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Cyclic Fluctuations of Zooplankton Dynamics in a Tidal Salt-Marsh Basin

By

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Summary

Zooplankton are pelagic aquatic animals that are limited in their movements by the water currents around them and are major links in aquatic food webs between primary producers and higher trophic levels. Their populations are temporally and spatially variable, as they are sensitive to changes in salinity, temperature, and dissolved oxygen. This is especially true in highly dynamic environments, like estuaries, where environmental conditions are highly variable across seasonal and daily cycles. In order to examine the variability in zooplankton populations across a tidal cycle, we collected zooplankton samples from North Inlet Estuary at 30-minute intervals over a half tidal cycle in July 2019. These zooplankton samples were analyzed by conducting taxonomic identification and abundance estimates. These abundances were then compared to changes in tidal stage and environmental parameters within the estuary. Major taxa all had peak abundance when water height was 1.13 meters while the only major correlation with environmental factors was zoea with a 0.51 r-squared value against surface salinity. The trends observed across the tidal cycle were like those seen in a 1996 study at the same location.

Introduction

Importance of Zooplankton

In aquatic ecosystems, plankton exist as microorganisms that drift within the water column (Jakhar, 2013). Phytoplankton convert solar energy into chemical energy while zooplankton eat other microorganisms for energy. Zooplankton allow the energy produced in the lower trophic levels to reach organisms in the higher trophic levels. Changes in zooplankton abundances can affect the abundance of higher trophic level groups such as invertebrates, fish, seabirds and marine mammals. Zooplankton also play pivotal roles in nutrient cycles, including carbon, nitrogen and phosphorus. In a 4-yr study at Lake Kinneret, zooplankton were found to provide nearly half the carbon needed by metazoan zooplankton grazers when the lake was in its most eutrophic phase (Hart & Stone, 2000). In another study at Lake

Kinneret, found that at certain points, zooplankton excretions accounted for up to 46 and 58% of the phytoplankton phosphorus and nitrogen uptake (Bruce et al., 2006).

Changes in Zooplankton Abundances

Zooplankton abundances are very sensitive to change. Besides presence of prey or predators, environmental factors can also impact how much zooplankton is in a body of water. In the euphotic zone (upper 200m) of the ocean, changes in factors such as current, tide, temperature, light and nutrients affect zooplankton abundances (Koppelmann & Frost, 2008). This explains why zooplankton distributions are notoriously ephemeral, and abundances are difficult to quantify. Another cycle that affects zooplankton abundances is the lunar cycle. Zooplankton abundances are generally higher during new moon and first quarter phases and lower during full moon and last quarter phases of the cycle (Gliwicz, 1986). This is theorized to be due to visibility conditions for the predators that eat zooplankton. During more full moon phases, there is more light available, which allows predators to see and eat zooplankton during the night. When the moon is less full, predators are less successful at finding zooplankton after the sun sets and zooplankton abundances rise. Another explanation is that changes in lunar cycle affect zooplankton migration, with less migration occurring while the moon is full.

Estuaries

Estuaries are locations where salt water meets fresh water. They are typically where a freshwater river flows into a body of salt water such as the ocean. These locations are important as they offer a pathway for many species that move between salt water to fresh water to reproduce. Estuaries often lack consistent conditions, and instead display strong gradients in environmental conditions based on weather, season and distance from the ocean. These conditions include salinity, sedimentation and nutrients (Elliott & McLusky, 2002). This variety of conditions leads to multiple habitats being found within estuaries, including broad coastal lagoons, salt marsh creeks and intertidal areas (Houser & Allen, 1996). In the case of this study, an intertidal area was used at North Inlet Estuary in Georgetown South Carolina. Intertidal areas experience more extreme changes over shorter periods of time than other areas, not even having a permanent water column. In these ecosystems, salinity, temperature, and dissolved oxygen are among the most important factors for species survivability (Abowei, 2009). Dissolved oxygen is mainly added to water via aquatic plants producing oxygen via photosynthesis as well as the air-sea interface.

