Zooplankton Diversity and Community Composition along 167°W in the Equatorial Pacific

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Abstract

Zooplankton are important primary consumers in the marine food web and lead an important role in carbon cycling in the open ocean. Understanding what influences zooplankton community composition can help us understand the impacts of climate change on this delicate relationship. Data was collected from 28 December 2023, through 10 January 2024, on the *R/V Thomas G. Thompson* near American Samoa between 5°S and 5°N along 167°W. A closing zooplankton net with 200µm mesh was used for net tows from 200m to surface at stations between 5°S and 5°N along the 167°W longitudinal line. Zooplankton abundance was highest at the equator with 345 organisms m^{-3} and increased from 5°S to the equator; and decreased from the equator to 5°N in a bell-curve shape. Species diversity (Shannon-Weiner) was lowest at the equator (0.878) and highest at 1°N (1.067) and 5°N (1.059). Calanoid copepods had the highest abundance over all sites (74-88% of composition), and north of the equator, calanoid copepods and gelatinous zooplankton (larvaceans) dominated most of the species composition. There were no significant relationships between species community composition and temperature, salinity, or nutrients. Results demonstrate that higher water temperatures and different current regimes impacted abundance and species presence during the 2023 – 2024 Strong El Niño. With many processes occurring with zooplankton in the open ocean, it may be that multiple variables are impacting the resulting diversity and abundance relationships. Monitoring zooplankton composition over time is vital for monitoring the health of our oceans as it has implications for global fisheries and carbon cycling.

Plain Language Summary

Zooplankton are small drifting organisms present in the surface ocean and are important in the overall cycling of carbon through phytoplankton as well as through fishes and larger organisms. Understanding the abundance and composition of zooplankton species in the equatorial pacific can help us understand how energy cycles throughout the open ocean. This study investigates the relationships between water chemistry factors, zooplankton community, abundance, and currents from 5°S to 5°N along 167°W. Data was collected on research cruise TN427 from 28 December 2023 to 11 January 2024 on the *R/V Thomas G. Thompson* in Pago Pago, American Samoa. A zooplankton net was deployed down to 200m and organisms were identified under dissecting microscopes. It was found that species abundance was highest at the equator and north of the equator, with calanoid copepods dominating the species composition overall. There were no significant relationships with important water chemistry factors. Currents influenced abundance, with high abundances north of the equator and low abundances south. As climate undergoes more severe fluctuations and phenomenon such as El Niño continue to increase in frequency and severity, understanding the impacts on important communities like zooplankton is even more important for monitoring our ocean carbon cycling, and fisheries.

Introduction

Zooplankton play a vital role in connecting the autotrophic marine primary producers and microbial communities to the greater marine food web by transferring energy up trophic levels via consumption by secondary consumers and contributing to the organic carbon pool that is available for microbial communities. Zooplankton consume phytoplankton and excrete them as dissolved organic carbon (DOC) through sloppy feeding, excretion and fecal pellet leakage, particulate organic carbon (POC) through ingestion and egestion and dissolved inorganic carbon

(DIC) through respiration (Steinberg & Landry, 2017). Globally, more than 35% of total POC flux is attributed to fecal pellet carbon from zooplankton. However, since these measurements are made from sediment traps and they can break apart, the estimates are likely conservative (Turner, 2015). Additionally, as zooplankton undergo diel vertical migration (DVM) and move throughout the water column twice a day, they move the organic carbon from the surface ocean to below the photic zone, cycling carbon through different current channels and microbial communities. Much of the biomass (fecal pellets and carcasses) from zooplankton falling to the seafloor either becomes a sink on the seafloor or becomes incorporated into the deeper ocean microbial food webs (Steinberg & Landry, 2017).

The composition of zooplankton species and groups within a community can heavily influence the export and transport of carbon in the surface ocean and into the deep. For example, gelatinous zooplankton can have massive blooms and subsequent die-offs which lead to rapid exports of POC to the deep ocean (Steinberg & Landry, 2017). The composition of zooplankton communities is mainly dependent on temperature, location, currents, nutrients, and phytoplankton abundance and diversity (Steinberg & Landry, 2017).

Two cruises at 180°W and 140°W found that zooplankton biomass was higher at the equator near 180°W as opposed to 140°W, which slowly increased in biomass from the equator to 5°N then decreased (Roman et al., 2002). Another study focused more on the Western Equatorial Pacific near Japan, but found that zooplankton abundance and diversity was highest in the equatorial section of their cruises, specifically among different diversity indexes including Shannon-Weiner, Pielou's Evenness Index and Simpson's Diversity Index (Long et al., 2021). They also identified that warmer temperature, high nitrate, and movement of water masses all influenced the distribution of zooplankton communities significantly (Long et al., 2021).

