UNIVERSITY OF WASHINGTON FRIDAY HARBOR LABRATORIES

Effects of water source and mixing on phytoplankton dynamics within a tidally influenced system

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Phytoplankters are primary producers and an important energy source within pelagic nearshore habitats. The growth of these organisms is affected by riverine-oceanic interactions. A measurable interaction over 24 hours is the density difference between these water sources, where less-dense riverine water is warmer and has lower salinity. Ebb currents enhance the advection of riverine output, placing it on top of the oceanic water and creating stratification. Primary production increased during stratification periods, but reduced when transitioning between a flood and ebb current. Visual analysis of phytoplankton community composition also highlighted increases in the population during high ebb and flood current rates. The large increase in Skeletonema population during this study suggested that the movement or growth of certain phytoplankton genera are affected by these water source interactions. This study concludes that since changes happen within the water column over a short period of time, an entire tidal exchange must be monitored before any conclusions can be made about the water column or its occupants.

INTRODUCTION

Particulate organic matter (POM) is composed of plankton, degraded algae, and miscellaneous detritus. While algae provide the basis for food webs within the photic zone, POM may be a primary source of nutrition for nearshore benthic and pelagic primary consumers (Britton-Simmons et al., 2009), as well as for food webs below the photic zone. POM in nearshore habitats may be primarily composed of phytoplankton (Page et al., 2008); however, other sources have reported that POM may also be composed of algal and particulate detritus (Duggins et al., 1989). Phytoplankton productivity is affected by environmental factors in the water column such as salinity, temperature, light, and nutrient availability. These factors ultimately influence the density and taxa of phytoplankton. Oceanic and riverine water sources affect the abundance and type of nutrients that feed into the nearshore habitat, and drive the variation in phytoplankton blooms at certain times of the year.

The mixing of water sources by tidal influence within nearshore habitats creates a turbulent environment where the water column is well-mixed. Previous nearshore phytoplankton studies have concluded that water-source mixing can influence phytoplankton dynamics (Chen et al., 2005; Epply, 1979; Wetz et al., 2006). Harrison et al. (1991) found that the Fraser riverine plume was important for mixing nutrients into the Strait of Georgia. While riverine water may not contain large amounts of nutrients or POM (Harrison et al., 1991), they can influence the composition of the local marine bodies that they feed into via nutrient mixing (McManus et al., 2003) and stratification. Harrison et al. (1991) found phytoplankton primary productivity was affected by mixing between Fraser and oceanic water, which brought nutrients to the surface and created an environment where phytoplankton could grow. In other studies, the physical force of the river contributed to the dispersion of POM. These studies focused on the influence of nutrient upwelling on phytoplankton communities within saltwater estuaries or shallow tidal areas (Chen et al., 2005; Wetz et al. 2006), thus their results cannot be qualified to describe an environment such as that of the Salish Sea, which has a vastly greater volume of water and different hydrodynamic regime. These same studies concluded that a short-term, hourly study was

needed to better understand how the mixing of sources influenced phytoplankton dynamics (Harrison et al., 1991; Chen et al., 2005; McManus et al., 2003).

My study explored how POM in the Salish Sea is influenced by the interaction of riverine water and oceanic water. I observed the density and taxa of phytoplankton found in the surface layer of the water column over multiple tidal exchanges. By analyzing phytoplankton samples for density and composition and comparing them to salinity, chlorophyll concentration, and nutrient samples taken from the water column, it is possible to determine to what extent the riverine water is influencing the Salish Sea phytoplankton population on the order of an hourly time scale. The riverine water was expected to alter the water dynamics within the sampling area by changing the density of the water column, which was in turn expected to alter the composition of the phytoplankton community in the sampling area. The data gathered during this sampling should shed further light on how tidal mixing of oceanic and riverine sources influence the density and composition of the phytoplankton community.

MATERIALS AND METHODS

Measurement Site and Date. The target area (48.739776, -123.003273) off of Skipjack Island, WA, is within the Salish Sea, centrally located between the Strait of Georgia and the San Juan Archipelago. The location was chosen because it is potentially influenced by the riverine flow of the Fraser River and oceanic water from the Strait of Juan de Fuca. Sampling was conducted between 14:00 on May 3 and 14:00 May 4, 2012. The predicted currents are measured as ebbs (-) and floods (+), and for this period were semidiurnal, with a -2.71 m/s maximum ebb current and a +1.83 m/s maximum flood current (***Figure 1***). The predicted current speed was used since dynamics within the water column are more likely to be affected by the water velocity.

