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Computation in the Physical Sciences

On the Edge of Discovery:

Zooplankton Abundance in the Discovery Passage

**Abstract:**

Plankton forms the basis of marine food webs globally (Beamish & McFarlane, 2014). In the Strait of Georgia, spring plankton bloom timing and abundance is paramount to the success of many upper trophic level populations, especially pacific salmon. Here we explore the spring zooplankton bloom in the Discovery passage, a complex salmon migration route, to determine the affects of sea surface temperature and significant wave height on bloom success. However, we found zooplankton abundance is generally not well correlated to either sea surface temperature or significant wave height in the narrow discovery passage.

**Introduction:**

At the basis of marine food webs are microscopic organisms that float with the ocean currents, known as plankton. Both zooplankton (those requiring respiration) and phytoplankton (those requiring photosynthesis) provide food for upper trophic level organisms and support marine ecosystems globally (Beamish & McFarlane, 2014). In the Strait of Georgia, phytoplankton typically undergo a large bloom at the beginning to middle of spring when the water begins to stratify and the amount of sunlight exposure increases (Beamish & McFarlane, 2014). Similarly just after this bloom of phytoplankton, the Strait undergoes a zooplankton bloom (Beamish & McFarlane, 2014). The timing of this spring bloom is paramount to many marine organisms in higher trophic levels, including juvenile Pacific Salmon (Beamish & McFarlane, 2014). Recently there have been changes in the timing of spring phytoplankton and zooplankton blooms in the Strait, which scientists attribute to climate change. Ultimately this has complicated the migration of Salmon out of the Strait, as well as their early development (Johannessen & McCarter, 2010; Allen & Wolfe, 2013). In addition, researchers have recently proposed that the lack of primary productivity in narrow and turbulent migration passages out of the Strait puts further stress on these young migrating Salmon, as they encounter a lack of food. This combination of the annual bloom variance in the narrow migration passages is a particularly new and mysterious area of research, which is still underexplored. For my Keystone I want to explore the feasibility of predicting the timing and strength of plankton blooms in the Discovery passage using a common oceanic productivity model known as NPZ (Nutrient, Phytoplankton, and Zooplankton) model (Franks, 2002). Creating an NPZ model and analyzing the output is outside the scope for this 3-week project. However, a complex and accurate NPZ model includes variables and parameters that account for the biotic factors as well as abiotic factors (Franks, 2002). Many of the biotic factors and relationships are addressable through the literature, however the abiotic factors in this region are somewhat understudied. Thus the primary motivation for this project originates from a necessity to understand the abiotic affects on plankton in the Discovery Passage. Since plankton growth is heavily affected by both vertical water turnover and temperature, we examine the multivariate relationship between sea surface temperature, wind driven vertical turnover and Zooplankton abundance in the narrow Discovery Passage. Unfortunately, vertical turnover is extremely difficult to measure, even wind driven vertical turnover, therefore we use significant wave height as a proxy for wind driven vertical turnover.

**Methods:**

In order to examine these multivariate relationship between sea surface temperature, wind driven vertical turnover and Zooplankton abundance, we employ two main methods; time-series analysis of all three variables for the spring bloom seasons 2009-2012, and multivariate linear regression on these same spring bloom seasons. Data for analysis came from two sources; Environment Canada and Department of Fisheries and Oceans/BC Centre for Aquatic Health Sciences. Sea surface temperature, and significant wave height data were collected every hour at Sentry Shoals buoy in the Northern Strait of Georgia, and recorded by Environment Canada (Figure 1.). Zooplankton Abundance was collected approximately twice per week in the Discovery Passage near the Campbell River Warf (Figure 1.). The Department of Fisheries and Oceans executed the collections and the data was recorded and analyzed by the BC Centre for Aquatic Health Science. Zooplankton collections only occurred during the spring bloom seasons in 2009, 2010, 2011, and 2012. The spring bloom season for each year is outlined in table 1.

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Figure 1. Displays a Google Earth map showing the data collection sites (Sentry Shoals Weather Buoy and Discovery Passage Shoreline) in relation to each other.

|  |  |  |
| --- | --- | --- |
| **Year of Collection** | **Start Date** | **End Date** |
| 2012 | 2012-03-30 | 2012-07-01 |
| 2011 | 2011-03-07 | 2011-07-03 |
| 2010 | 2010-03-03 | 2010-6-28 |
| 2009 | 2009-02-24 | 2009-07-05 |

Table 1. Shows the start and end date of the spring bloom season zooplankton collections.

All sea surface temperatures were measured in ° C, significant wave heights were measured in meters and Zooplankton Abundance was measured in zooplankton per meter cubed.

