Bottom-up Analysis of Lower Trophic Levels Within Foraging areas of the Southern Resident killer whales.

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The Salish Sea hosts a complex ecosystem of food webs that are influenced by both anthropogenic stressors and physical processes. Anthropogenic influences include human impacts on marine life while environmental processes mostly include constant fluctuations determining marine organism abundance and distribution. Both of these human and natural processes combined create a harmful dynamic within the marine ecosystem. Understanding the preliminary cause of changes in marine organism health can be achieved by looking at top-down verses bottom-up trophic interactions. Top-down analysis starts with the effects of higher trophic levels such as marine mammals and their cascading influence on lower trophic levels such as fish populations and primary production. Bottom-up evaluation starts with the lower trophic levels. In bottom-up analysis, levels of primary production may

determine fish densities, which are known to cause fluctuations in marine mammal populations.

The Southern Resident killer whales (SRKW's) serve as a vital model for analyzing these interactions in order to assess future conservation efforts. In 1995 their population declined until 2005 when they were listed as Endangered under the Endangered Species Act (Hanson et al., 2010). Their declining numbers led to the National Marine Fisheries Service Recovery Plan in 2008 which established 3 primary factors attributing to their decline; presence of vessels, toxins and prey availability. The presence of vessels and exposure to toxins are both examples of top-down effects on these marine mammals. Prey availability is a bottom-up control of these killer whales and is currently a poorly understood topic in most coastal systems (Reum et al., 2011;Horne and Gauthier, 2004). In the late 1800s Southern Resident killer whales most common diet; chinook salmon (*Onchohynchus tshawytscha*), started declining in major river systems (NMFS, 2008). The decline of chinook has a direct effect on whale populations because the number of whales fluctuates in response to the abundance of chinook runs (NMFS, 2008). In order to sustain long-term fish populations, studies have suggested that bottom-up control of trophic interactions are the principle mechanism that should be the focus of current research efforts (Ware and Thomson, 2005;NMFS, 2008). In addition, physical factors play an important role in coupled trophic interactions that influence fish populations (Emmet and Sampson, 2007). Understanding the ecological importance of the Southern Residents' prey could be the key to conserving

these endangered species.

Little is known about the diet of the Southern Resident killer whales. Past studies have calculated the diet of these whales based on opportunistic observations of predator-prey interactions, stomach contents of whale carcasses, and sampling prey fragments from the surface of the water after a foraging event (Ford and Ellis, 2006;Ford et al., 1998). It has been found that from May to October, that salmon are the dominant food source (Ford et al., 1998). Chinook salmon appear to be their preferred prey and coincidentally are the least common salmon species in the northeastern Pacific (NMFS, 2008;Ford and Ellis, 2006). The reason for this preference could be due to their large size and high lipid content (Ford et al., 1998). This energy efficient fish caused concerns when their native population started declining in 1990 (Noakes et. al, 2000). In response to this decline, fish hatcheries contributed to an increase in abundance of chinook salmon termed ‘blackmouth’, which have been steadily replacing wild chinook populations (NMFS, 2008). Blackmouth reside in the San Juan Islands year-round, allowing an alternate food preference for the killer whales (Barsh et al., 2010). Other salmon prey species that are more abundant but not as targeted are chum, pink, coho, and sockeye salmon (NMFS, 2008). A study by Ford et al. (1998) conducted analyses on the stomach contents of resident killer whales and found 4% of SRKW’s prey items were non-salmonids and were labeled as either epibenthic or demersal species. Even though studies have found the general consistency of the SRKW’s diet, there are no accessible records of charts locating prey densities

or spatial and temporal distributions of prey in correlation with the SRKW's range (Horne and Gauthier, 2004). This could be an important link to establish for future understanding of critical foraging areas.

Since chinook salmon are predominantly targeted by Southern Residents, it is important to understand what controls chinook populations. Seasonal variation in prey preference of chinook salmon most likely occur in response to fluctuating prey in coastal waters (Hunt et al., 1999). Healey (1991) found that the importance for chinook feeding on sand lance (*Ammodytes hexapterus*) and Pacific herring (*Clupea pallasii*) populations increased from south to north along the Pacific coast (Hunt et al., 1991). A more recent study conducted by Barsh et al. (2010) in the San Juan Islands found that most of their diet consisted of sand lance, crab larvae, and insects. Even though there is seasonal variation in abundances of these prey, Barsh et al. (2010) found that juvenile sand lance were the chinooks largest source of food in terms of biomass. In 2010, 83% of the wild chinook analyzed in their research consumed sand lance. These small 15-20 cm long fish consume zooplankton during foraging activity and bury themselves in sand between these periods (Pearson et al., 1984). A non-for profit group, 'Friends of the San Juans', recently documented sand lance abundance around the islands. Their map of sand lance distribution illustrates that these forage fish prefer sandy protected bays away from areas of major current flows.

Chinook densities are not only found to fluctuate with forage fish populations but also with biomass of zooplankton. A study of the ecosystem off

the coast of Washington and southern British Columbia found a positive linear relationship between fish yield and zooplankton (Ware and Thomson, 2005). Zooplankton are heterotrophic plankton that cycle carbon and other elements in the ocean (Roemmich and McGowan, 2006). They maintain a patchy distribution within the water column and have been found to aggregate in areas where phytoplankton is available (Johannessen and Macdonald, 2009;Roemmich and McGowan, 2006). Phytoplankton are photosynthetic organisms in the upper euphotic zone that rely on nutrients for growth (Kodner, 2011;Takashi et al., 1977). These nutrients are supplied to the phytoplankton by environmental factors such as river run-off, currents and tides. These physical forces create upwelling and mixing of particles within the water column allowing nutrients to reach the surface (Takahashi, 1997).

The way in which nutrients are distributed within the marine ecosystem of the San Juans depends on current interactions with the topography of the ocean floor (Zamon, 2002). In areas consisting of deep canyons and steep walls, there is a high-energy zone with fast currents running along the bottom. Haro Straits' deep topography demonstrates this high energy by continually mixing suspended particles at mid depth (Johannessen et al., 2006). The general coastal area of Washington and British Columbia coast are found to have high levels of nutrients because there is annual upwelling coming from the fluctuation in freshwater discharge of the Fraser and Columbia River systems (Yin et al., 1997;Ware and Thomson, 2005). High levels of nutrients and phytoplankton have been consistently referred to areas of high primary

productivity (Ware and Thomson, 2005).

Our project will measure phytoplankton biomass in Southern Resident killer whale's critical habitat in order to define primary productivity levels. Land-based nutrients are another source influencing photosynthetic activity. Nutrients from land supply nitrogen to the marine ecosystem stimulating primary production in certain areas around the San Juan Islands (Whitney et. al, 2005;San Juan County Conservation District, 2001). A satellite-imaging program, Sea-viewing Wide Field-of-view Sensor (SeaWIFs), is used to map out areas of high chlorophyll a concentration or high primary productivity. A high signal of chlorophyll a representing high biomass can be seen in the most recent SeaWIFs images of the Pacific coastal regions (SeaWIFs, 2002). Detailed SeaWIFs images of the San Juans are unavailable, however correlations can be made based on past trends of chlorophyll a concentrations along the Pacific coast. These trends depict a correlation between influx of freshwater from a river or land source and areas of high primary productivity (Whitney et. al, 2005).