Additionally, certain zooplankton species can be brought to an area based on warm water events such as Pacific decadal oscillation (PDO) or ENSO (El Niño Southern Oscillation), favoring cold/warm water copepods and altering the community composition (Keister et al., 2011). The Equatorial Pacific has several current regimes, including the Equatorial Undercurrent, the North Equatorial Countercurrent, the South Equatorial Current, and the South Equatorial Undercurrent (Fig. 1). The proximity to the coast of South America, which has upwelling could contribute to higher zooplankton diversity (Miloslavich et al., 2011).

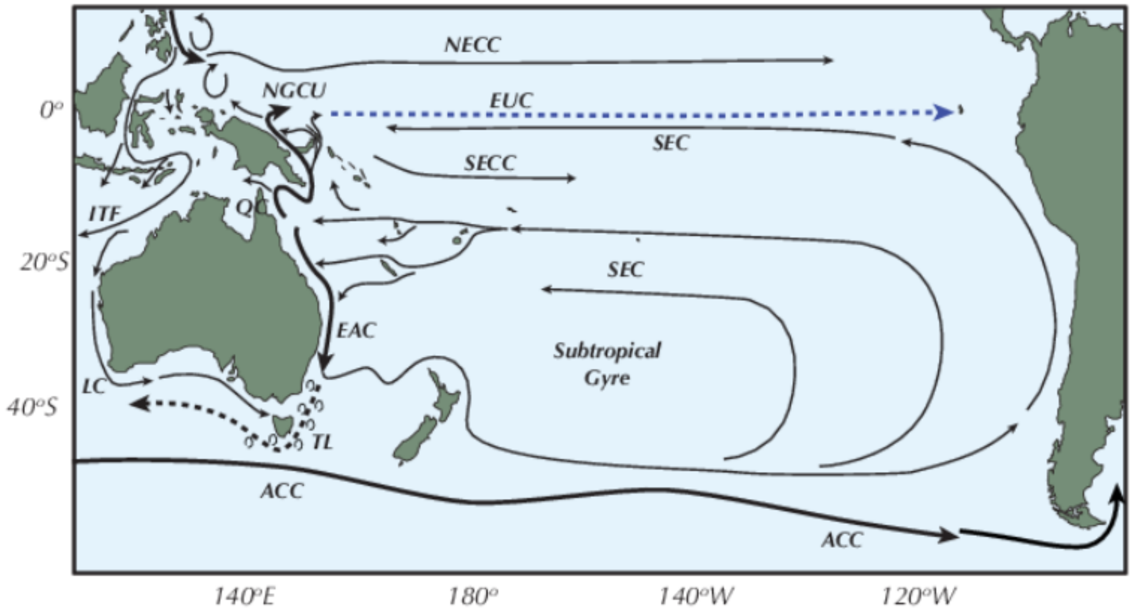

Figure 1. Major currents within the South Equatorial Pacific. ECC: North Equatorial Counter-Current; NGCU: New Guinea Coastal Under-current; EUC: Equatorial Under-Current; SEC: South Equatorial Current; SECC: South Equatorial Counter-Current; ITF: Indonesian Through-Flow; QC: Queensland Current; EAC: East Australian Current; LC: Leeuwin Current; ACC: Antarctic Circumpolar Current Developed by (Evans et al., 2018).

In terms of the relationship of zooplankton and phytoplankton abundance, studies have shown that with higher phytoplankton diversity comes higher zooplankton productivity (Striebel et al., 2012). Ocean heatwaves can impact the phytoplankton community composition by causing a shift from majority of diatoms to a majority of dinoflagellates (Arteaga & Rousseaux, 2023). Recent studies have modeled the potential impacts of a climate changed future on zooplankton and predicted that future fish communities will experience a reduced carrying capacity due to the low nutrient carnivorous zooplankton predicted to succeed, decreasing the number of copepods present (Heneghan et al., 2023). In a warmer, more acidic climate, we could expect the potential carbon circulation and sequestration from the surface ocean due to zooplankton to decrease, and potentially impact the fisheries or organisms higher up in the trophic level. Understanding the community composition is one way for us to monitor the health of the planktonic food web and learn more about what parameters influence zooplankton abundance and composition.

I hypothesize that the zooplankton community will be higher with warmer temperatures and higher nutrient conditions. I also hypothesize that the South Equatorial Current will have higher zooplankton diversity due to its origin from the Antarctic Circumpolar Current which typically has high nutrients.

Methods

Data collection

The *R/V Thomas G. Thompson* departed from Pago Pago, American Samoa on 29 December 2023, and returned to Pago Pago, American Samoa on 11 January 2024. Samples were collected at 5°S, 3°S, 1°S, 0°, 1°N, 3°N, and 5°N (Fig. 2).