Effects of Climate Change

Understanding what type of cycles zooplankton undergo is important for fully understanding the impact of climate change on these species. Oceans have experienced a smaller change in temperature via global warming due to water having a high heat capacity (Richardson 2008). The top 300 meters of the oceans have experienced a temperature increase of around 0.31°C since the 1950s (Levitus et al., 2000). Since then, upper ocean temperatures have continued to rise by about 0.13°C per decade (Laffoley & Baxter, 2016). However, aquatic species are often very sensitive to even the smallest change in temperature. One of the more famous examples is coral reef bleaching in which just a few degrees higher than normal temperatures over extended amounts of time can lead to eventual coral death (Hoegh-Guldberg 1999). Besides temperature, changes in salinity are also a concern. Climate change is predicted to decrease spring salinity via increased January-May streamflow which could lead to hypoxia and reduced zooplankton abundances (Stone, 2019). Zooplankton have been observed to have changes in their life cycle events, abundance, and community structure as a result of climate change, but in locations such as estuaries, it may be more difficult to understand the magnitude of the effect of climate change. Since these ecosystems have nearly constantly changing levels of abundances already, it is difficult to tell whether climate change is the culprit behind a change in abundance or if it is simply a result of a routine cycle. Deeper understanding of these cycles that these zooplankton undergo is the only way to ensure that scientists can be aware of if, and in what capacity, climate change is impacting these species.

Methods

Zooplankton Sample Collection

Samples were collected by Joshua Stone and Imani Hanley from North Inlet Estuary on July 10, 2019. 153-micron nets were towed every 30 minutes across a half tide cycle. Collected specimens were then placed in a buffered 3.7% formaldehyde seawater solution to preserve them and labeled with appropriate data such as time, date and sample. Originally, we intended to collect fresh samples for this project in 2020, but due to Covid-19 restrictions, previously acquired samples had to be used. For this project, ring samples 1-15 were analyzed to assess zooplankton taxon and abundance. Ring sample #13 was lost due to a malfunctioning flowmeter.

Zooplankton Sample Examination

Samples previously collected were funneled through a 150-micron mesh filter and then placed in a beaker with different amounts of water depending on the density of the sample. Samples were then stirred and agitated before having 10-20 mL subsample collected via a Stemnel pipette. Agitation was used to ensure that samples were as homogenous as possible, and that portions used for observations were as accurate to the actual distribution of organisms as possible. Subsamples collected via Stempel pipette were then examined using a microscope. Number of each taxa were recorded along with the portion examined versus total volume of sample. Each sample had at least 100 total organisms identified to help ensure accurate results. Following examination, samples were placed back into original containers with a combination of salt water to formalin to have a 3.7% formaldehyde mixture to preserve the organisms. Linear regression was used to compare zooplankton abundances with temperature, salinity and dissolved oxygen. R-squared values indicating the fitness of each model are displayed in Table 3.

Data Analysis

Counts from each sample were converted to total abundance within the ring net tow. Abundance was calculated for each sample via the following equation:

$$\begin{aligned} \mathit{Abundance} = \ (\mathit{Number\ species\ counted} \div \mathit{portion\ sample\ counted} \\ \div \mathit{Cubic\ meters\ filtered} \end{aligned}$$

Cubic meters filtered was found by information collected using the flowmeter during the sample collection to estimate how much water passed through the net on each tow. Portion of sample collected refers to volume of the sub-sample examined under a microscope compared to the total volume of the net sample before the sub-sample was extracted. This process was repeated to find abundance of each taxa from each sample.

Results

Zooplankton Counts and Abundance

Zooplankton counts varied widely between samples (Table 1). Some samples had over 100 individuals within a single taxonomic group while others had low diversity or abundance. This is tied to how dense the sample was and how much water was filtered. Copepods, chaetognaths, zoea and shrimp seemed to be most common in all samples which suggests that they are the most abundant species in the sample. These 4 were used for further analysis due to consistent larger counts as opposed to taxa only found in a few samples.

Copepods, chaetognaths, zoea and shrimp were most abundant of all species observed (Table 2). Total net tow abundance calculations allowed direct comparison between different ring samples despite variation in the volume of water filtered.