It is apparent that physical factors play an important role in distribution and abundance of lower trophic levels. Bathymetry, temperature, salinity, nutrients, turbidity, tides, and currents all contribute to primary production, which in turn affects forage fish and salmon populations. Figure 1 summarizes the trophic interactions between all of these factors along with primary literature that has established these relationships. This project focuses on a region where the Southern Resident killer whales have displayed foraging behavior on a yearly

basis. Our general goal is to analyze bottom up control of the Southern Residents in this region and to link areas of foraging activity with high levels of primary productivity.

A study in 2006 observed when the Southern Residents were engaged in feeding activity and organized observations into areas of varied feeding probabilities. Their map is displayed in Figure 2 and was used as a base for our range of study (Ashe et al, 2010). Specifically, we will measure the environmental variables and densities of lower trophic levels within the western region of San Juan Island and Salmon Bank. This study area lies within the Southern Residents annual foraging area and is known to yield a large quantity of salmon (Horne and Gauthier, 2004). A study conducted by Ware and Thomson (2005) connected these fish densities with high levels of primary productivity off the Pacific coast and found a positive linear relationship between fish yield and chlorophyll a concentration (Figure 3). *Therefore, if high salmon populations vary in response to levels of primary production, we would expect there to be a linear relationship between primary productive hotspots and fish yield within the SRKW's foraging region off the west coast of San Juan Island and Salmon Bank.* Fish yield was defined as both forage fish and salmon populations.

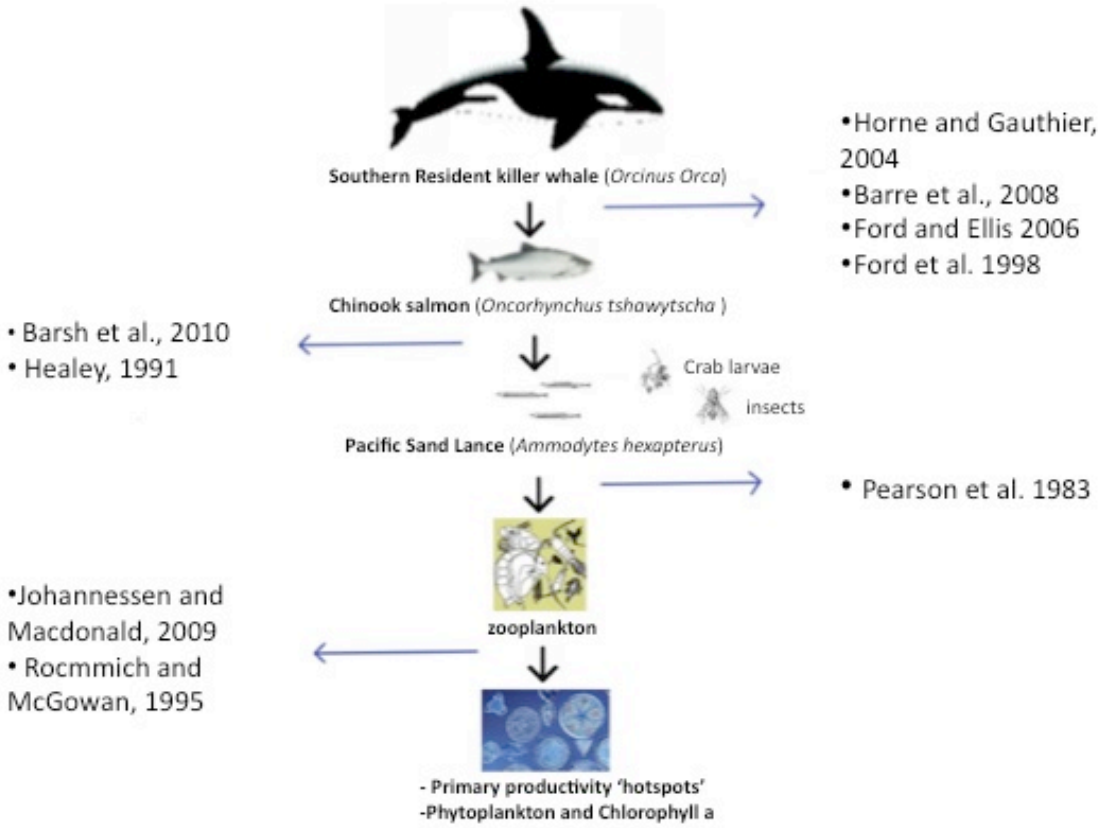


Figure 1. A trophic model illustrating trophic interactions among the Southern Resident killer whales, chinook salmon, sand lance, zooplankton, phytoplankton and primary productivity 'hotspots'.

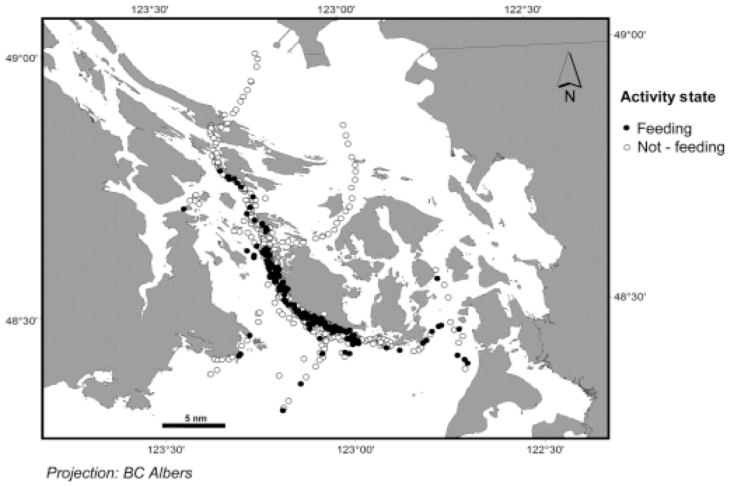


Figure 2. Map of feeding and not-feeding behavior locations of Southern Resident killer whales out of 764 observations. Highest feeding activity is found along the western coast of San Juan Island.

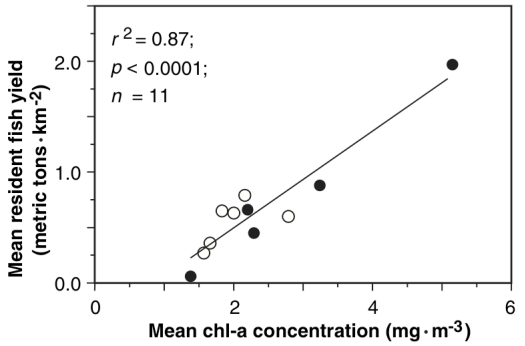


Figure 3. Mean resident fish yield graphed against mean chlorophyll a concentration within 11 large-scale areas off the coasts of Washington and British Columbia.

Methods:

Sampling sites:

Salmon Bank and the western coast of San Juan Island is the primary

zone of sampling and specific sample sites were established by using Global Positioning System (GPS) coordinates calculated before departure. All other measurements were located in opportunistic areas the research catamaran; the Gato Verde encountered based on weather conditions and observations of the SRKW's. Samples outside of the main transect were aimed to be outside of the annual foraging zone of the Southern Residents, depicted in Figure 2. The main transect consisted of 5 sample sites over Salmon Bank and 2 sites to the west of the San Juan Island coast (Figure 4). Salmon Bank sampling sites were chosen because of differences in depth and bathymetry. Outer east and west Salmon Bank sites were located over the deepest bottom floor topography areas east and west of the bank. The other two sites were over the eastern and western slopes of the bank, and the last site was directly over Salmon Bank (mid Salmon Bank). There were two other continuous sites in front of False Bay, and Lime Kiln state park off of the west coast of San Juan Island.

