it can be hypothesized that killer whale call rate increases in areas of the water with less visibility.

Visual range can be affected by a number of different factors that influence light attenuation, such as water depth, what kinds of materials are suspended in the water, and the quantity of those materials (Gallegos 2000). Such factors can be as simple as the lack of light due to nightfall, or can be more complex. Phytoplankton, for example, contribute to both the absorption and scattering of light in water (Gallegos 2000). Particle content and salinity changes from estuarine areas of the water like the Fraser River runoff can also affect visibility (Sutherland et al. 2011). As there are many variables that affect visibility in water, visibility in turn affects the form and function of eyesight in many of the creatures that live in the water, including killer whales.

Odontocete eyesight is adapted for an aquatic environment, but is also thought to be effective outside of the water. The structure of an odontocete eye is similar to that of a human, with subtle differences that allow them to see effectively both in and out of the water, such as the difference in shape of the lens. Odontocete lens structure is almost spherical, creating a pressure on the iris which causes a large bulge on the cornea. The curvature of the lens is steeper in odontocetes than it is in humans, as it has been determined that all of the refraction is carried out by the lens, and none by the cornea. (Dral, 1975).

For many years, it was unclear how the lens of the odontocete eye was able to change shape drastically enough to account for both air and water visualization, as a change in lens shape seemed to be the only sound theory about how this unique vision worked. In sea otters, it was found that the eye has an accommodation range, a range in which the eye focuses a clear

image on the retina, and its curvature is altered to be visually accurate in water and in air (Murphy et al. 1990). It was found, however, that it is unlikely that odontocetes have an accommodation range like that of the sea otter, and while some accommodation must occur as the eye moves from one medium to another, it is thought that this change is due to other unique attributes of the odontocete eye, not an accommodation range (Dral, 1975). The most likely theory of how odontocetes see well both out of and submerged in water combines several different factors that influence their vision. Odontocetes can focus images on their retina at different angles in different media (Dral, 1975) and they have two areas of high density ganglion cells on which the images are focused (Mass and Supin 1997). In water, the image of the subject they are viewing is focused on both areas of ganglion cells, whereas out of the water, the image is solely focused on one area of ganglion cells, similar to terrestrial mammal visualization (Mass and Supin, 1997). Odontocetes also have “giant” axons making up a great portion of the optic nerve, of which there are no comparisons to terrestrial mammals (Mazzatenta et al. 2001).

In addition, it was found that both odontocetes and mysticetes have a lower density of optic nerves and fibers that attribute to underwater viewing (Mazzatenta et al. 2001). The strength and accuracy of odontocete vision underwater is thought to be emmetropic (accurately focused) when their vision is directed with one eye at a subject, however above water, odontocete vision is only emmetropic within the naso-ventral view, a view in which odontocetes see within an approximate 80 degree range by focusing their vision forward. The idea of the naso-ventral view comes from age-old observations of behaviors such as spyhopping.

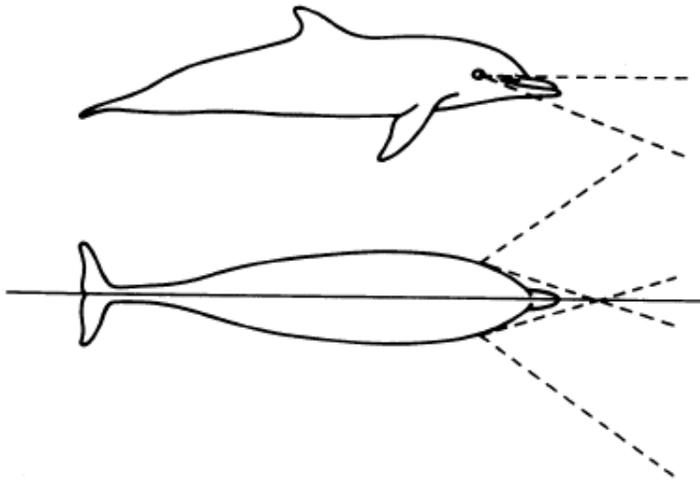


Figure 1: The naso-ventral view where vision is emmetropic in air (Dral,

1975).

Odontocetes are adept at seeing well in their aquatic world, and are even thought to have accurate vision out of the water if objects are seen through the naso-ventral view (Dral, 1975). However, they are just as affected by light attenuation as any other mammal, both aquatic and terrestrial, and things such as nightfall, chlorophyll from phytoplankton, and particles in the water may play a part in reducing their ability to see in the water. From what is known about the theory that vocal communication is imperative to maintain social cohesion in killer whales, it is safe to assume that, in areas of the water with limited visibility, the overall call rate of killer whales increases.