Tidal Cycle

The zooplankton abundances were compared to time of collection (Figure 1). The initial sampling occurred at low tide with increasing tide until the final sample collected at high tide (half-tidal cycle). All major zooplankton taxa had similar trends in abundance, with the highest peak for each occurring around 1:30 pm before a sharp decline. However, there were slight differences between a few of the taxa; for example, chaetognaths were the only major taxa that did not exhibit an initial high peak at low tide. The water height across this cycle was initially 0.01 meters, increasing to 1.61 meters during high tide at the last sampling.

Environmental Factors

Salinity at both surface and bottom level was not well correlated with zooplankton abundances (Figure 2). For each taxon, there appeared to be no trend or pattern that could be observed with respect to salinity. Similarly, temperature also showed little correlation with zooplankton abundance at both the bottom and surface of the water column (Figure 3). Abundances across all taxa appeared similar during both high and low temperatures. Dissolved oxygen (DO) appeared to have some correlation with zoea with r-squared values of 0.49 for bottom DO and 0.51 for surface DO (Figure 4). Higher zoea abundances occurred at higher amounts of DO at both the bottom and surface of the water column. There was little difference observed between surface versus bottom conditions in relation to zooplankton abundance. Most taxa showed very low R-squared values. The highest observed R-squared value for chaetognaths was 0.16 when compared to part of tidal cycle. For shrimp, the highest observed R-squared value was 0.0805 when compared to surface temperature. Copepods had the highest R-squared value at 0.055 when compared with surface DO. Zoea abundance had by far the highest R-squared value with 0.51 when modelled as a function of Surface DO. These differences are interesting because even though each of these taxa had peaks in abundance during the same parts of the tidal cycle, linear regression analysis suggests they are correlated differently with environmental factors. The cause of these differences could be tied to the magnitude of the peaks. For shrimp, the peak in abundance occurred around the same time as the other taxa, but it was relatively minor compared to the increase in abundance observed among other taxa. Zoea in some studies have been shown to be more affected by DO than other environmental variables (Tomasetti, 2018). When exposed to either lowered salinity or lowered pH, zoea had lower survival rates when exposed to lowered salinity.

Discussion

This analysis of zooplankton abundance through the tidal cycle revealed that many prominent microorganisms had peaks at similar tidal phases. Namely, copepods, zoea, chaetognaths and shrimp peaked in abundance around times 13:17 and 13:47 with a subsequent peak shortly after at 15:46. Similar trends were observed in the 1996 study (Houser & Allen, 1996). There were peaks for both copepods and zoea at points before high tide like the peaks observed in this study. This suggests that zooplankton observed during the previous study were following similar cycles as the ones in this sample. The reason no direct trend was observed in linear regression could be that these points of peak abundance are when conditions are most ideal. For example, salinity could be beneficial to zooplankton, but too much could be harmful. This could explain why little direct correlation is observed. These trends were like the ones observed in the 1996 study which saw relationships with zooplankton abundances, but their regression analysis showed little explanation for the variability observed (Houser & Allen 1996). However, there were multiple instances when the tidal cycle abundances from the 1996 study were different from the observations in the present study. This could be due to other environmental factors that were not included in this study. For example, the 1996 study occurred during a different lunar phase, potentially impacting zooplankton predation.

Possible Concern

While it was intended that the samples observed were as close to the actual distribution as possible, there are possible sources of error that could have led to possible sources of error in the abundance estimates calculated in this study. For example, although over 100 organisms were observed per sample, each portion analyzed only accounted for up to ~7% of the total sample. This could mean that the observed abundances could deviate from the actual abundance of the sample, not to mention that the samples collected might also deviate from the actual distribution as well. However, these deviations should be minor since errors of this nature are more common in rarer taxa and the zooplankton analyzed in this study were the most common in each sample. In the comparison to the previous study, both time of year and moon phase differed between the 1996 and 2019 sampling events. Both factors impact zooplankton abundance so these differences could explain some of the differences between the two studies.

Future Studies

In order to best understand zooplankton cycles, additional studies are needed. Long-term monitoring is essential to characterize zooplankton response to season and lunar cycle. Predators for example are an important reason why zooplankton abundances decrease during fuller moon phases. Predation could be a possible explanation why zooplankton abundances are shifting as observed across a half tidal cycle as well. Many zooplankton, for example, feed on each other so the increased abundance of one could lead to lowered abundance of others. Another possible avenue would be to look at how combinations of these conditions could be affecting zooplankton abundances. In the study looking at zoea versus pH and salinity, the combination of both low pH and salinity was shown to be greater than either factor on its own (Tomasetti, 2018). So rather than one factor driving abundance up or down, different combinations could lead to different outcomes in abundance depending on the species.