Protocol:

At each station the protocol was as follows:

1.) Record fish finder backscatter

1.) Conductivity-temperature-depth (CTD) device deployment

2.) 5 minute horizontal plankton net tow

3.) Vertical plankton net tow

When the exact GPS coordinate of the sampling site was reached the first step was to record fish finder backscatter by taking pictures while other deployments occurred. A Hero high definition video camera took time lapsed

photos for the first half of the study and the second portion of photos were taken by an android phone running an open source time-lapse application every minute. From April 17 to May 10, a GP-1650 WF fish finder was used to calculate the amount of backscatter present within a 45° coverage at 50 kHz and an 11° coverage at 200 kHz. Backscatter data after May 10 was recorded from a Lowrance Elite-5X Down Scan Imaging fish finder that scanned at a 30° coverage at 800 kHz and 55° coverage at 455 kHz.

An 85 lb. CTD was deployed using a crane attached to the starboard side of the Gato Verde. A pulley system was devised using shackles to minimize unequal weight distribution and the CTD was lowered by releasing rope wrapped around a winch. The maximum depth to lower the CTD device was chosen based on the overall depth of the site and varied based on sea state. Outer east and west Salmon Bank CTD deployments were lowered to around 20 meters, east and west slope sites allowed the CTD to reach around 10 meters and mid Salmon Bank was lowered to around 7 meters. The CTD device measured chlorophyll a, temperature, and salinity within the water column. A flourameter and transmissometer were attached to the CTD to measure chlorophyll a concentration and the amount of light scattered by suspended particles.

One horizontal and one vertical plankton net tow followed the CTD deployment. Both horizontal and vertical measurements used a 15 µm plankton net with a flow meter attached to the opening. For the horizontal measurement, the 15 µm net was towed for 5 minutes along a transect starting at the exact GPS coordinate of that sampling site and captured phytoplankton at the surface.

A GPS recorded where and when the net starts (waypoints), and when the plankton net was lifted from the water for both horizontal and vertical plankton tows. In order to measure the speed of the currents the flow meter quantitatively counted the speed of sifting particles through the net. The flow meter reading was specifically recorded for the horizontal plankton tow. A lead weight was attached to the plankton net for the vertical tow, and was lowered to 30 or 100 feet depending on the depth of the site.

Quantification of cell count estimation:

Phytoplankton cell counts were calculated and organized by genus. Total cell counts were taken from 2, 125 μL subsamples of 1 mixed sample bottle per horizontal tow. Vertical cell counts were taken from subsamples of unmixed vertical tow sample bottles and were recorded based on presence of genus. The amount of cell/μL counted under both 40X and 20X magnification was calibrated. Calibration calculations were based on flow meter dial readings, area of the field of view, area of the palmer counter within the microscope slide, the volume of the subsample, and total amount of cell counts per tow.

Calculations required for calibration:

Flow meter dial readings were summed to give revolutions per second of the fan. Velocity was measured using the equation v=xn+a given by the company who made the flow meter device; TSK. *V* is velocity in meters per second, *x* is the calibration parameter (.16), *n* is the number of revolutions per second, and *a* is another calibration parameter of .01. Distance was found by multiplying the velocity counts by the time the plankton net was towed. In order to calculate the

cylindrical water column that filtered through the net for each 5 minute horizontal tow, the diameter of the 15 μL (19 cm) net was used to calculate the area of the top of the net multiplied by the distance. The volume of sample counted under both 20X and 40X magnification, was measured by taking area counts of both the palmer slide and both fields of view with a micrometer. The percentage of the area counted within one field of view on the palmer counter was multiplied by the amount of volume pipetted into the slide (125 μL). Cell counts under either field of view were quantified by taking the total number of cell counts divided by 10 field of view cell counting sessions per horizontal tow multiplied by the volume of seawater under each magnification. The amount of cell counts per mL present in the environment was calculated by using the total volume of water collected in the bottle of the net (25 mL) and dividing by the total volume filtered.

Analysis of Fish Finder backscatter:

Fish finder photos were organized into presence verse absence of large targets. If larger targets were present, the total count was recorded.

Plots:

Plots of fish yield were based on presence or absence of large targets and were graphed against levels of phytoplankton cell counts, and chlorophyll a concentration in the upper 10 meters of the water column. Physical factors such as ebb and flood tidal currents will be plotted against both phytoplankton biomass and fish yields in our area of study.

Figure 4. Transect of 7 sampling sites. Two sites are off of the west side of San Juan Island in front of Lime Kiln and False Bay. Five other sample sites are over Salmon Bank. There is an outer west, west slope, mid, east slope and outer east slope coverage of Salmon Bank.

Results

CTD verse Cell counts/liter:

Fluorescence, conductivity and temperature data was taken from CTD casts and values from the upper 1 or 2 meters of the water column were averaged on all of the 5 different sampling days. A principle components analysis (pca) was run on the all variables; date, site, cell count/liter in the environment, chlorophyll a, salinity, and temperature. The highest amount of variance driving the system was the amount of cells per liter in the environment (99.9%). Chemistry variables are not contributing to the difference between cell counts among sites. Within the chemistry variables, conductivity accounted for 82% of

the variance among cell counts. An outlier for both pca analyses was on April 30 with 230 cell counts per liter on mid Salmon Bank (see Appendix). This site also had the highest temperature value of 9.2 degrees Celsius compared to an average of 8.5 degrees Celsius for all other sites. The average chlorophyll a concentrations among sites was .147 mg/m^3 while the average conductivity was 32.41 mS/cm. Salinity and temperature values in the upper water column were consistent throughout sites with subtle slope changes. Temperature thermocline was present in the upper 2 meter water column and values steadily decreased as depth increased. Salinity measurements steadily increased as depth increased (see Appendix). Changes in salinity temperature and chlorophyll a were minimal and stayed consistent among sites.

Chlorophyll a concentrations from the upper water column verse cell counts were plotted in linear regression model to see if there was a significant correlation. Chlorophyll a concentrations graphed against cell counts per liter had an R^2 value of .4432. Chlorophyll a concentration as a representation of biomass was therefore not linear in our study.

Cell counts/liter verse site and date:

Cell counts per site varied over time. There were no significant trends in cell counts among sites.