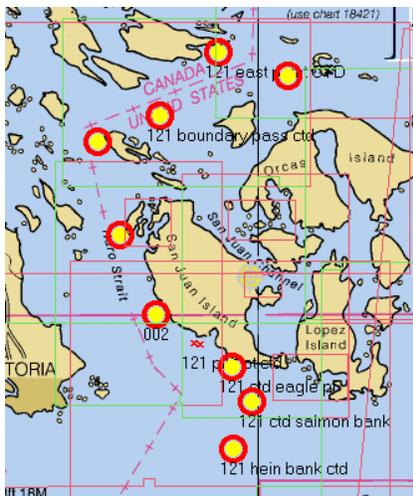
## Methods

Visibility indices of eleven specific areas in the Salish Sea were created using transmissometer and fluorometer data from SBE17plus CTD casts, 8cm diameter secchi disk deployments, and plankton tows taken from April 16-May 25, 2012. The visibility indices were determined from the following equation created specifically for this study:

$$S + T - F - P$$

Where S = secchi disk reading, T = transmissivity, F = fluorescence from the presence of phytoplankton, and P = phytoplankton abundance, counted from ten, 1mL<sup>3</sup> squares under an *Olympus* microscope. Positive values of secchi disk readings and transmissivity were used due to the interpretation that as these values increase, so does the clarity of the water. Similarly, negative values of fluorescence and phytoplankton abundance were used considering the negative relationship of these values to water clarity. As the total index value increases, so should the visibility in the water.

The eleven waypoints at which the visibility indices were made are East Point, West Bank, Boundary Pass, Turn Point, Kellett Bluff, Lime Kiln, Pile Point, False Bay, Eagle Pass, Salmon Bank, and Hein Bank.



Linear regression relationships between the various data collected from the CTD and the secchi disk readings were plotted in Excel. The compared variables included fluorescence, transmissivity, and secchi disk reading. Phytoplankton abundance for each of the waypoints over

a span of multiple days was counted using photographs of fixed samples from plankton tows deployed to 20m at each location.

The data analyzed from the CTD was averaged data between two and thirty meters, negating the first meter, as initial deployment of the CTD requires that the instrument sits at the surface of the water, extending approximately one meter below the surface, before being lowered in order for it to calibrate and collect accurate data. The averaged data collected between 2-30 meters was then averaged for each waypoint and those values were then applied to the visibility index equation.

In addition to the data collected during this four week time span, archived CTD data of the same waypoints was analyzed in the same respect to maximize total data. The archived data was from spring and fall 2011. The analyzed archived data was also applied to the visibility index equation. The values obtained from the visibility index equation were then plotted against calculated call rate.

Call rate was calculated from data recorded from the hydrophone array deployed from the *Gato Verde*, the stationary hydrophone located at Lime Kiln, and archived data from spring and fall 2011. Audacity was used to determine the call rates of the resident whales that were encountered at the various waypoints. The overall call rate was calculated from one minute segments of recordings taken at the different waypoints. For recordings under 40 minutes, the calls in every minute were counted. For recordings over 40 minutes, calls were counted every five minutes.

Both new and archive data of hydrophone recordings and oceanographic data were analyzed for the call rates and the visibility indices. With the various relationships of the factors

affecting the visibility indices, principle component analyses were performed in R to easily visualize if one factor was the sole contributor to the results of the equation. An additional visibility index equation was created to find if there was a different relationship between the selected variables:

$$S+T-F$$

Where S=secchi disk reading, T=transmissivity, and F=fluorescence from the presence of phytoplankton. A principle component analysis was performed in R with the new visibility index equation to find if any one variable was the main driver of the results.

In the final stages of the research, the relationship between the derived visibility indices and overall call rate for each waypoint were plotted against each other. The product of the first visibility index equation for each location was regressed linearly against each individual variable from the visibility index equation to see if there was a significant linear trend relating any one variable to call rate.

## **Results**

When regressed against each other, the average fluorescence and average transmission readings obtained from the CTD over the course of sampling at each waypoint produced an  $R^2$  value of 0.203 (Figure 1) indicating an insignificant linear relationship between variables.