Conclusions

This study showed how many zooplankton abundances are affected similarly by changing conditions such as stage of tidal cycle. Many observed taxa had similar peaks as close to each other as within the hour in a day. These trends also matched ones observed over 20 years ago in the same location. At the same time, these zooplankton are not necessarily being affected driven to the same degree by environmental factors, as zoea was the only one to be significantly correlated with any of the observed environmental factors. As we continue to see rising temperatures, it is increasingly important to understand what cycles affect species in order to gauge what risk we may be exposing ourselves to in the upcoming years. For zooplankton especially, monitoring these species will allow us to properly maintain the food webs that they are pivotal to.

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Tables and Figures

Sample #	Copepods	Fish Larvae	Chaeto.	Zoea	Megalopa	Shrimp	Ephyra
Ring 1	71	18	0	36	7	18	2
Ring 2	22	35	10	91	5	26	0
Ring 3	22	5	33	86	1	31	3
Ring 4	15	3	38	26	1	22	2
Ring 5	20	0	72	57	4	45	2
Ring 6	20	0	33	35	2	18	1
Ring 7	17	0	27	72	0	53	2
Ring 8	25	6	15	33	3	18	2
Ring 9	138	2	82	179	16	48	4
Ring 10	175	4	34	175	7	36	1
Ring 11	57	1	18	100	5	19	2
Ring 12	31	4	19	61	6	12	2
Ring 14	12	5	25	71	3	18	0
Ring 15	8	0	13	92	2	11	1

Sample #	Amphipod	Hydromed.	Polychaetas	Nematode	Actinophai	Unknown	Sum	Ratio
Ring 1	1	0	0	0	0	0	153	0.029
Ring 2	1	2	6	0	0	0	198	0.050
Ring 3	0	5	1	0	0	0	187	0.067
Ring 4	0	3	1	0	0	0	111	0.057
Ring 5	1	5	2	0	0	2	210	0.057
Ring 6	3	1	3	0	0	2	118	0.040
Ring 7	4	9	8	3	1	0	196	0.067
Ring 8	1	15	3	4	0	0	125	0.040
Ring 9	1	17	14	4	0	4	509	0.036
Ring 10	1	18	4	0	0	0	455	0.022
Ring 11	1	6	4	0	0	0	213	0.025
Ring 12	0	15	6	0	0	0	156	0.031
Ring 14	2	6	6	0	0	0	148	0.017
Ring 15	0	9	2	0	0	0	138	0.025

Table 1: Counts for all species across all samples used in study. At least 100 individuals counted per sample. Ratio refers to volume of sample counted versus total sample volume, for example, some samples were 300 mL but only 20 mL were analyzed.

Sample	Time	Cubic meters filtered	Copepods	Fish Larvae	Chaet	Zoea	Megalopa	Total
Ring 1	9:17	157.77	15.75	3.99	0.00	7.99	1.55	33.94
Ring 2	9:47	200.86	2.19	3.48	1.00	9.06	0.50	19.72
Ring 3	10:17	221.28	1.49	0.34	2.24	5.83	0.07	12.68
Ring 4	10:47	217.50	1.21	0.24	3.06	2.09	0.08	8.93
Ring 5	11:18	278.15	1.26	0.00	4.53	3.59	0.25	13.21
Ring 6	11:47	235.21	2.13	0.00	3.51	3.72	0.21	12.54
Ring 7	12:18	285.89	0.89	0.00	1.42	3.78	0.00	10.28
Ring 8	12:47	259.96	2.40	0.58	1.44	3.17	0.29	12.02
Ring 9	13:17	291.53	13.02	0.19	7.74	16.89	1.51	48.01
Ring 10	13:47	356.93	22.06	0.50	4.29	22.06	0.88	57.36
Ring 11	14:19	253.88	8.98	0.16	2.84	15.76	0.79	33.56
Ring 12	14:47	306.39	3.29	0.42	2.02	6.47	0.64	16.55
Ring 14	15:46	257.40	2.80	1.17	5.83	16.55	0.70	34.50
Ring 15	16:17	228.22	1.40	0.00	2.28	16.12	0.35	24.19

Table 2: Abundances for all major taxa, sample collection time and cubic meters filtered for each net tow collected on July 10, 2019.