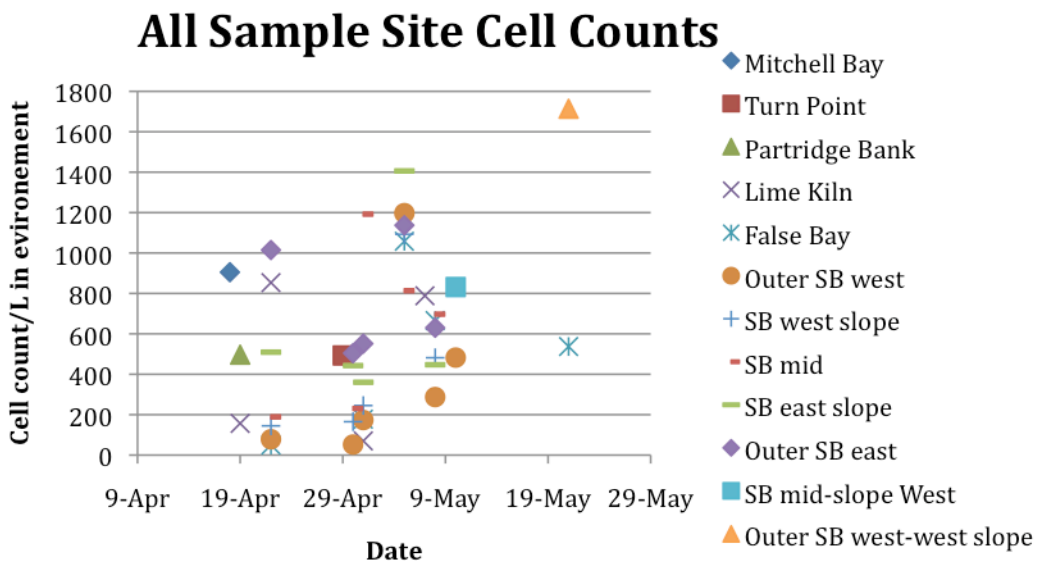


Figure 5. Cell count per liter in the environment over time for Mitchell Bay, Turn Point, Partridge Bank, Lime Kiln, False Bay, outer Salmon Bank west, Salmon Bank west slope, and mid Salmon Bank. The highest amount of cell counts per liter in the environment was on May 21 when the Southern Resident killer whales were seen foraging.

The lowest cell counts were sampled from the outer Salmon Bank west site over most of the sampling days. Salmon Bank cell counts were highest compared to other Salmon Bank sampling sites on May 1, and lowest on May 5. The highest cell counts per liter in the environment compared to all other biomass counts were on May 21 between outer Salmon bank west and the western slope. This sample site was established due to presence of the Southern Residents at the time of phytoplankton collection. Figure 6 compares cell counts among sites over time and highlights the two sample days when whales were present and foraging with a black square symbol.

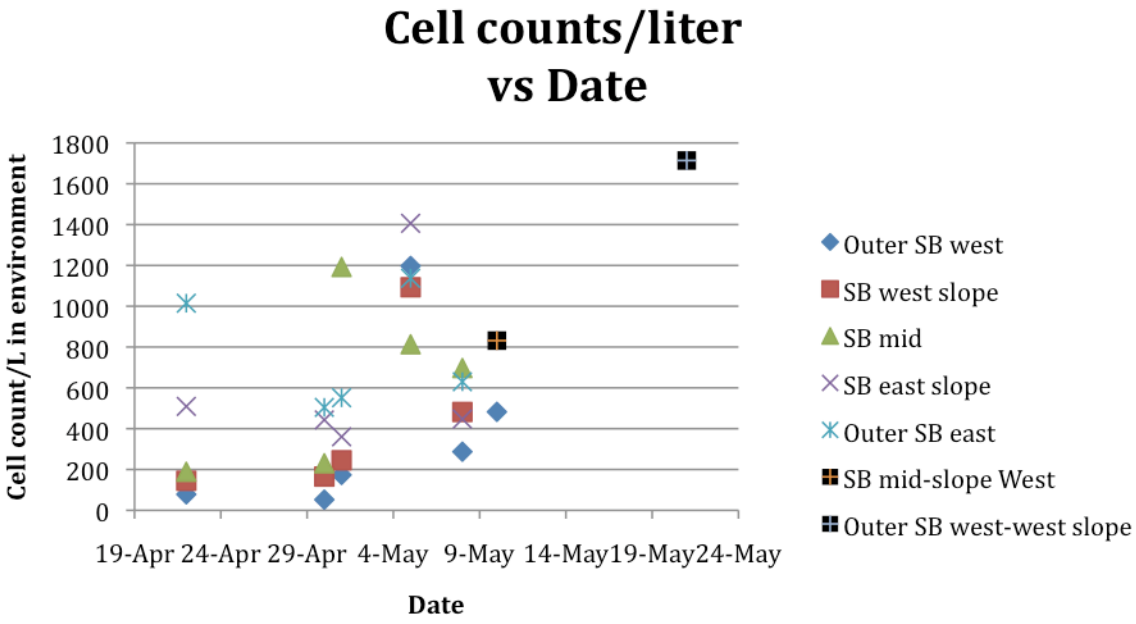


Figure 6. Scatter plot of cell counts per liter in the environment within each Salmon Bank sampling site over time. The two black symbols represent the samples taken while the Southern Resident killer whales were foraging.

To address the similarity of the sites, T tests assessed the average of each cell count per liter in the environment per sample site. Sample sites compared in t-tests were all of Salmon Bank, and False Bay. Table 1 contains p values for each of the comparisons. There was no significant difference between any of the sites compared (see Table 1.) that includes all Salmon Bank sites and False Bay as an outlier. Each Salmon Bank sampling site was averaged across all dates and analyzed with a t test against the mean cell counts per liter in the environment in False Bay samples. All p values were insignificant (>.05).

Site	outer SB west	SB west	SB mid	SB east slope	outer SB east	False Bay

		slope				
outer SB west					p=.1476	
SB west slope	p=.8122			p=.454	p=.1612	
SB mid	p=.3768	p=.4645		p=.9752	p=.5503	
Average SB						p=.7735

Table 1. Table with p values comparing mean cell count per liter differences between Salmon Bank and False Bay sample sites. All p values were insignificant (> .05) between Salmon Bank sites and False Bay compared to the average of cell counts over Salmon Bank.

Ebb verse Flood:

Tidal exchanges were categorized as ebb verse flood for all days for which cell counts were recorded. Cell counts per liter per site were binned as flood and ebb (figure 5). Figure 5 depicts higher cell counts during the samples taken on a flood tide compared to the ebb. Statistical calculations to see if there was a significant difference between the mean cell counts for ebb and flood cell counts per site were calculate by a t-test which were not found to be insignificantly different (p=.7735).

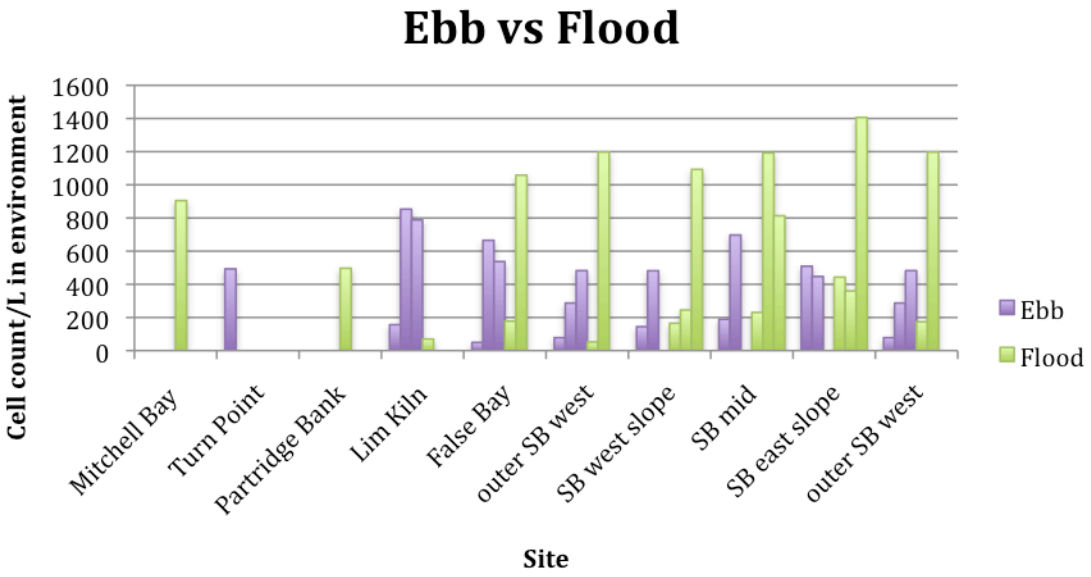


Figure 7. Graph of both ebb and flood cell counts per liter in the environment verse site.