When the average secchi disk reading was regressed against average transmissivity for all of the days sampled, at all of the various waypoints, the  $R^2$  value produced was 0.1117 (Figure 2) not revealing any significant linear relationship between secchi disk reading and transmissivity.

When the averaged secchi disk reading was regressed against fluorescence, the  $R^2$  value was also found to be 0.1117 (Figure 3), again indicating that there was no significant linear relationship to be found between the two regressed variables.

A plot of phytoplankton abundance over time at the various waypoints shows an increase in overall abundance at most of the waypoints over time. Kellett Bluff shows an increase, then a decrease in abundance over time, considering both the morning and afternoon samples. West Bank and Hein Bank were only sampled once and therefore do not show an increase, nor a decrease in abundance (Figure 4). This overall increase indicates the presence of a phytoplankton bloom throughout the duration of the sampling.

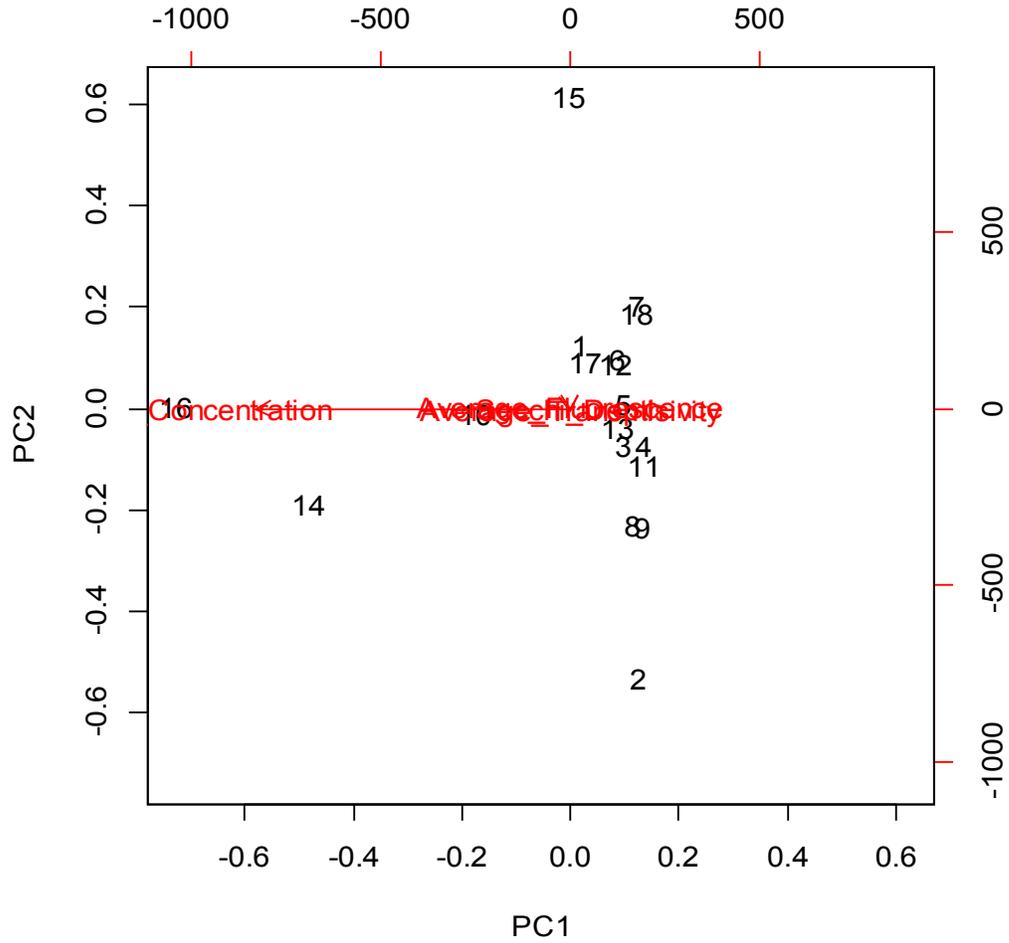
Phytoplankton abundance was also plotted to reveal the phytoplankton diversity. The diversity shows the presence of a skeletonema bloom. It also shows an abundance of chaetoceros at False Bay on the first sample day (Figure 5).

Average call rate at each location where calls had been recorded from both archived and collected data were plotted, but did not have statistical support, indicated by the error bars (Figure 6).