Before we explored the multivariate relationships between sea surface temperature, significant wave height and Zooplankton Abundance, we conducted a short statistical analysis of the relationship between sea surface temperature and significant wave height. The relationship was explored to confirm, as well as gain a better understanding of the trends of the environment in which the zooplankton live. And since sea surface temperature varies closely with air temperature, we were able to make it a proxy for seasonal change. We could then set the sea surface temperature as a control variable to examine the pattern of significant wave height throughout the year. We then plotted and performed linear regression on this relationship for monthly averages occurring between 2009 and 2012. Time-series analysis for sea surface temperature, significant wave height and Zooplankton Abundance was performed using weekly averages of the data during the spring bloom season. We then performed interactive multivariate linear regression on the three variables for each spring bloom season between 2009 and 2012. The goal of this regression was to examine the affects of sea surface temperature and significant wave height on zooplankton abundance. The code to perform data munging, plotting and statistical analysis was developed using ipython notebook. The notebook and script is viewable through the following link: <https://github.com/kwfawkes/Kyles_project>.

**Results:**

**Sea Surface Temperature & Significant Wave Height**

Sea surface temperature and significant wave height in the Northern Strait of Georgia display a negative relationship for a monthly timescale between 2009 and 2012. The linear model revealed a linear regression slope of -0.028. This means that for every degree of increase in average monthly sea surface temperature, the average monthly wave height will decrease by 0.28m on average. The model also revealed an value of 0.496 (Table 2.), meaning that approximately 50% of the variability in the significant wave height is explainable by the variation in sea surface temperature. We reject the null hypothesis for this relationship, since the p value for the relationship between the variables is less than 0.05 (Table 2.). Therefore, the correlation in this negative relationship between sea surface temperature and significant wave is statistically significant.



Figure 2. Shows the linear regression model and relationship between sea surface temperature and significant wave height between 2009 and 2012. Data observations were averaged monthly during the timeline.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Stat** | **Test** | **Timeframe** | **Variable** | **Value** |
| P-value | Linear regression | 2009-2012 | Constant | 6.77E-17 |
| P-value | Linear regression | 2009-2012 | Sea surface temperature | 4.73E-08 |
| R-squared | Linear regression | 2009-2012 | R-squared | 0.495972815 |

Table 2. Shows the R-squared and p-values for linear model of the relationship between sea surface temperature and significant wave height. Relationship is analyzed for monthly averages from 2009 to 2012.

**Zooplankton Abundance, Sea surface temperature, and significant wave height**

**(Time-series)**

The time-series of zooplankton abundance, sea surface temperature, and significant wave height for each year reveal that plankton abundance generally exhibits a unimodal curve during the spring bloom. Plankton abundance generally remains low during March and the beginning of April, but rapidly increases near the middle of April to peak in latter April and the beginning of May (figure 3.). The population then seems to decrease into the late weeks of May and into June, however each year seems to show a small positive increase in zooplankton abundance leading into July. Sea surface temperature generally shows a steady increase throughout the spring months (figure 3.). However significant wave height exemplifies rather erratic behavior throughout the spring months. The significant wave height is generally greatest in the early spring throughout March and decreases into the later spring months but continues to fluctuate (figure 3).



Figure 3. Shows a time-series plot of Zooplankton abundance in relation to sea surface temperature and significant wave height for the spring bloom season in each year between 2009 and 2012. Data observations were averaged weekly for each variable.

**Zooplankton abundance, sea surface temperature, and significant wave height**

**(Statistical analysis)**

Zooplankton abundance shows the strongest correlations with sea surface temperature and significant wave height in 2009 with an value of 0.611 and slopes of approximately 251 and 2001 respectively (Table 3a.). This means that about 61% of the variability in Zooplankton abundance is explainable by the variability in sea surface temperature and significant wave height combined. Also, an average weekly temperature increase of one degree will result in an average weekly increase of 251 plankton per square meter on average. Similarly, the slope of 2001 between zooplankton abundance and significant wave height identifies that for every meter increase in average significant wave height, plankton population will undergo an average weekly increase of 2001 on average. The slope of the interaction term is only -326, meaning that for every unit increase of the interaction term, the average weekly plankton population will decrease by 326 per square m on average. However, the p-values for the interactions between both the significant wave height and the interaction term are both above 0.05 (Table 3b.). This means that we cannot reject the null hypotheses in these instances, and must accept the possibility that the variability of zooplankton abundance relative to their quantities may be due to randomness. However, the p-value for the relationship between sea surface temperature and zooplankton abundance is just 0.0304, which means that the correlation of this relationship is statistically significant.

|  |  |  |
| --- | --- | --- |
| **Year** | **R-squared** | **Stats Test** |
| 2012 | 0.403314272 | Linear regression |
| 2011 | 0.366363515 | Linear regression |
| 2010 | 0.148005072 | Linear regression |
| 2009 | 0.610644298 | Linear regression |

Table 3a. Shows the R-squared values for the interactive multivariate linear models between significant wave height, sea surface temperature and Zooplankton Abundance for the spring plankton bloom each year. Variable observations were averaged weekly for each spring.