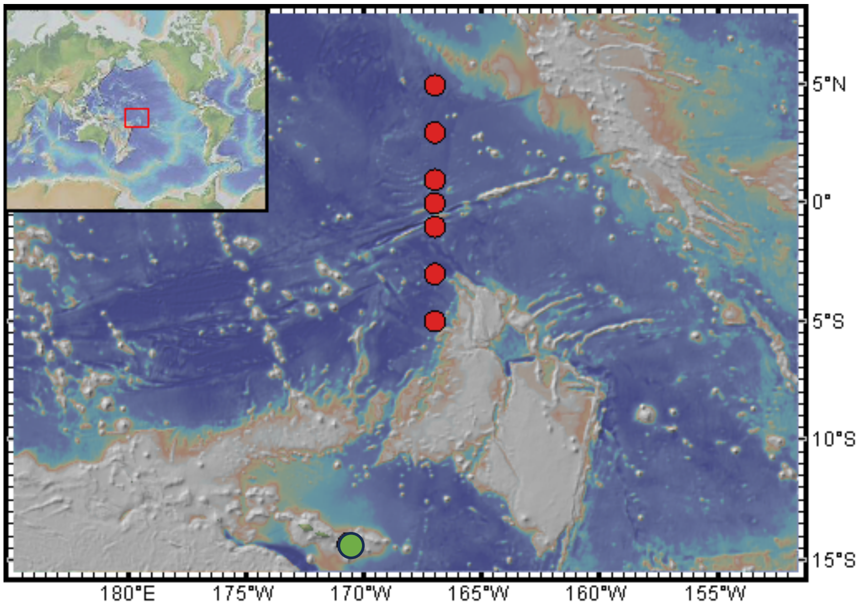

Figure 2. 2023 Senior Thesis Cruise plan. Red dots indicate sampling locations. The green dot indicates the Port of Pago Pago, American Samoa.

Zooplankton samples were collected with one replicate at each station using a 1m-diameter 200μm mesh closing plankton net with flow gauge from 200m to surface. After being brought back onto the ship, the zooplankton net was thoroughly rinsed with seawater, after which the organisms in the cod end were be emptied into a container and preserved in a 5% formalin and seawater solution until brought to a laboratory for analysis. In preparation for counting, the sample was mixed gently, and 4-15 mL aliquots were taken using a Stemple pipette. Zooplankton were categorized to the order level, and copepods were separated into "cyclopoid" and "calanoid" sub-groups. Data was collected using a Seabird SBE-9 CTD with temperature, salinity, pH, oxygen, and fluorescence sensors attached. Current data was collected using a Teledyne RD Instruments Acoustic Doppler Current Profiler (ADCP).

Nutrient samples were collected from Niskin bottles on the CTD rosette from multiple depths. A 60 ml nutrient bottle was rinsed three times and filled with water from the Niskin bottle. Samples were then placed in a cooler to be shipped back to the University of Washington Marine Chemistry Lab for further analysis. After nutrients were processed and data was produced, the entire cast was analyzed, the average from 200m to the surface was used for statistical comparisons to zooplankton. Nitrate, Nitrite, Ammonium and Phosphate were analyzed.

The ADCP data was post-processed by Cody Cruz using UHDAS+CODAS software from the University of Hawaii available at https://currents.soest.hawaii.edu/docs/adcp_doc/index.html (Firing et al., 2012). In addition to removing all periods beyond 5° S and 5° N to obtain a pure transect, threshold editing was applied to eliminate velocity values in bin ensembles with less than 80% good pings or greater than 500 mm/s error velocity magnitude. Phase correction was not warranted, but a final amplitude correction of 1.006 was applied, resulting in median water-track calibration bias estimates of 1.0005 for amplitude and 0.0525° for phase. ADCP post-processing documentation, further post-processing Jupyter notebooks, and the fully processed data are available at https://github.com/GHOpenonic/equatorial-pacific-turbulent-mixing.

Analysis

$$abundance = \frac{(count * dilution\ factor)}{vol\ water_{filtered\ or\ projected}} \tag{1a}$$

$$dilution\ factor = \frac{total\ volume\ of\ sample}{volume\ of\ aliquot} \tag{1b}$$

$$vol\ water_{filtered} = \frac{{diameter_{net}}^{2}}{2} * 26873(flowmeter_{end} - flowmeter_{start}) * 10^{-6} * \pi \tag{1c}$$

$$vol\ water_{projected} = \frac{{diameter_{net}}^{2}}{2} * distance_{projected} * \pi \tag{1d}$$

$$H' = \sum_{i=1}^{S} P_i \log_2 P_i \qquad 2$$

$$S = \frac{(S-1)}{\ln(N)} \qquad 3$$

$$J = \frac{H'}{\ln(S)} \qquad 4$$

Once the samples were counted with a dissecting scope, standard abundances were calculated using equations 1a-d. Equation 1a calculates the zooplankton abundance from zooplankton counts and aliquot dilution. Equation 1b calculates the dilution factor from the volume of the zooplankton sample and the volume of aliquots counted. Equation 1c calculates the volume of water filtered using a flowmeter on the zooplankton net. Equation 1d calculates the volume of water filtered just from the projected distance traveled.

Data was analyzed and compiled in Rstudio. The R package ggplot2 was used for graphing and plotting all data (Wickham, 2016). R packages tidyverse and plyr were used for data sorting and management (Wickham et al., 2019). In addition, R package tabula was used for calculating the Shannon-Weiner Diversity Index (H') (Equation 2), Margalef's richness index (S) (Equation 3), and Species Evenness (J) (Equation 4) (Frerebeau, 2019). Statistical tests such as Analysis of Variance (ANOVA) and Tukey Student T-Tests were utilized in RStudio to identify significance between groups (RStudio Team, 2020).