The first visibility indices created with phytoplankton abundance, fluorescence, transmissivity, and secchi disk reading are plotted showing a wide range of visibility at the various waypoints (Figure 7), changing on each sample date.

Average visibility indices plotted against average call rate indicates no correlation between the two variables (Figure 8).

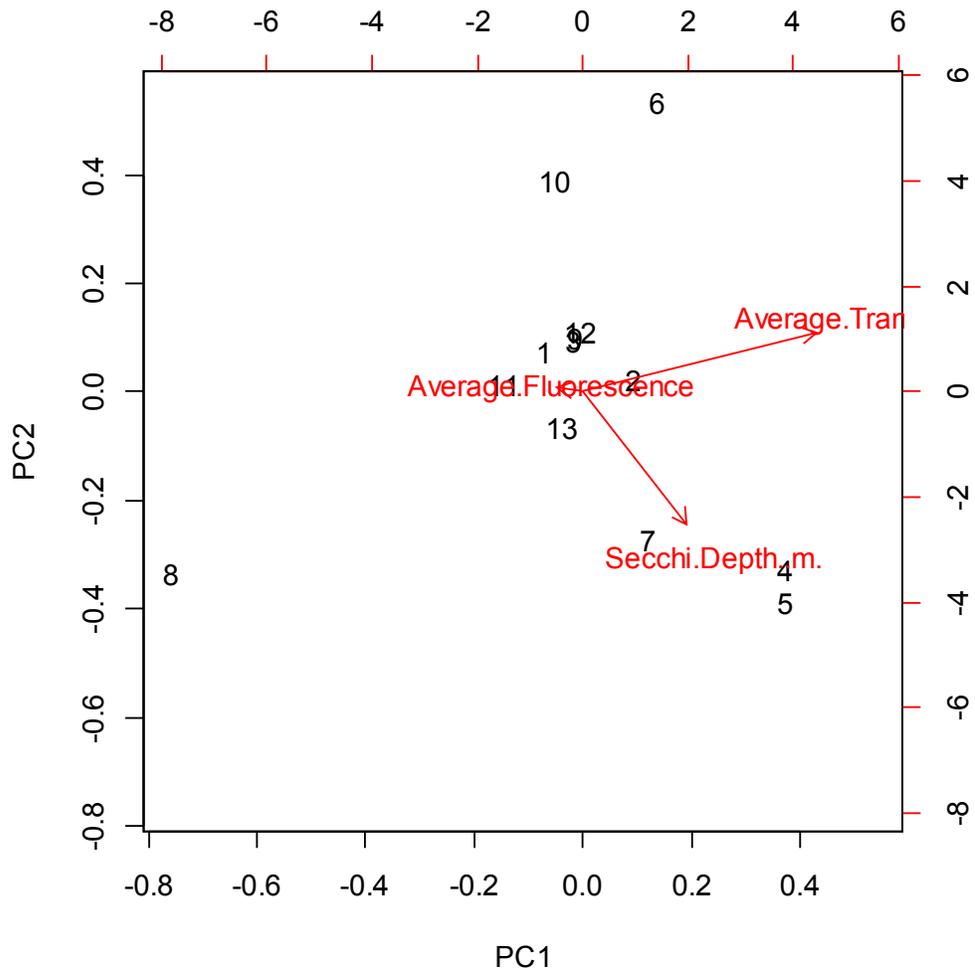
A principle component analysis of the results from the visibility indices plotted against call rate indicates that phytoplankton is the main driver of the equation, with little influence from the other variables (Figure 9).



A range of visibility indices from the second visibility index equation,  $S+T-F$ , indicate a large spread of visibility across the various waypoints, similar to the large variance of the first visibility indices (Figure 10). The lack of phytoplankton in the equation led to the production of an entirely new set of visibility indices.

The second visibility index, averaged, plotted against average call rate revealed similar results as the first visibility index equation and call rate plot, in that there appears to be no significant relationship between call rate and visibility (Figure 11). Even with the lack of phytoplankton in the index equation, there is still not a visible relationship.

The principle component analysis for the second visibility index shows that each variable drives the results of the equation in some respect, as opposed to the previous visibility index which had only one major driver, phytoplankton (Figure 12).



Call rate per minute was linearly regressed against each individual variable that made up the visibility index equations, phytoplankton abundance (Figure 13), fluorescence (Figure 14), transmissivity (Figure 15), and secchi disk reading (Figure 16). There was no significant linear relationship revealed in any of the regressions.