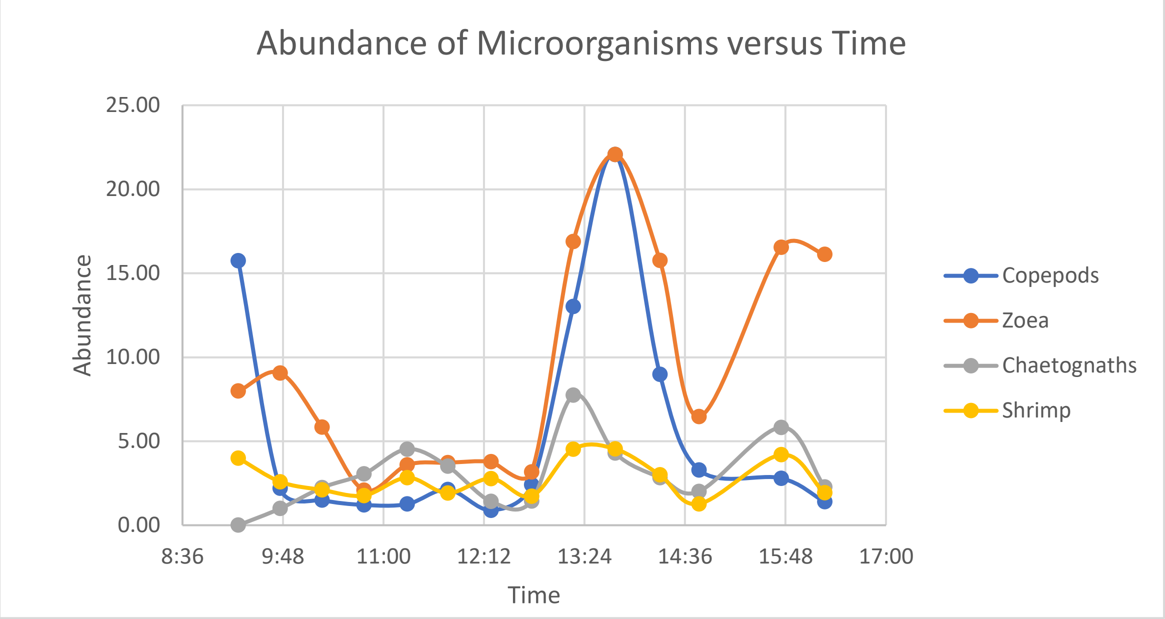
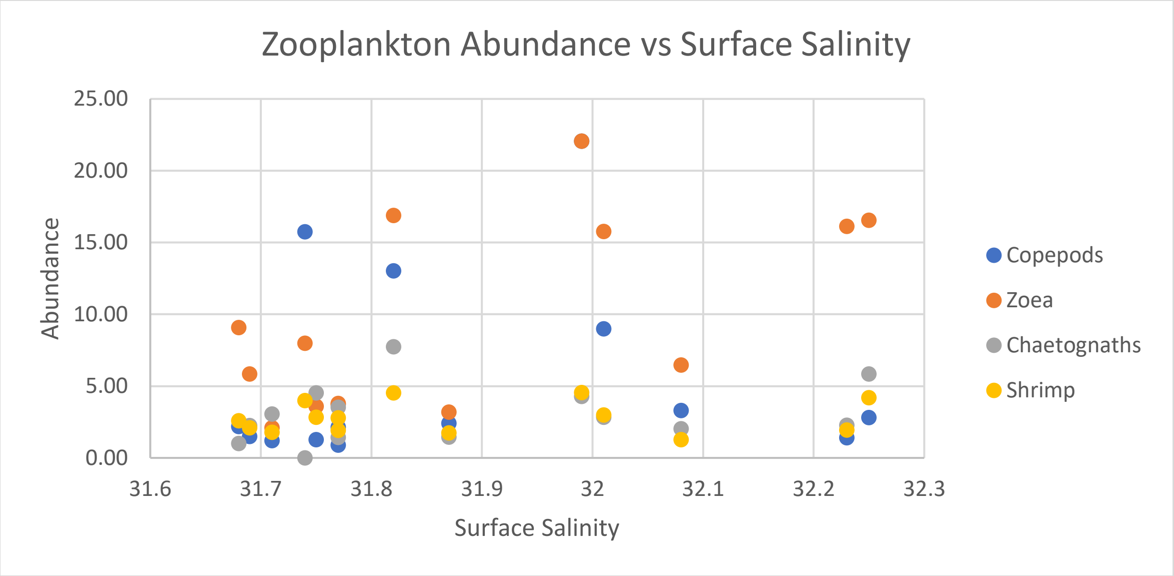