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Test** | **Value** | **Variable** |
| 2012 | Linear regression | 0.015227649 | Constant |
| 2012 | Linear regression | 0.095893847 | Sea surface temperature |
| 2012 | Linear regression | 0.180115104 | Sea surface temperature & sig wave height |
| 2012 | Linear regression | 0.083780778 | Sig wave height |
| 2011 | Linear regression | 0.077476419 | Constant |
| 2011 | Linear regression | 0.493148839 | Sea surface temperature |
| 2011 | Linear regression | 0.943792921 | Sea surface temperature & sig wave height |
| 2011 | Linear regression | 0.618090728 | Sig wave height |
| 2010 | Linear regression | 0.628747512 | Constant |
| 2010 | Linear regression | 0.873337109 | Sea surface temperature |
| 2010 | Linear regression | 0.916157625 | Sea surface temperature & sig wave height |
| 2010 | Linear regression | 0.800040013 | Sig wave height |
| 2009 | Linear regression | 0.318299746 | Constant |
| 2009 | Linear regression | 0.030455324 | Sea surface temperature |
| 2009 | Linear regression | 0.376950345 | Sea surface temperature & sig wave height |
| 2009 | Linear regression | 0.541228359 | Sig wave height |

Table 3b. Shows the p-values for the interactive multivariate linear models between significant wave height, sea surface temperature and zooplankton abundance for the spring plankton bloom each year. There is a p-value for each relationship between zooplankton abundance and the other model terms. Variable observations were averaged weekly for each spring.

**Discussion:**

The short background statistical analysis revealed we conducted on the relationship between sea surface temperature and significant wave height revealed that there is a statistically significant negative relationship, and moderate correlation between sea surface temperature and significant wave height. Sea surface temperature in the Strait of Georgia follows the dominant air temperature trends (Beamish & McFarlane, 2014), meaning that we can use sea surface temperature as a proxy for seasonal progression over the year. Furthermore, we assume that warmer water temperatures are indicative of the summer months and cooler water temperatures are indicative of the winter months. Thus, in general the Strait of Georgia generally receives larger average significant wave heights in the winter than in the summer. This confirms both the literature and the multivariate time-series plots (figure 3.) that the spring plankton bloom occurs when the sea surface temperature is increasing and the average significant wave height is decreasing (Beamish & McFarlane, 2014; Johannessen & McCarter, 2010). The time-series plots of zooplankton abundance, sea surface temperature, and significant wave height also revealed that the peak of the zooplankton bloom generally occurs in the last few weeks of April, and begin decreasing in early May (figure 3.). 2009 was the lone exception to the both the zooplankton, and sea surface temperature trends. The peak of the zooplankton spring bloom in 2009 didn’t occur until late May and early June, additionally the sea surface temperature exhibited a peak around the end of this zooplankton peak during the middle of June (figure 3.). After the zooplankton peak in late May and early June, the zooplankton proceeded to decrease rapidly into late June before rapidly increasing again just before July. The temperature simultaneously decreased after its peak in mid June (figure 3.). 2009 was also spring that exhibited the strongest correlation between the zooplankton abundance and the sea surface temperature-significant wave height interaction term, and the only spring where the relationship between zooplankton abundance and sea surface temperature was statistically significant. This would seem to support the recent scientific hypothesis that zooplankton bloom onset in the Strait of Georgia is dictated by sea surface temperature, and is thus changing due to climate change (Johannessen & McCarter, 2010). However, significance of this relationship is only exhibited by the 2009 spring, which does not completely explain the hypothesis. Perhaps there is another variable or condition, which must occur for zooplankton abundance to be dictated by sea surface temperature. I would hypothesize that the inclusion of phytoplankton abundance and nutrient concentrations in the water column would improve the predictability of zooplankton in the discovery passage. This project provides insight into the trends of zooplankton, and their impacts from sea surface temperature and significant wave height in narrow passages near the Strait of Georgia. However, further analysis of the Discovery passage zooplankton population will be required to parse apart the biotic factors from the abiotic factors and actually create a useful prediction model.

References:

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