Results

Zooplankton diversity over the transect was relatively consistent except for the equatorial sample, which had a much lower diversity compared to the other latitudes (Fig. 3a). Species evenness was particularly low at the equator, likely due to a dominance of copepods and overall high abundance, whereas there is no discernable trend at the other sampling latitudes (Fig. 3b). Species richness was highest at 1°S and was lowest at 1°N, while the equator was close to the mean, which was 7.42 species (Fig. 3c). Total species abundance followed a bell-curve-like shape, lowest at 5°S (93 m^{-3}) and 5°N (121 m^{-3}) and highest at the equator (345 m^{-3}) (Fig. 3d). There were not any statistically significant relationships between any diversity variables.

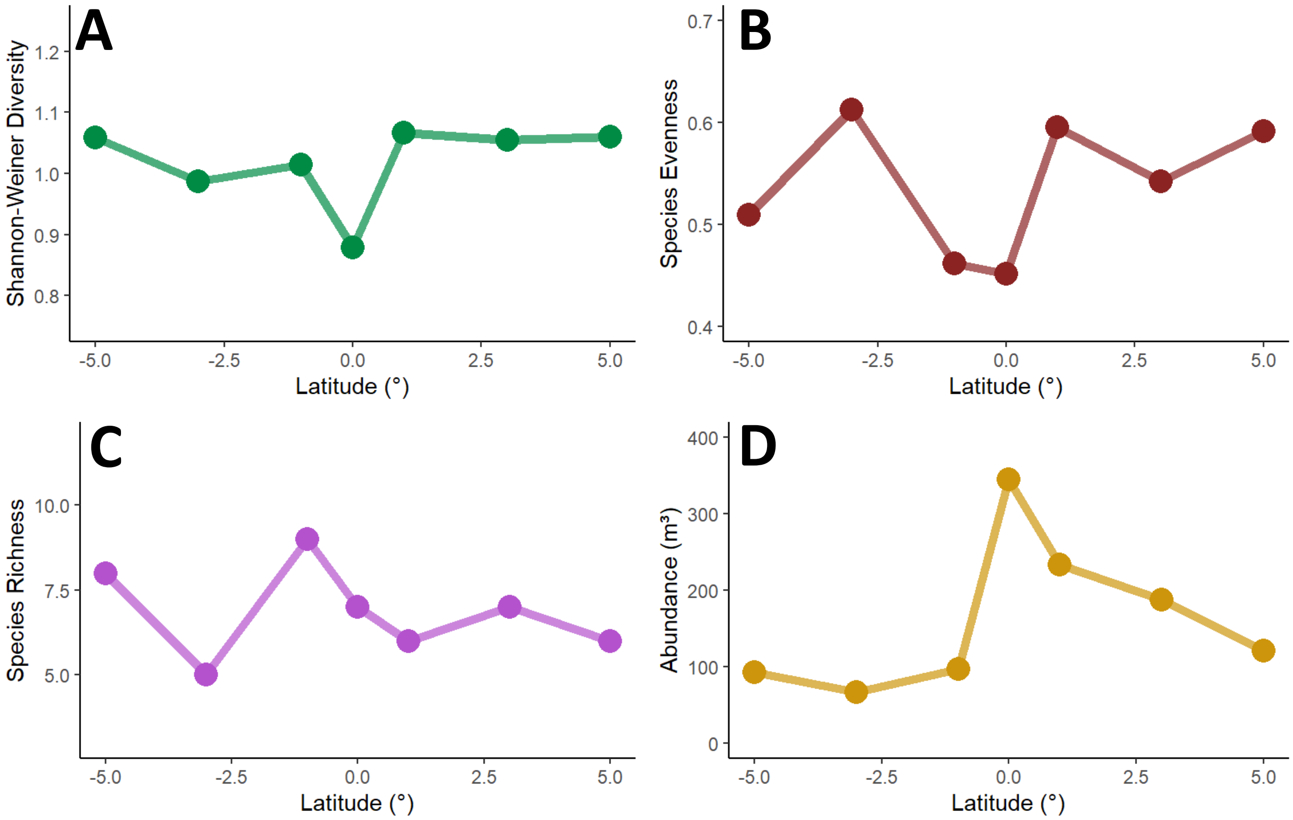

Figure 3: Zooplankton Community Composition metrics along the 167°W transect from 5°S to 5°N. A) Shannon-Wiener Diversity, B) Species Evenness, C) Species Richness, D) Total Zooplankton Abundance (m^{-3}).

Species abundances were highest at the equator, with calanoid copepods having the highest abundance at all stations, comprising at least 74% of the organisms counted (Fig. 4a). Abundances are low south of the equator, peak at the equator, and subsequently decrease (Fig.