Genus composition:

Cells were identified to the genus level for all horizontal net tows. Thalassiosira, Thalassionema, and Chaetoscerous were the most abundant genus's counted from transects (Figure 8-12). The toxin producer Pseudo-nitzschia is most abundant in the first week of sampling with the highest composition in Mitchell Bay, Lime Kiln and False Bay. Pseudo-nitzschia composition decreases over time while Thalassiosira dominates over every site and day. Skeletonema increases in composition over time and is most abundant in sample sites where the Southern Residents were foraging.

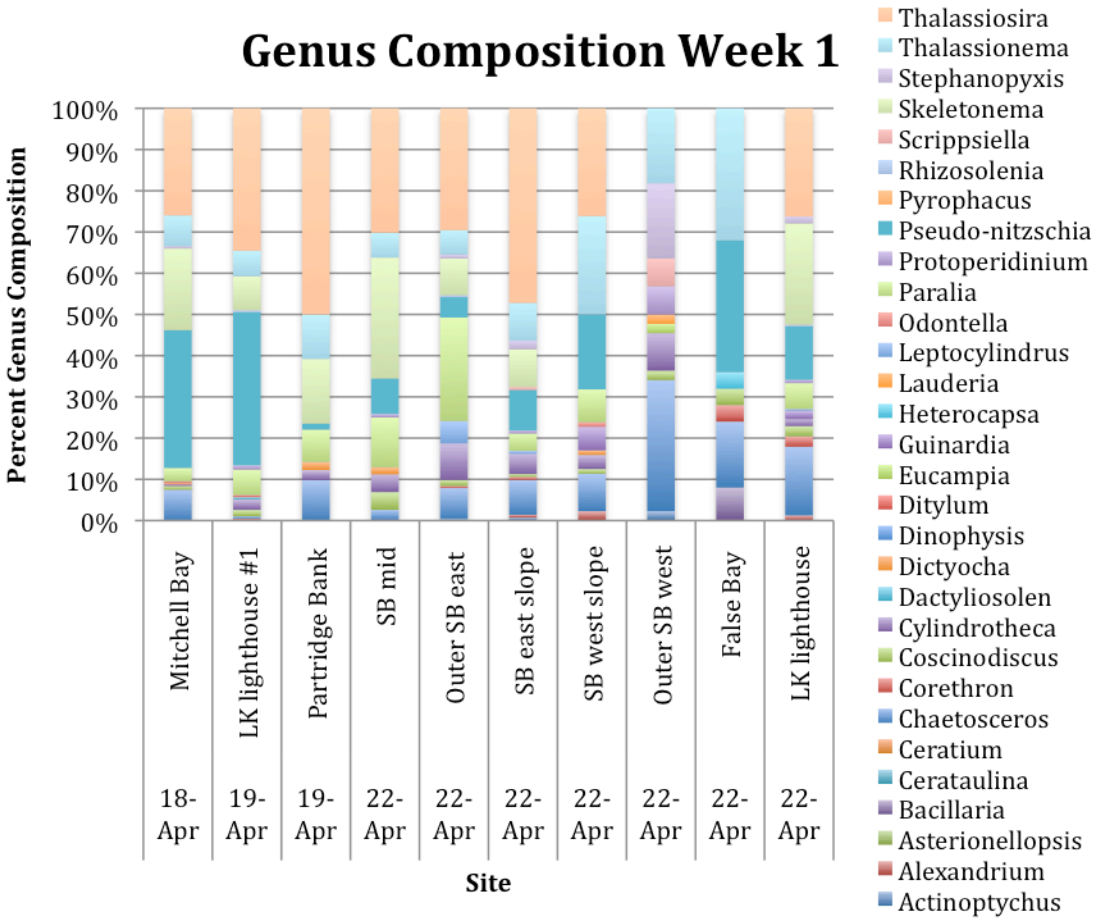


Figure 8. Percent genus composition of Mitchell Bay, Lime Kiln, Partridge Bank, east and west slope of Salmon Bank , outer east and west Salmon Bank, mid Salmon Bank and False Bay. Thalassiosira, Skeletonema, and Chaetosceros are the most dominant genus's present.

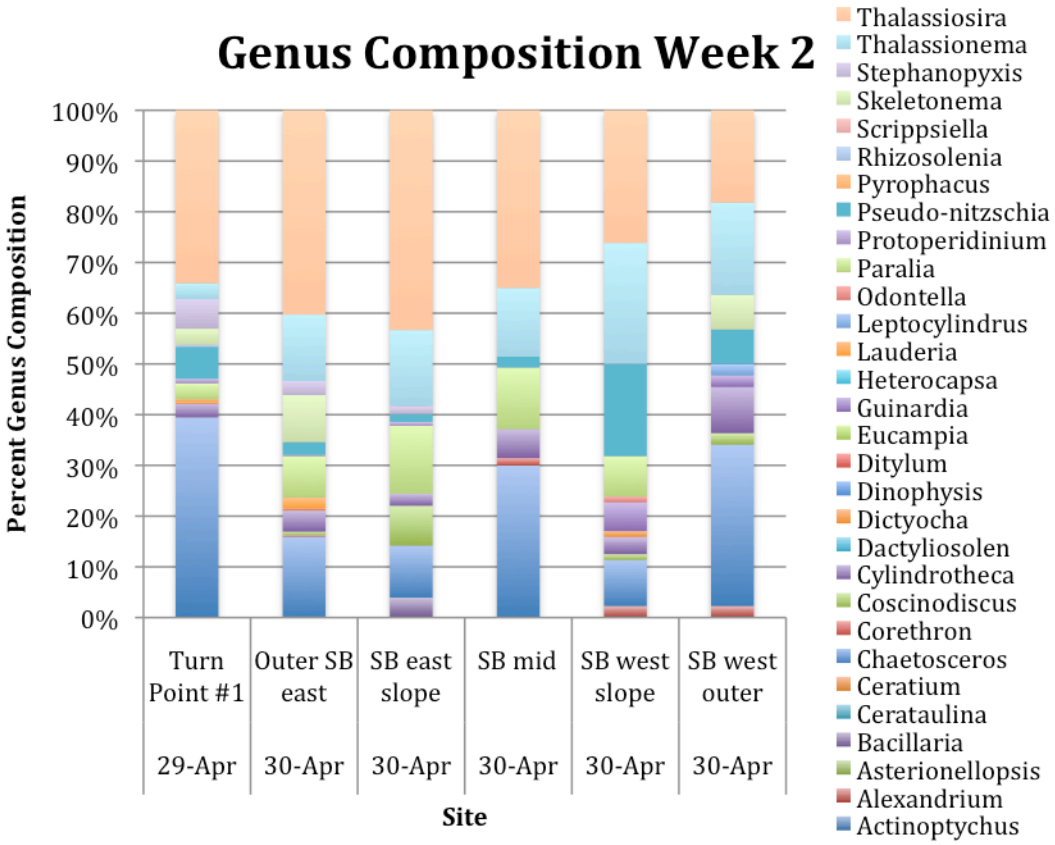


Figure 9. Percent Genus Composition for the second week of sampling for 5 sites over Salmon Bank. Thalassiosira is the most dominant genus present.