## **Discussion**

The relationships between the variables used in the first visibility index equation did not yield any significant linear relationships. The expected results might have shown a negative linear relationship between fluorescence and transmissivity, a positive linear relationship between secchi disk reading and transmissivity, and a negative linear relationship between secchi disk reading and fluorescence. Visually, the plots indicate the expected relationships are depicted, however, the  $R^2$  values deem the relationships to be statistically insignificant (Figures 1-3). The measure of fluorescence does not always show a relationship between cell size and chlorophyll content, supporting the lack of relationships found in the collected data with fluorescence (Edmondson, 1980).

The abundance of phytoplankton found in the Salish Sea at the various waypoints over time showed an increase in abundance at each location that was sampled more than once, except for Kellett Bluff, which revealed an increase from the first to the second day, and a decrease from the second to the third day (Figure 4). This increase in abundance is directly correlated with the spring skeletonema bloom that occurred during data collection. During spring 2011, a skeletonema bloom in the Salish Sea was also witnessed in the waters on the north end of San Juan Island (Donahue, 2011). The drastic variance in abundance from one

waypoint to another was found to be typical of the environment in which the sampling occurred (Donahue, 2011). Phytoplankton blooms are often unpredictable in that they can occur on a timescale from days to weeks, except that they usually occur during neap tides (Cloern, 1991).

Fluorescence, transmissivity, secchi disk reading, and phytoplankton abundance were all considered for the visibility index equation. The variables were linearly unrelated, but it was determined that they might have an effect on the visibility in the water. The visibility indices for each of the different areas revealed quite a diverse range of visibility relating to the various components of the equation (Figure 7). Due to the bathymetry and the strong tidal mixing of particles in Haro Strait, it was expected that each waypoint would vary greatly from the next (Johannessen, 2004). When the indices were plotted against call rate for the six waypoints that contained both call rate and visibility data (Lime Kiln, Eagle Point, Hein Bank, Salmon Bank, False Bay, and Turn Point), no relationship was shown (Figure 8).

The average call rate that had been determined from archived data and collected data at the six different locations was also statistically insignificant. The error bars on the plot show how there was little significance in the calculation of average call rate (Figure 6). This insignificance was most likely due to the sporadic nature of the killer whales and the lack of call data for each location that corresponded to oceanographic data. The time period in which the study was made (April 16-May 25) was relatively short, hindering the collection of more data and accuracy of results.

Due to finding no relationship between average call rate and visibility indices at the six different waypoints, the results were statistically analyzed in greater detail to see if there was a large influence on the index equation from solely one of the variables. The statistical

test performed on the data was a principle component analysis and allowed the variables in the visibility index equation to be shown in a manner that indicated which variable was driving the equation with the greatest force. The test revealed that the main driver of the equation was phytoplankton abundance, and that there was little, if any drive from the other variables in the equation (Figure 9). The drive from phytoplankton was believed to be due to the quantities of phytoplankton counted. The abundance was so high at certain waypoints, that smaller numbers from the other variables had little effect on the product of the equation. The phytoplankton dominance of the equation can be attributed to the skeletonema bloom that occurred during data collection. This particular bloom is common in the Salish Sea during the spring and accounts for the drastically high numbers in abundance (Hobson, 1997).

After considering the influence of phytoplankton on the visibility index equation, phytoplankton was taken out of the equation and new visibility indices were created (Figure 10) in order to see if a relationship between average call rate and visibility could be found. The new plot revealed no such relationship (Figure 11). A principle component analysis was performed on the new data to determine if a different variable was again solely driving the equation. In this statistical analysis, however, it was found, that although there was one variable that was influencing the equation more than the others, the extent to which it had an influence was only slightly greater than the influence of the other variables (Figure 12).

Upon finding no relationship between call rate and the visibility indices again, the individual variables of the initial visibility index equation were regressed against the average call rate to find if any one of the collected variables had an effect on call rate. The

individual regressions did not show any linear relationship, indicating that the individual variables did not have any effect on call rate (Figures 13-16).

## **Conclusion**

In conclusion, it was found that, with the data collected and the interpretations made from this study, killer whale call rate is unaffected by visibility, or lack thereof, in the water. It was also found that there are no significant linear relationships between the collected oceanographic data fluorescence, transmissivity, secchi disk readings, and chlorophyll. Statistical support was not found to support the initial hypothesis of this study, however, with further collection and investigation of data over a greater span of time, a different conclusion could be reached.

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