4). When including calanoid copepods, the Shannon-Weiner diversity index was highest at 1°S and 1°N (Fig. 4a), however when excluding calanoid copepods, the diversity is highest at 5°S and the equator (Fig. 4b). Additional analysis comparing richness with calanoid copepods and without calanoid copepods was included to have higher resolution understanding what species are more dominant over different latitudes. Species richness was highest at 1°S with 10 species counted at that sampling location (Fig. 4a). Species dominance switches from homogenous species composition south of the equator to cyclopoid copepods, larvaceans and chaetognaths north of the equator (Fig. 4b).

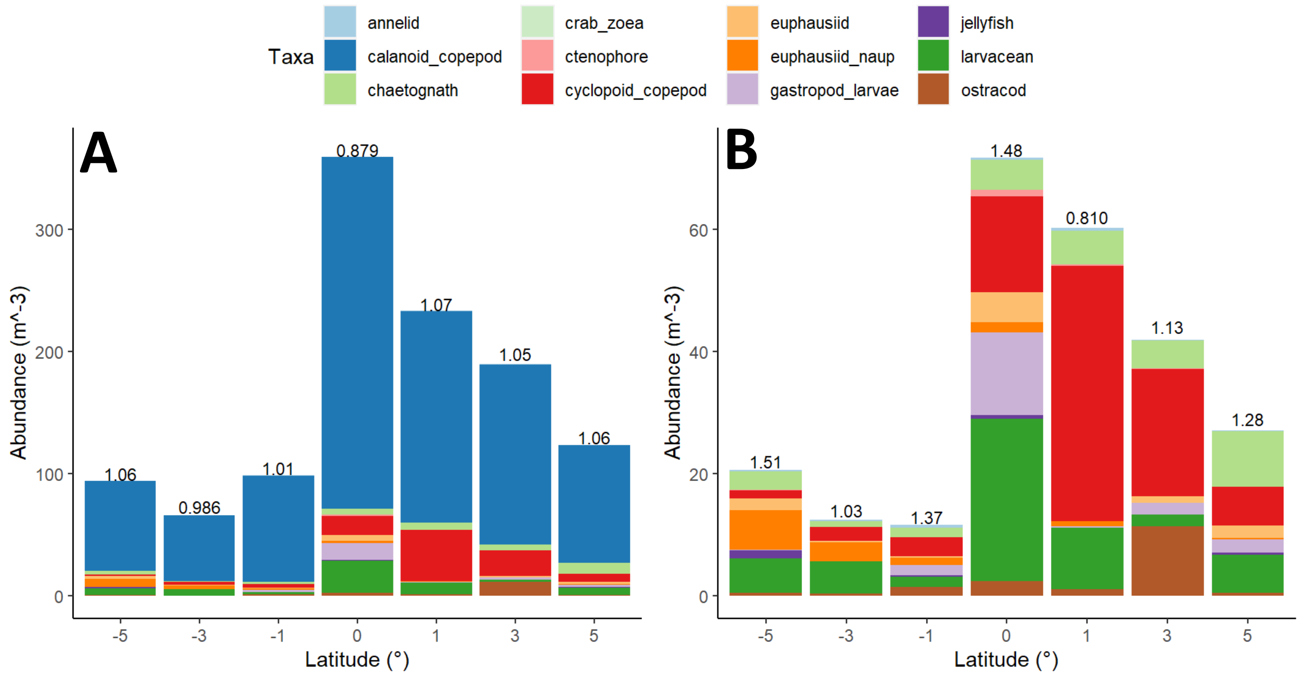

Figure 4: Zooplankton species composition at each station. A) Species abundance and composition including calanoid copepods, B) Species abundance and composition not including calanoid copepods. The number denotes the Shannon-Weiner diversity index.

In terms of trends with water chemistry, there were no statistically significant relationships with any factor measured from the CTD or with nutrients (these include: salinity, temperature, fluorescence, dissolved oxygen, pH, phosphate, silicate, nitrate, nitrite, and ammonium) and species abundance or diversity. In observations of important water chemistry factors, temperature (R^2=0.38, p>0.1) and fluorescence (R^2=0.47, p<0.1) had a negative linear relationship with total species abundance (Fig. 5ab). There was a positive relationship between total species abundance and phosphate (R^2=0.42, p>0.1), as well as with nitrate + nitrite (R^2=0.38, p>0.1) (Fig. 5cd).