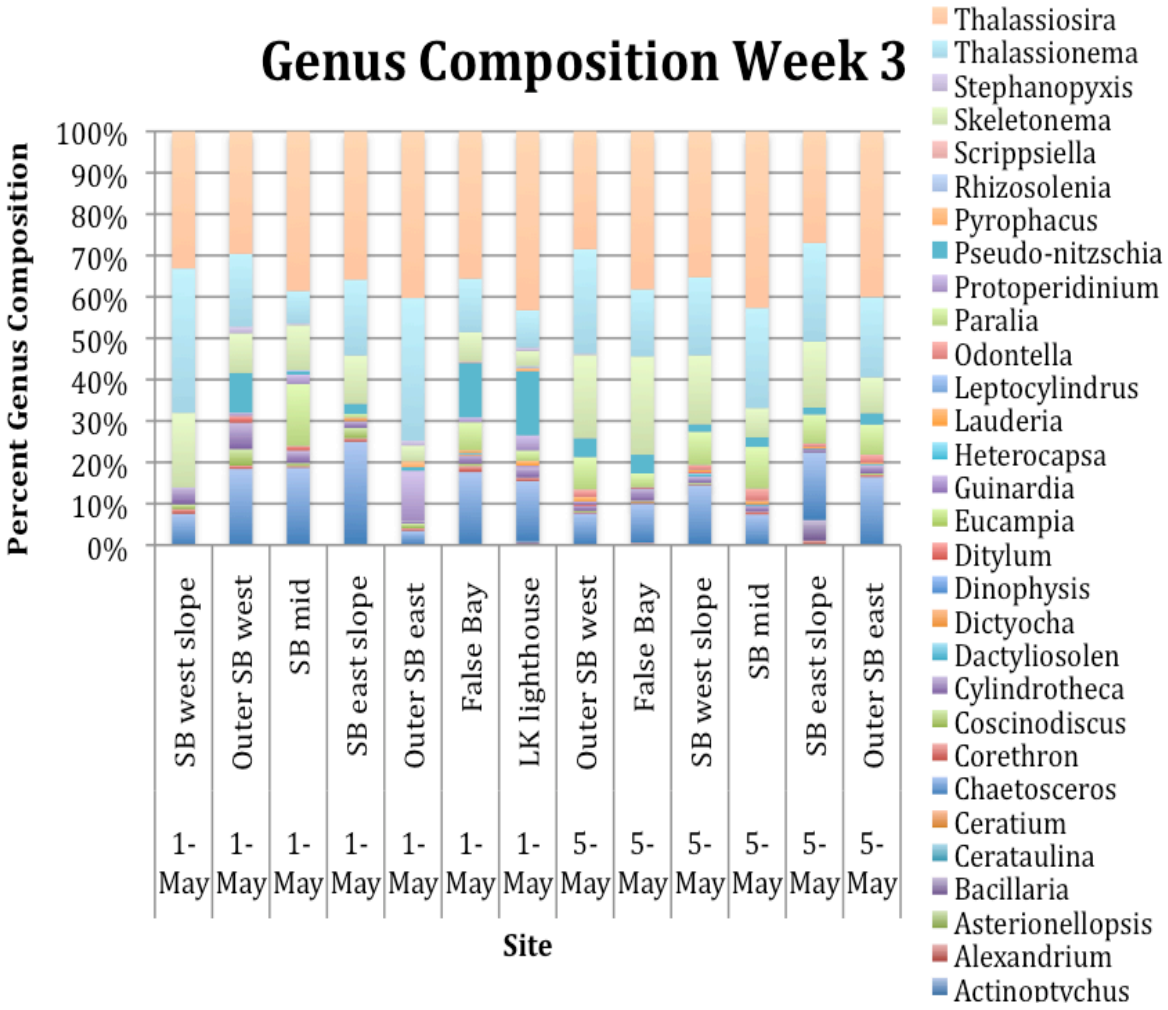


Figure 10. Genus composition percent for week 3 of sampling. Sites include all sites over Salmn Bank and False Bay and Lime Kiln.

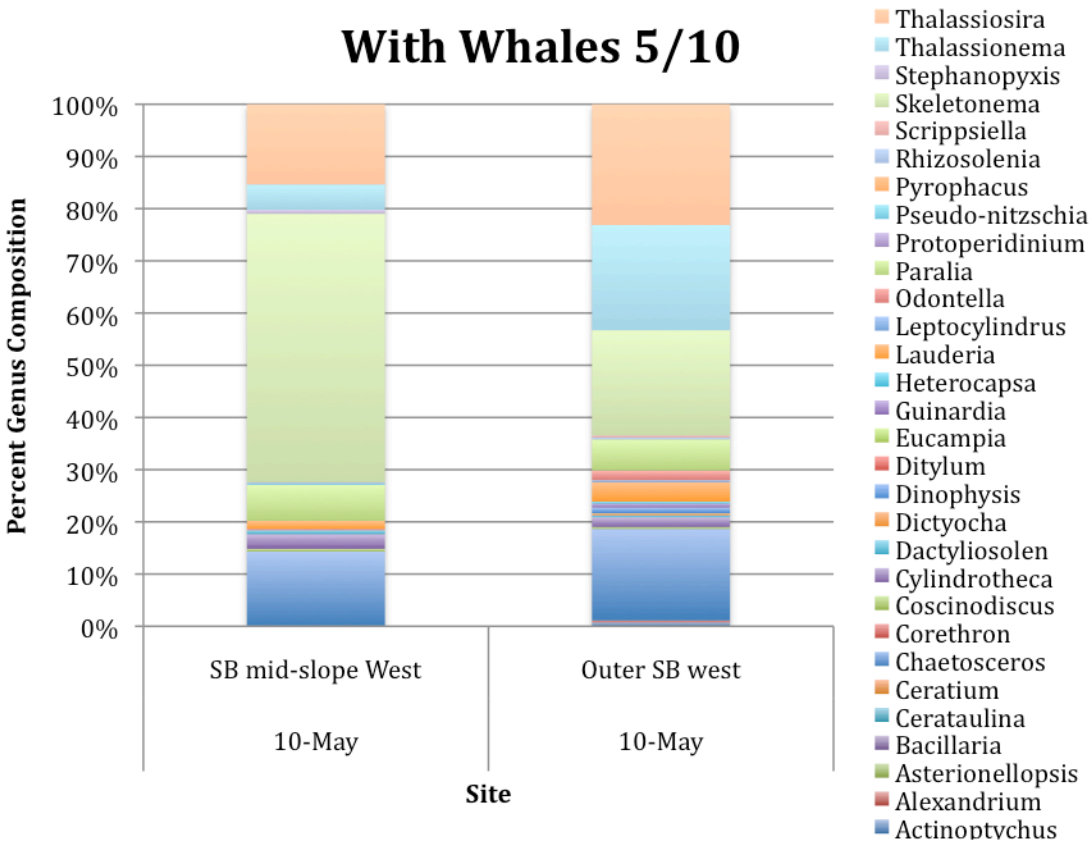


Figure 11. Percent genus composition when whales were present and foraging on April 10. The sample taken between Salmon Bank mid and the west slope of Salmon Bank is dominated by the genus Skeletonema.