Figure 1: Abundances of major zooplankton species across time. Sampling began at low tide with increasing tide as time continued until max high tide reached at the last sample.



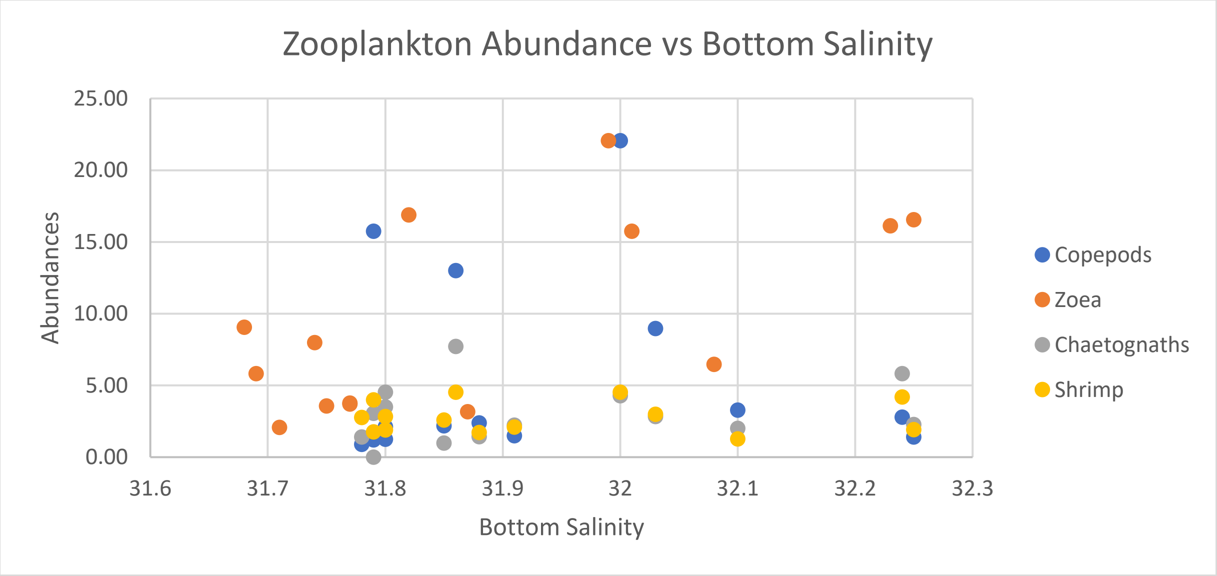


Figure 2: Graphs comparing major zooplankton abundances against both surface and bottom salinity.