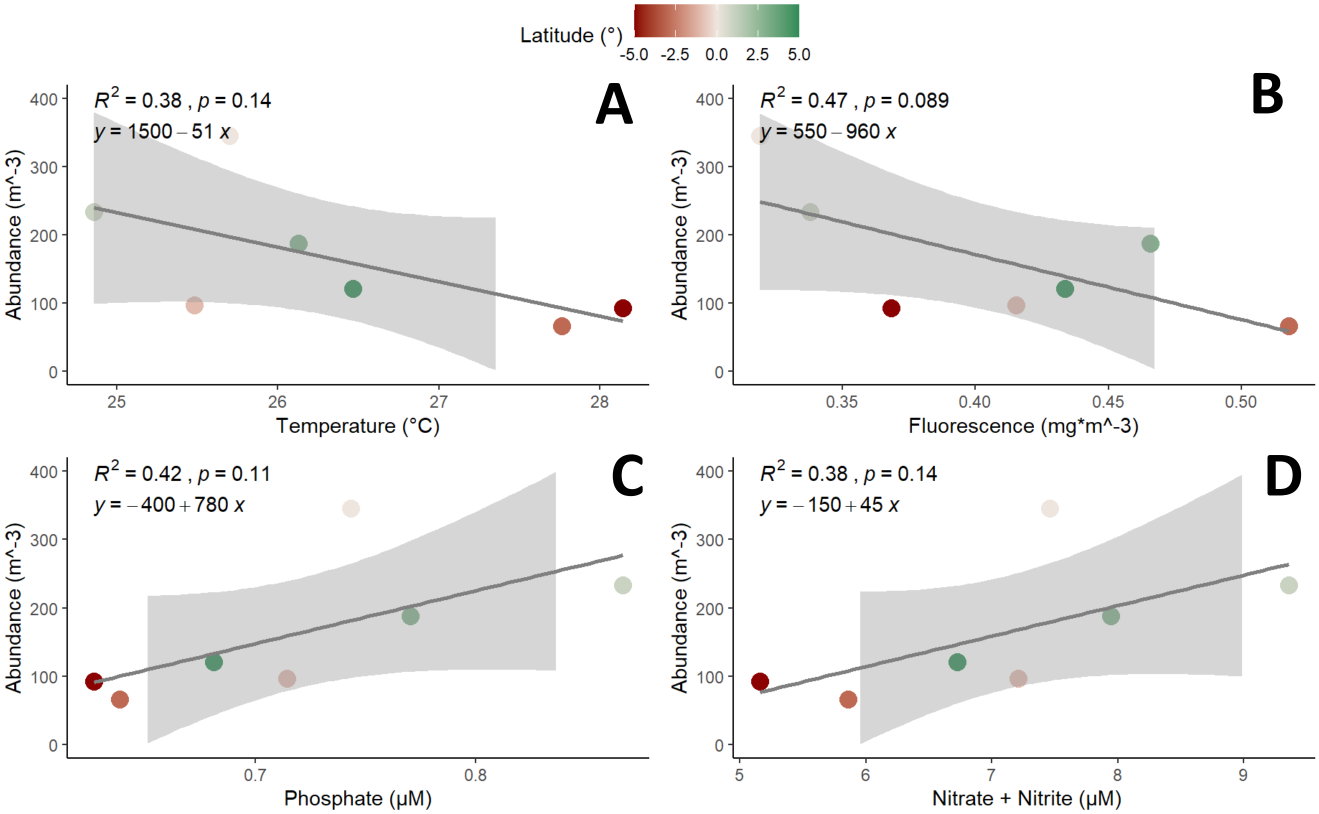

Figure 5: Total abundance of zooplankton and different environmental variables. A) Temperature, B) Fluorescence, C) Phosphate, D) Nitrate + Nitrite. The latitude of the station is denoted by color of points. Shaded area indicates 95% confidence interval.

Currents had mostly northwest directionality from 5°S to 2°S, the south equatorial countercurrent (Fig. 6). There were some southeast undercurrents at 1°S and the equator equatorial undercurrent, with surface currents moving northwest at the equator to 2°N (the south equatorial current) (Fig. 6). From 3°N to 5°N there is a strong easterly undercurrent, which is likely the north equatorial countercurrent (Fig. 1, Fig. 6).