POM Sampling Strategy. Stationary sampling was conducted aboard the R/V *Centennial*. The boat was anchored at the target area and powered down. A conductivity, temperature, and density

meter (CTD) with 9 Niskin bottles was lowered to between 90 and 100 m to gather data on the water column. The CTD gathered continuous readings of temperature, chlorophyll (Chl. A) (as a way to measure biomass), and salinity from the surface to a depth of 100m, or 10 m from the bottom of the sampling site. These data were interpreted relative to the output volume of the Fraser River, which is independently monitored by the Canadian Ministry of the Environment (the specific sensor is located in Hope, B.C., CA, just before the River splits and enters the Strait of Georgia). My water samples were collected every 1m from 10 m to the surface. Samples of 2 L from each depth were placed in a carboy and gently homogenized. Using a water pump fitted with 20 micron filtration netting, the homogenized sample was concentrated to 500 mL from which 45 mL of the concentrated sample was taken and preserved with Lugol's solution for community composition and cell density analysis. A total of 13 tows were conducted over the span of 24 hours.

Nutrient Samples. After homogenizing the water samples from the upper 10 m during Tows 10 and 13, three replicates for each tow were collected from the filtered water coming from the water pump and filtered a second time using a 0.45 micron syringe. The samples were analyzed and measured for nutrient content by the University of Washington Marine Chemistry Laboratory.

Data Analysis. The POM samples were analyzed under a compound microscope. Phytoplankton were identified to genus and enumerated. These data were compared to the CTD data and patterns of change throughout the tidal cycle.

RESULTS

Riverine and Oceanic Interactions. CTD results from the tows (***Figure 1***) indicate a significant interaction between the oceanic and riverine sources within the surface layer (CTD profile data not shown). Although there was no quantitative measure of current speed, a visual inspection confirmed that the peak ebb and flood currents were proportionate to those velocities seen in **Figure 1**. The Fraser River had an average flow of 5,910 m^3/s over May 3rd and 4th, nearly doubling the flow from the same dates in previous years 2010 and 2011 (***Figure 2*****,** data courtesy of the Canadian Ministry of the Environment). My data indicate that this influx of fresh water into the oceanic system had notable effects on the temperature and salinity of the surface water. The significant correlation of these factors is illustrated in **Figure 3**, which is indicative of mixed water sources. The average temperature and salinity over the first 10 m of the water column were found to be significantly positively correlated (linear regression, p = 0.002) (***Figure 3***). The maximum temperature was 8.56 dC and salinity was 29.51 during the maximum ebb current, while during the highest velocity flood current, the temperature reached 8.41 dC with a salinity of 30.00. These data indicate that denser oceanic water was also generally colder, while warmer waters had a lower salinity.

Salinity and temperature affect Chl. A, which is used as a proxy of phytoplankton biomass (***Figures 4 and 5***). The measured salinity did not have a statistically significant relationship (p = 0.185) to Chl. A; However, the graph shows that on average, tows with a salinity above a maximum of 30.14 generally had Chl. A density of less than 4 ug/L (***Figure 4***). For tows with a salinity of less than 30.14, the Chl. A was above 4 ug/ L. The outlying point at 9.43 ug/L is also included in this spectrum and represents ideal growing conditions, corresponding to the highest temperature recorded during the tows (***Figure 5***).

Biomass trends tended to follow temperature patterns (***Figure 5***). The relationship between Chl. A and temperature were shown to be statistically significant (linear regression, p = 0.005).The data suggests that even a marginally higher water temperature yielded a greater Chl. A during those tows,

eventually peaking during Tow 10 (8.56 dC), which was taken during the peak ebb tide (-2.71 m/s). The relationship between, Chl. A and current speed was significant (linear regression, p = 0.039), where Chl. A was consistently higher during ebb flow than the flood.