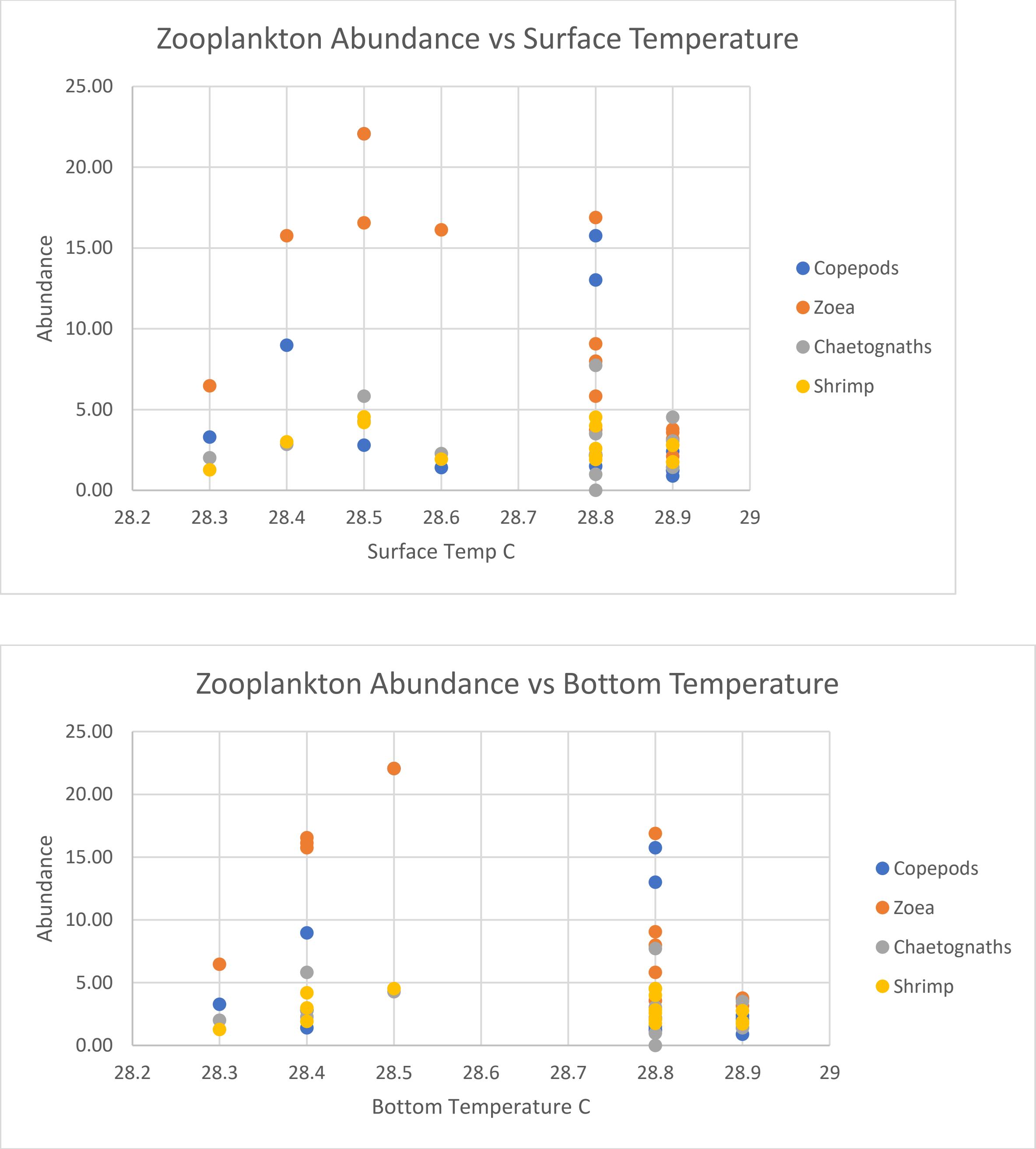
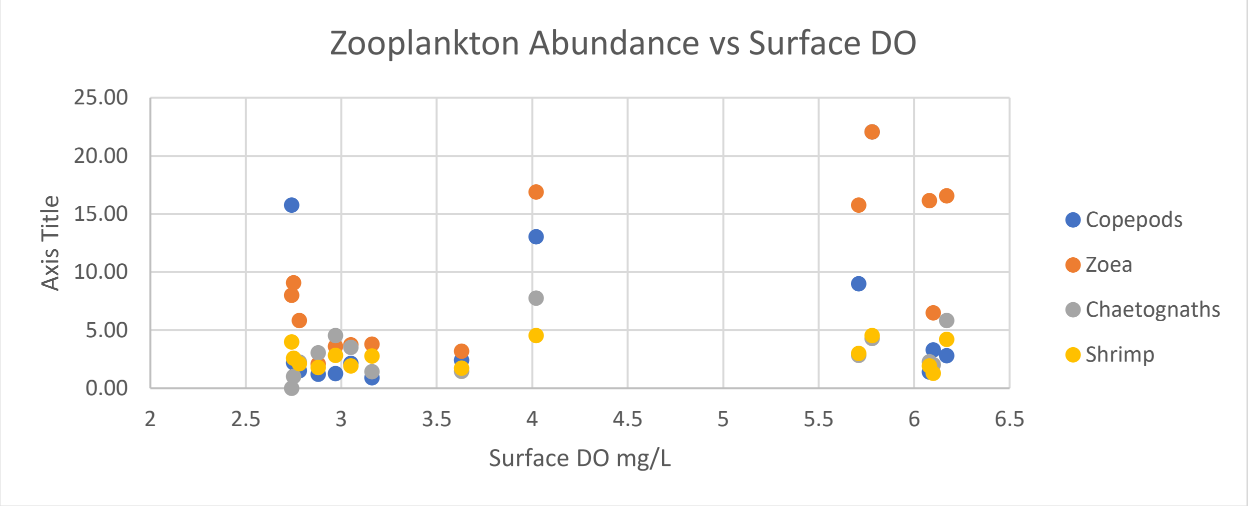