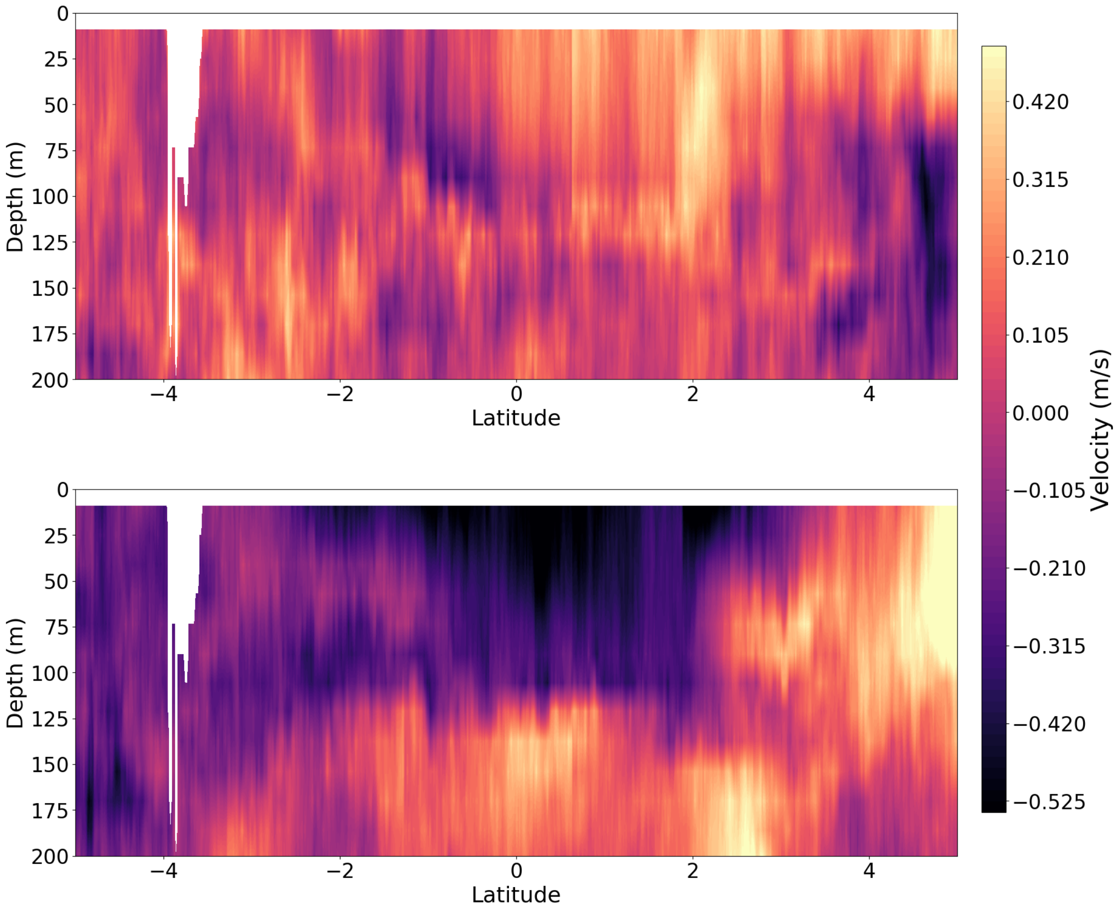

Figure 6: Water current projections from surface to 200m across A) meridional velocity (north-south) and B) zonal velocity (east-west). Code processing courtesy of Cody Cruz.

In non-metric multidimensional scaling, there were no strong relationship between stations or between species of zooplankton (Fig. 7). 5°N and the equatorial station had close proximity to euphasiids, suggesting there may be a relationship between both stations via that species (Fig. 7). Additionally, ctenophores and chaetognaths were grouped, and larvaceans and calanoid copepods were groups close to 1°S, indicating a relationship (Fig. 7).

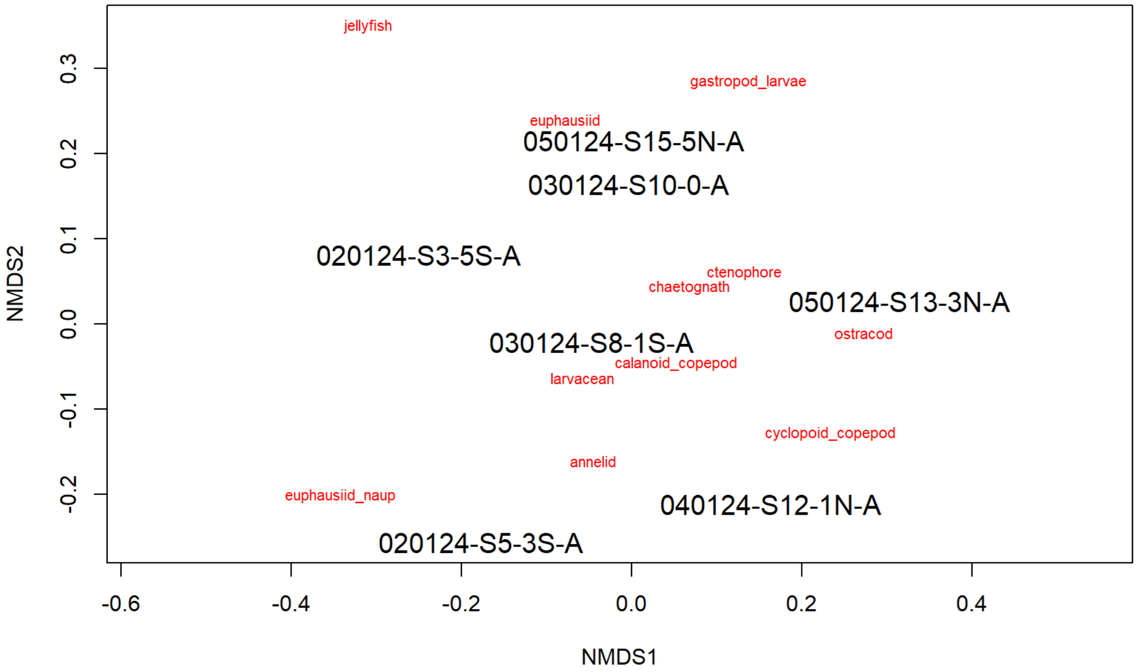

Figure 7: Non-metric multi-dimensional scaling plot. Shows closeness between stations (black) and species (red).