Nutrient Sampling. Water samples taken from the homogenized water column indicate that the ebb current during Tow 10 had lower nutrient concentrations than the Tow 13 oceanic flood current (***Table 1***).

Determining Composition of Biomass**.** The total number of phytoplankton counted from each of the 13 visual analysis samples fluctuated with the tidal cycle, with numbers ranging from 216 to 4,380 cells. Chl. A was correlated with total cell counts (linear regression, p = 0.001), indicating that the visual analysis samples were an accurate representation of the phytoplankton community being sampled. Temperature (linear regression, p = 0.084) and salinity (linear regression, p = 0.215) showed weak correlation. Current speed and cell counts per tow showed an insignificant correlation when outlying points were included (linear regression, p = 0.238), but a higher correlation (linear regression, p = 0.004) when they were not. **Figure 6** displays the percent composition of the 26,242 total phytoplankton counted. The most dramatic increases in cell counts were at Tows 4 (2,772 cells) and 10 (4,389 cells), both of which were taken during the stratified ebb current (-1.71 and -2.71 m/s, respectively). The second two significant peaks occurred during the highest flood currents of Tows 7 (3,262 cells) and 13 (3,172 cells) (+1.26 and +1.83 m/s), which were periods of turbulent mixing between waters of different salinity densities. The temperature during Tow 10 was the highest recorded during the 24-hour sampling.

Plankton community composition remained relatively even over the first 3 tows, with the representative genera *Skeletonema* and *Chaetoseros* only differing by an average of 3.5% (***Figure 6***). The presence of *Skeletonema* increased over *Chaetoseros* by 34.9% during Tow 4 and remained the dominant genera for the remainder of the study, decreasing to 45.3% of the total cell count of Tow 9

and reaching a maximum of 66.9% of the total during Tow 11. Peak cell counts occurred during maximal current speeds (***Figures 6 and 7***). Comparing composition to current speed, *Skeletonema*'s percentage increased on or just after the ebb in Tows 4 and 11 (***Figure 7***). *Skeletonema* composition was reduced during heavy mixing between Tows 3 and 4, then again between Tows 8 and 9 (water column profile data not shown). *Skeletonema* percent composition remained consistently high during the exchange from ebb to flood current following Tow 3 (***Figure 7***).

DISCUSSION AND CONCLUSIONS

The voluminous output from the Fraser River and the heavy ebb current observed at the sampling site influenced the pelagic ecosystem in the Salish Sea. This assertion is supported by both the salinity and temperature of the water measured during the high-ebb tide cycles. The southward movement of water during the ebb brought lower salinity water into the sampling area, stratifying the water column. Likewise, the temperature readings were measurably different in the surface layer than deeper in the water column. These dynamic patterns of stratification and mixing were observable over the course of a single tidal exchange.

Most photosynthetic organisms grow better in warmer environments due to improved or accelerated metabolic function (Staehr et al., 2006). The concentration of biomass was located primarily where waters were warmer and salinity was lower within the water column (***Figure 3***). An explanation for this observation is that the lower density riverine water flowing over the oceanic water stratified the water column and reduced the depth of the mixed layer, thus increasing those organisms' exposure to sunlight and allowing them time to reproduce, as opposed to phytoplankton residing in lower strata in the water column which have less exposure to light. During mixing between the oceanic and riverine systems, Chl. A would generally increase throughout the water column. An explanation for this

observation would be that the Chl. A generated in the upper layer during stratification was being mixed back into deeper water during the flood tide sampling.

Harrison et al. (1991) reported that the Fraser River plume was not a primary source of nutrients itself, but the force of the water output upwelled benthic nutrients that correlated to increased primary production during tidal mixing, making the edge of the riverine plume highest in primary productivity. In this project, it was observed that primary production (as measured by Chl. A) increased during the heaviest ebb, yet the nutrient samples analyzed reported fewer nutrients in the ebb current water than the oceanic flood. This evidence suggests stratification within the water column enhanced phytoplankton growth in the upper layers and allowed them to consume the nutrients within the plume.

The comparison between total cell count and current speed was found to be statistically insignificant when including the outlying data points on the 7^{th} and 13^{th} tows, yet displayed a better correlation than Chl. A when these points were removed. This disparity can be explained by less photosynthetic activity during night (Tow 7) where more growth may have taken place, and the heavy mixing that homogenized the water column on the incoming flood tide during both these tows. Another explanation would be grazing by nocturnal predators.