Figure 3: Comparison of zooplankton abundances versus temperature in degrees Celsius at both the surface and bottom of the water column



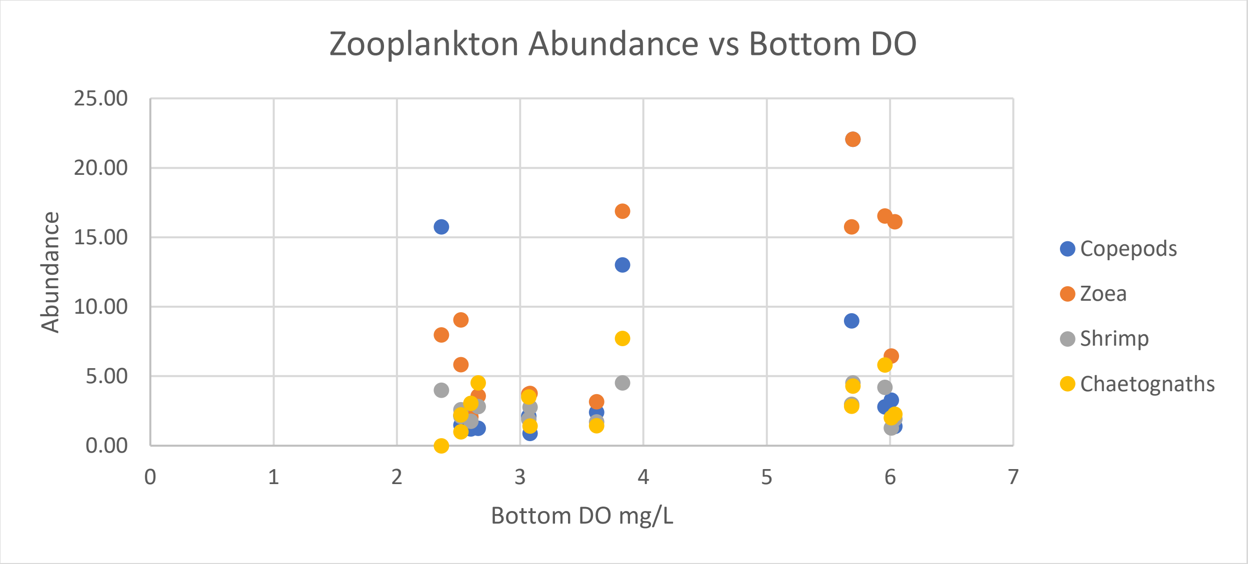


Figure 4: Comparison of dissolved oxygen content at both the surface and bottom of water column compared to major zooplankton abundances in study.

Environmental Factor	**Copepods**	**Zoea**	**Chaetognaths**	**Shrimp**
Surface Temp.	0.081	0.37	0.015	0.01
Bottom Temp.	0.031	0.4	0.024	0.006
Surface Salinity	0.004	0.386	0.064	0.012
Bottom Salinity	0.0002	0.389	0.038	0.001
Surface DO	0.055	**0.51**	0.089	0.027
Bottom DO	0.047	**0.488**	0.082	0.017

Table 3: R-squared values for all major taxa for each environmental factor observed. Significant values in bold, zoea for both surface and bottom DO.