Discussion

When looking at species diversity over all organisms, it is lower at the equator, but abundance is high, indicating that calanoid copepods are much higher there (80% of organisms counted). Due to the equatorial current and equatorial countercurrent, copepods may have a higher degree of survival in that environment compared to more delicate organisms such as pteropods or certain larvae due to higher resilience in different temperature and pH regimes. The high abundance at the equator and lower abundances at 5°N and 5°S were anticipated due to the upwelling in the area. However, due to El Niño there was decreased upwelling strength, and nutrients were consistent over all latitudes sampled. This was contrary to the hypothesis that nutrients would be higher at the equator, which may be due to high phytoplankton exploitation. Fluorescence was particularly low at the equatorial site, but sampling was conducted at night, so it is unclear if phytoplankton is indeed low at the equator, or if cells were dividing at that time and densities were lower than during day. Additionally, a delay in zooplankton response to fluorescence or phytoplankton activity further away from the production location is known to occur in the equatorial pacific (Roman et al., 2002). The delay could have caused the relationship between high abundance and low fluorescence (Fig. 5).

The high abundance identified at the equator is consistent with Roman et al., (2002) in the species abundance being highest at the equator and lower further away from the equator. Chordata were highest near 5°N in Long et al., (2021), which is not consistent with our findings of highest abundance of larvaceans at the equator (Fig. 4). High copepod abundance was found at 160°W along a longitudinal transect at the equator in (Long et al., 2021). While we conducted a latitudinal transect, we still found high abundances of copepods at the equatorial station, which aligns with the findings of (Long et al., 2021).

Species richness decreased north of the equator and correlates with the change in current direction between the equatorial current and the north equatorial countercurrent (Fig. 6). This was initially hypothesized based on the information provided by (Keister et al., 2011) that different currents can carry different compositions of species from different origin areas (Fig. 4; Fig. 6). Currents carrying different community compositions could impact the carbon cycling of an area, as different organisms process carbon at different rates and with different magnitudes.

In terms of the overall variability of zooplankton distribution, while it could be attributed to the factors presented and vary likely are connected to them, it is difficult to determine a specific source. In non-metric multidimensional scaling, there was little grouping present, indicating no strong differences between stations (Fig. 7). There was no relationship between day/night and zooplankton abundance despite diel vertical migration ($p > 0.05$), and previous literature shows that there is no relationship between zooplankton abundance during the night versus the day in the equatorial pacific (Gaudy et al., 2004). The distribution of zooplankton in the equatorial pacific is quite variable, and even if multiple replicates were taken, it is still very likely that there would still be a large amount of variation between latitudes and replicates.

Overall, water chemical constituents did not have a significant relationship with zooplankton abundance or diversity, which is unlike what other studies have found (Long et al., 2021). There were four linear relationships identified, with temperature and fluorescence having a negative relationship between abundance (Fig. 5ab). The negative relationship with temperature was contrary to the initial hypothesis of higher temperature would correlate with a higher abundance. The negative relationship with abundance and temperature makes sense, as biological organisms typically have their ideal temperature range very close to their lethal temperature range (Kish et al., 2016). Even a subtle, sudden increase in temperature due to an abnormal heatwave (El Niño) would result in widespread mortality.

Phosphate and nitrate+nitrite had a positive relationship with abundance (Fig. 5cd). This coincides with the hypothesis that higher abundance would correlate with higher nutrients. There was a significant relationship found between high nitrate and high zooplankton in (Long et al., 2021), likely due to the connection with phytoplankton. Time of day, sea roughness, and only one sample at each location all could have influenced the species diversity and nutrient relationships visualized from the data.

Additionally, none of the papers with similar data to compare to were conducted under Strong El Niño conditions, which could have heavily influenced the results due to an influx of warm water and current strength. Under El Niño, the south equatorial counter current changes directions from normal and flows from east to west (Zhang & Clarke, 2017), which could change the origin of zooplankton communities or water body metrics. El Niño also decreases the magnitude of upwelling, which causes decreased nutrients around the equator. With lower nutrients, there is a subsequent decrease in phytoplankton abundance, and a correlated suspected decline in zooplankton abundance.

Conclusion

Understanding how zooplankton abundances and composition changes with different environmental variables can help us understand the impact of climate change on them. The diversity and community spread were higher north of the equator, which was contrary to the initial hypothesis. There was also a negative correlation with total abundance and temperature, which was contrary to the initial hypothesis. High nutrients were correlated with high abundance, which aligned with the hypothesis. It was also found that larvaceans and copepods became dominant species north of the equator, both of which are relatively resilient species (larvaceans are gelatinous, copepods have a significant diversity). Carbon cycling is changed as the species diversity decreases, and the microbial communities are impacted, the ability for the surface oceans to sequester carbon from organism death and sinking declines. Future research should include multiple replicates over different years with varying ENSO exposure to compare the impact of ENSO on zooplankton abundance and species diversity over time.

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