Several trends observable within the taxonomy data suggest a discreet bloom of *Skeletonema*. The increase in total number of cells follows a dramatic increase in the genus' percent composition, while other genera of phytoplankton did not demonstrate a similar pattern. The decrease in total cells during the 9^{th} tow follows the decrease in *Skeletonema* percentage, which suggests the advection of these cells out of the sampling area. The advection explanation is more likely, as it seems improbable for such a bloom to occur within the span of two hours between Tows 3 and 4. The fluctuation in *Skeletonema*'s percent composition near Tow 9 can be interpreted as the return of the concentrated *Skeletonema* patch to the sampling area following the emigration during the flood tide between Tows 6 and 8.

The goal of this project was to determine the relationship between water dynamics and phytoplankton community composition and movement. The data are consistent with the hypothesis that water density and temperature controls biomass production. The connection between those environmental factors and biomass is evident in both the increase in cells over time, as well as the fluctuating composition of genera over time. Specific water parameters, such as the stratification of the water column, seem to correlate to phytoplankton growth and movement. Consecutive studies such as this one, over the span of a year, would yield useful results to further clarify these results. Studies such as this are also useful in the case of private industries such as biofuels and farming, which in their infancy suffered from a lack of information on how to produce products without the proper nutrients or environmental triggers. With an economic focus, future endeavors would focus more on nutrient sampling in comparison to species growth as a way to influence fatty acid production, which is valuable to biofuel and medical industries. More practically, results show that surveys and experiments conducted within a tidally influenced system must consider the spectrum of water dynamics during a full tidal exchange before any conclusions can be made about the composition of the water column or its inhabitants.

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FIGURES:

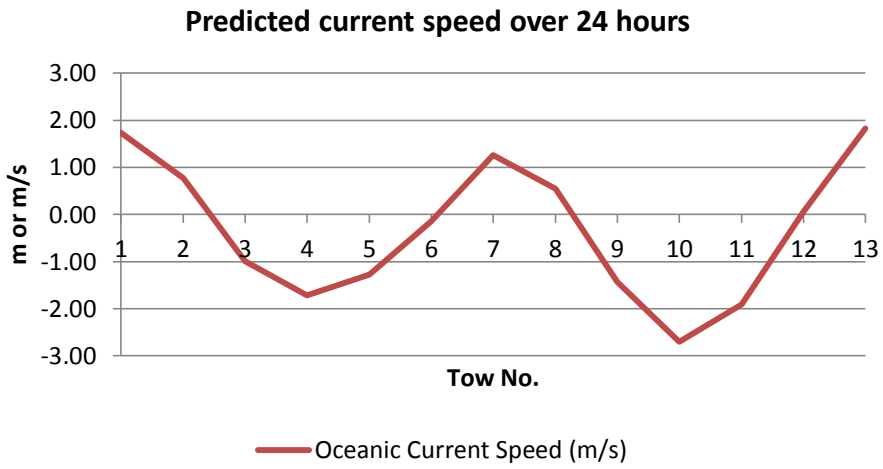

Figure 1: *Graphical representation of current speed during sample tows.*

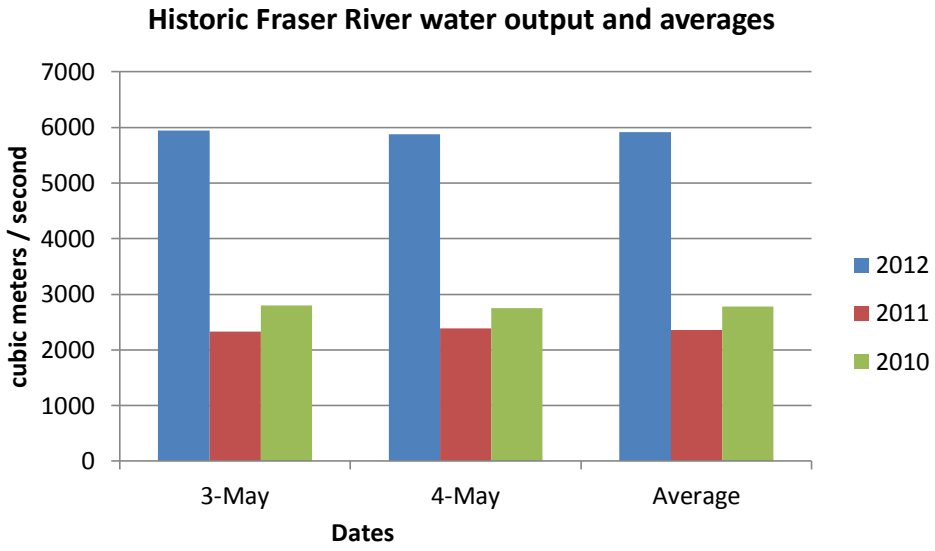

Figure 2: *Graphical comparison of the Fraser River's flow rate on May 3 and 4 over the past three years (2010 – 2012). The output of water in 2012 nearly doubled that in 2011 and 2010, which is also evident from the averaged water output from these two days.*

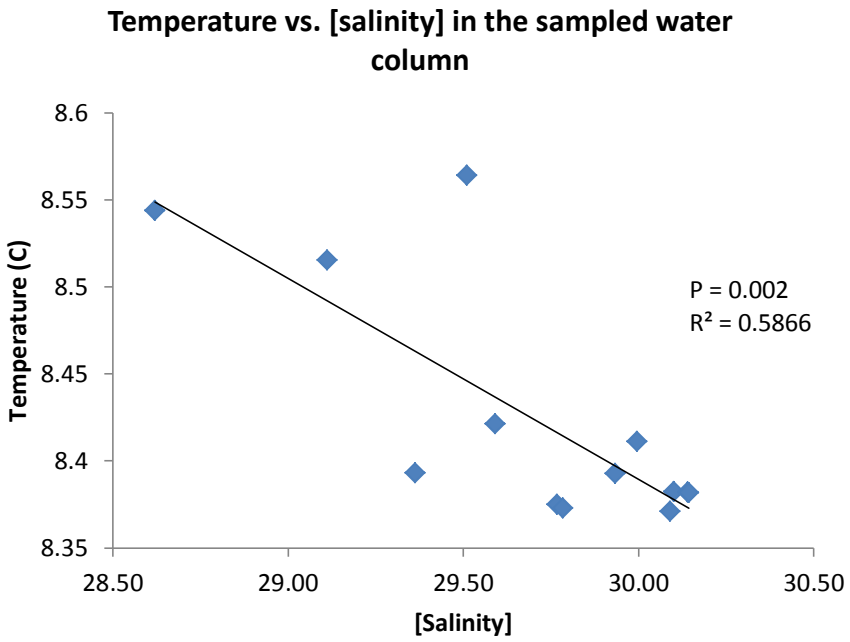

Figure 3: *Correlation of temperature and salinity in the upper 10 m of the sampled water column. These descriptors show a high correlation (p = 0.002).*