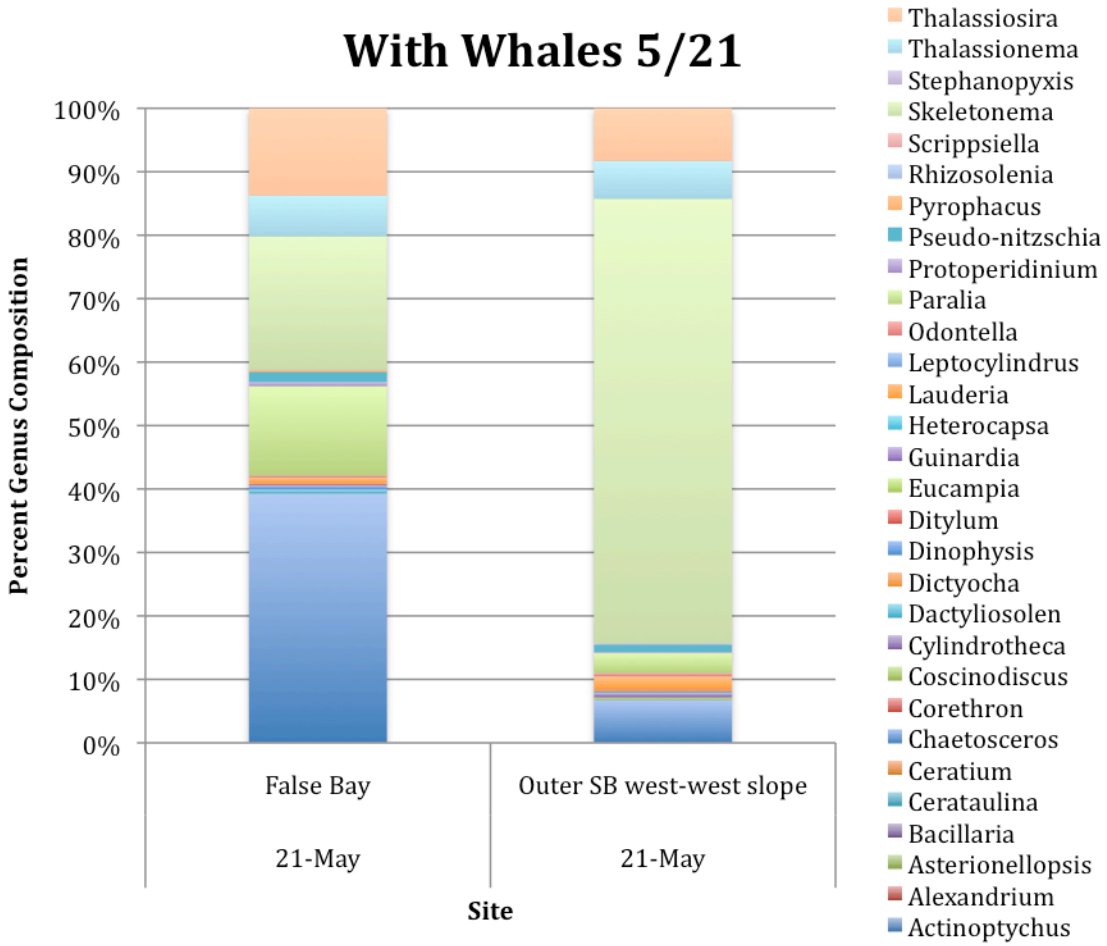


Figure 12. Percent genus composition on April 21 when Southern Residents were present and foraging. The sample between outer Salmon Bank west and the west slope of Salmon bank is dominated by the genus Skeletonema.

Fish finder backscatter:

Fish finder data was assessed by looking at general patterns in the presence of large targets. No large targets were identified in the 5 minute interval transects within each sampling site. Large targets were rarely observed outside of transects on site. Smaller targets were also not present in our exact transects, but could be identified outside of the 5 minute intervals. The highest percentage of backscatter was seen in the upper water column of biomass.

Discussion

CTD data:

Chemical variables measured did not contribute to difference in cell counts. Temperature, salinity and chlorophyll a concentrations in the upper 1 to 2 meter water column profile were consistent among sites. Johannessen et. al (2006) supports this result by examining the high turbidity region within Haro Strait. His study looked at the suspension of particles within the water column of Haro Strait and found that this is an area of intense particle mixing. Haro Strait's deep bathymetry and strong currents allow particles to be constantly mixed and suspended within the water column. These particles include nutrients, which play a vital role in phytoplankton production (Johannessen et. al, 2006). Our first expectation involving distribution of nutrients and particles was expected to differ based on the complex bathymetry along the west side of San Juan Island. Even if particles are well mixed within this area, flood and ebb tides could have distributed nutrients that originated from significantly different sources such as the Pacific Ocean or the Fraser River (Johannessen et. al, 2006). This study expected nutrients from the Fraser River fluxing south on an ebb tide around the west side of San Juan Island to hit the west slope of Salmon Bank and cause an upwelling of nutrients. This upwelling was hypothesized to cause a significant difference in cell counts along Salmon Bank. Our results of insignificant changes in chemical variables further support the strong currents present within the transect; especially within samples in close proximity to Cattle Pass where a large amount of water and strong currents are meeting at a small opening and shifting around San Juan and Lopez Island.

Chlorophyll a concentrations were not correlated with cell counts per liter in the environment. This was because the cell counts do not consider all other primary producers that are present. These primary producers were too small to count under the microscope, which led to their absence in final counts. Cynobacteria is an example of a primary producer that is abundant and hard to count under a microscope. Therefore, if chlorophyll a concentrations were expected to account for percent biomass, our cell counts would be less than the amount of biomass in the environment.

Cell counts/L per site:

All sites were insignificantly different from one another. This again supports CTD data that illustrates a well-mixed water column. No significant differences between sites means there is no primary productive 'hotspot' within the transect of study. The increasing trend of cell counts over time could be due to another variable not measured. Not only nutrients as mentioned earlier, but light is the other main contributor to phytoplankton productivity (Johannessen et. al, 2006). Most samples were taken within 5 days between the 18 of April and 21 of May, 2011, which means that the days were getting longer as samples were taken over time. A steady increase in cell counts in the environment could be due to the increased availability of light.

A continuation of this study would allow a trend to become more apparent or less significant in cell count data. More samples of each of these sites could also result in revealing primary productive hotspots. A suggestion for continuing sampling within the same transect would be to enlarge the amount of continuous

samples in an area of different tidal patterns compared to the west side of San Juan Island. The east side of San Juan would fit this definition and would serve as a comparable transect for finding primary productive 'hotspots'.