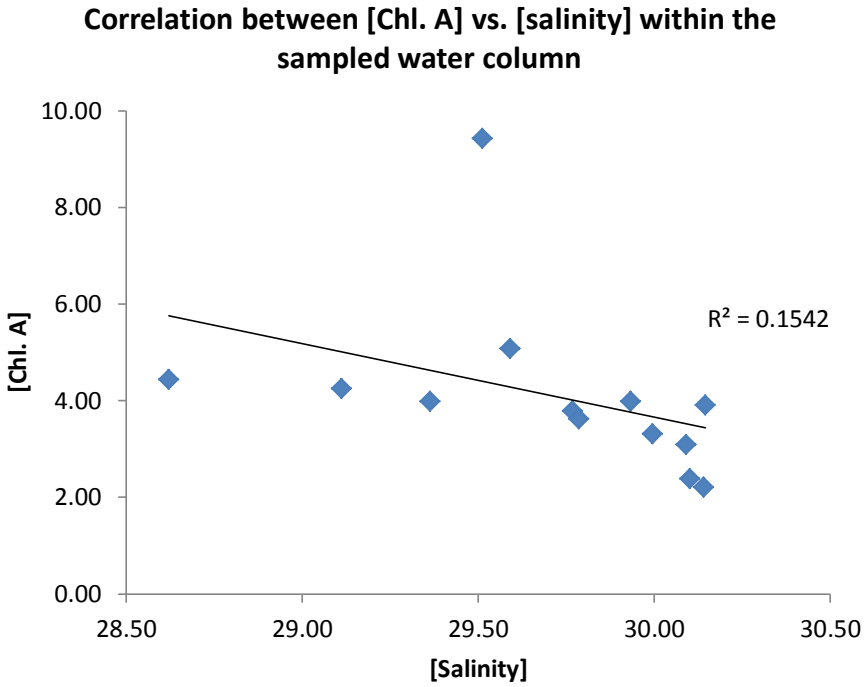

Figure 4: *Correlation between Chl. A and salinity in the upper 10 m of the sampled water column. The relationship between the two variables is more complicated than a linear regression illustrates.*

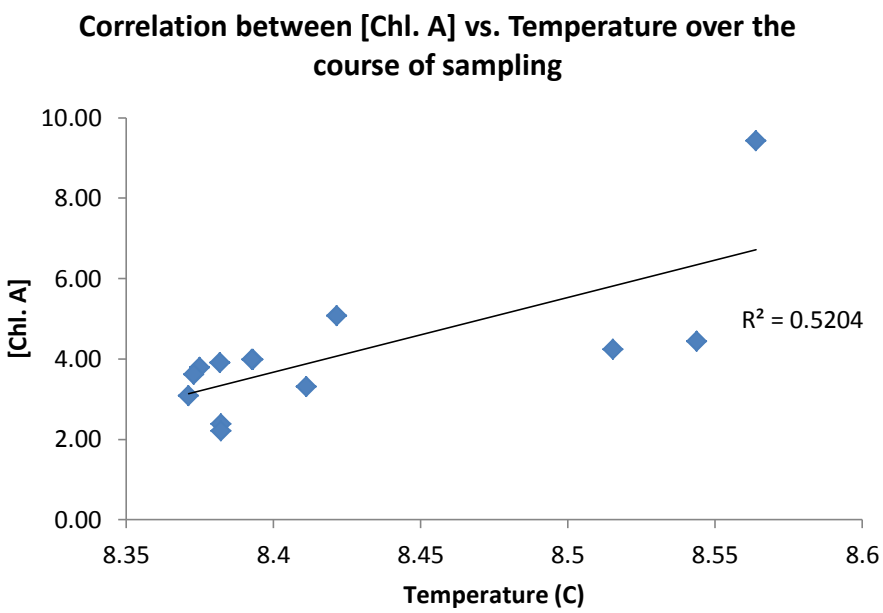

Figure 5: *Correlation between the Chl. A and temperature in the upper 10 m of the sampled water column. The correlation suggests that higher temperatures yield a greater density of Chl. A, or biomass.*