Ebb verses flood:

The average cell counts of ebb verses flood were insignificantly different. Despite differing bathymetry within the transect, ebb and flood contributions to upwelling and down-welling cell counts per liter expected on the east and west slopes of Salmon Bank were statistically insignificant. Ware and Thomson, 2005, found the same results in a study analyzing productivity off the coasts of Washington and British Columbia. They found that chlorophyll a concentrations were insignificantly different between upwelling and down-welling regions. This study suggested that insignificant biomass concentration differences between upwelling and down-welling regions indicates that factors other than wind-induced tidal exchange are vital for phytoplankton productivity (Ware and Thomson, 2005). In order to confidently conclude an insignificant relationship between ebb, flood and cell count, more detailed methods would need to be performed. Since there are varying strengths of flood and ebb tides throughout the day it would be beneficial to categorize tides based on strength. A study within Cattle Pass analyzed forage fish aggregations in comparison to pre-categorized strengths of the tide and succeeded in finding a correlation. They proposed a 'tidal coupling hypothesis' stating there are interactions between currents, plankton, and planktivorous fishes due to tidal phase (Zamon, 2003). Results showed that a flood tide was significantly associated with fish availability,

but also found that vertical distribution of plankton, temperature and salinity did not affect fish distributions. If our study could provide that missing link between tidal fluctuation and fluctuation of biomass, then lower trophic linkages could be further explained by environmental variables.

Genus Composition:

Genus composition fluctuates over time. Thalassiosira, Thalasionema, and Chaetoscerous were the most dominant species present among sites. These three genus species could thrive in these early Spring temperatures, and nutrient exchanges. Skeletonema was most dominant in samples taken when the Southern Residents were present and foraging. Another sample taken within the same week of the May 21 siting found a Skeletonema bloom to the north of San Jan Island. The timing of the increase in Skeletonema was at the same time the Southern Residents are present more frequently within the San Juans. This correlation was not explored further due to time constraints but it would be interesting to see if specific genus species of phytoplankton are more abundant when the whales are foraging more frequently in Haro Strait.

Pseudo-nitzchia was another genus that could be important to focus on in terms of change in composition over time. This toxin producer and cosmopolitan species has produced toxic blooms that can be harmful to the Southern Resident killer whale food chain. Pseudo-nitzchia seemed to be most dominant in the first two weeks of sampling, which could imply that during the peak foraging season pseudo-nitzchia is less abundant. Therefore our study implies there are no harmful effects of pseudo-nitzhia in our specific transect in the early Spring.

Fish finder backscatter:

An explanation for the absence of large targets during the sampling process may be that the samples did not correspond with the summer run timing of chinook returning to the Fraser River. Large targets that were rarely found outside of the 5 minute interval of our transect could have included the resident Blackmouth chinook that are annually within the Salish Sea. Fish finder backscatter of forage populations were unable to be identified due to time constraints, but comparisons to Horne and Gauthier (2004) who studied of fish populations in foraging zones of the Southern Residents led to the conclusion that smaller possible forage fish presence was also rare.

A suggestion for future methods of identifying forage fish populations would be to analyze foraging aggregations of birds. Zamon (2006) used this method to quantify forage fish populations in relation to tidal exchanges. Large target backscatter is easier to identify on a fish finder but trawls would be needed to conclude what species are present during time of sampling.

Conclusion

Overall, there were no hotspots present within our transect and there was an absence of large targets. This does not conclude that primary productive hotspots and fish yield are not linearly correlated. CTD data combined with insignificant difference among cell counts per liter in the environment among sites illustrate that the area to the west of San Juan Island is a well mixed and high tidal energy environment. Differences in bathymetry between Salmon Bank

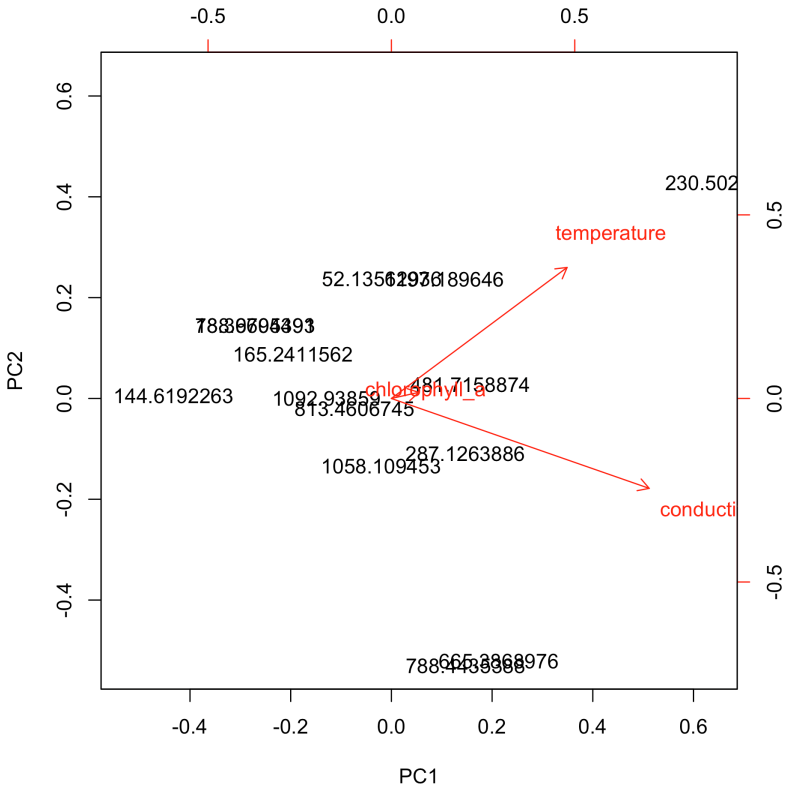
and the west side of San Juan do not have an affect on the distribution of phytoplankton because of this high energy system. Significance within these results could be found by an increasing the amount of samples taken over time and to include other transects that are in an area of different tidal patterns. An example would be to sample along a transect to the east of San Juan Island. Comparisons between cell counts to the west and east of San Juan Island might establish significant differences in cell counts and reveal primary productive hotspots.

The overall importance of this research project is to investigate a possible reason the Southern Resident killer whales are experiencing a decline. If bottom up affects have a greater affect on their population compared to top down affects that are currently a greater focus, then this could be valuable information for future research to expand on. NOAA fisheries will also have a greater amount of data about distributions of salmon in the Spring season, which could influence future forage area conservation for the whales. Foraging behavior is crucial to analyze because this activity is correlated with the location of prey (Gende and Sigler, 2006). A study on the foraging behavior of seals in relation to prey found that feeding was associated with oceanic ‘hot spots’ or areas of high primary productivity (Gende and Sigler, 2006). Our project aims to analyze these components around the western coast of San Juan Island and Salmon Bank and compare our results to other areas of high primary productivity and fish densities within and outside of the observed forage zone of the SRKW’s to test the significance of our conclusions. Another result is a

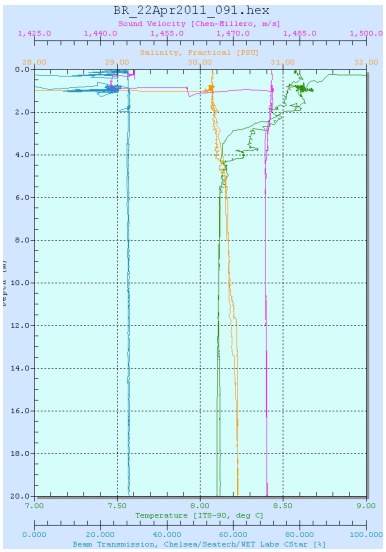
better understanding of environmental processes within the southern region of the San Juans. Recent concerns of increased temperatures have immediate effects on these processes that directly affect marine organisms. Therefore, our data will also contribute to updating the status of the San Juan Islands marine environment.

Appendices

PCA for temperature conductivity and chlorophyll a:



CTD cast 4/22 over outer Salmon Bank:



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