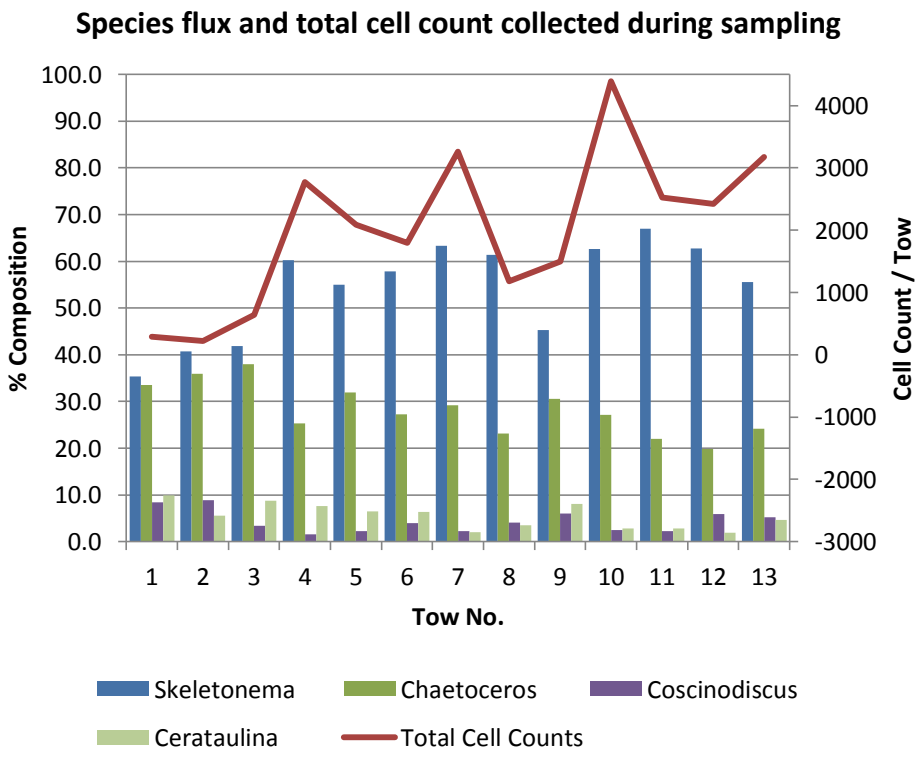

Figure 6: *The total cell count per tow is overlaid on the percent taxa composition of each tow. Note the dramatic percentage increase in* Skeletonema *during the* 4^{th} *and* 10^{th} *tow.*

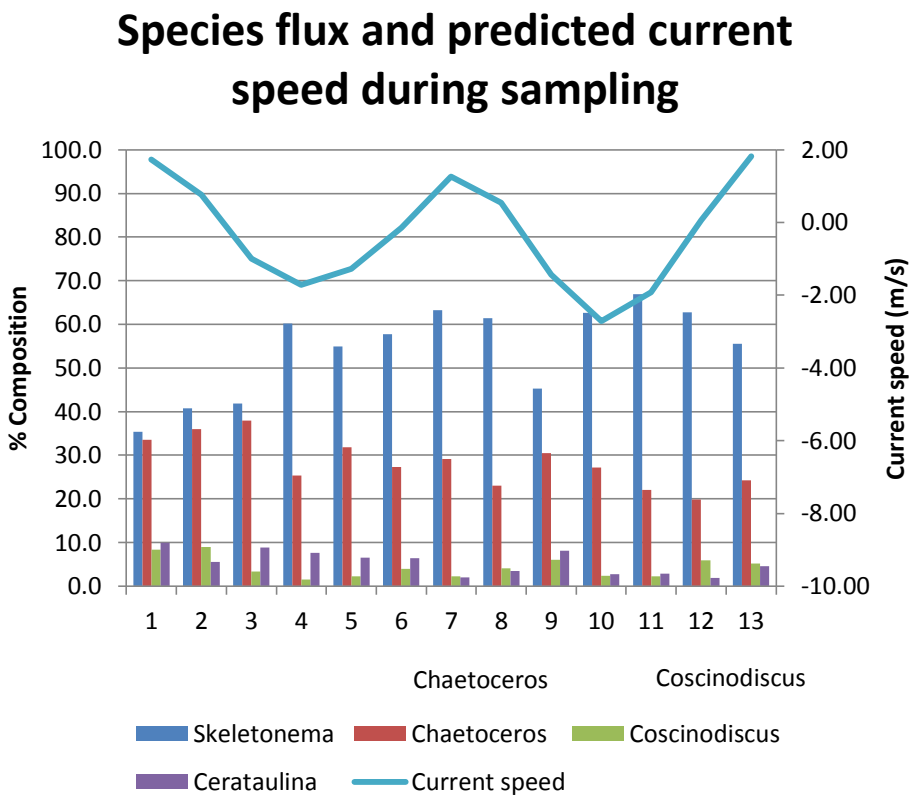

***Figure 7**: Predicted current speed is overlaid on the percent composition of taxa recorded from each tow. Note the decrease in* Skeletonema *percentage during periods of mixing (Tows 3, 9, and 13).*

TABLES:

Nutrient	Tow 10 (Ebb)	Tow 13 (Flood)	P-Value
[PO4-P]	57.1	60.8	0.001
[SiO4-Si]	981.9	1024.3	0.007
[NO3-N]	277.2	292.9	0.001
[NO2-N]	3.1	3.3	0.001

***Table 1:** Average nutrient composition of the ebb and flood tide. Results indicate that the ebb was less nutrient-dense than the flood current and that their relationship is statistically significant.*