Zooplankton Diversity and Abundance in the Western Pacific Ocean

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Abstract:

Zooplankton plays a crucial role in marine ecosystems by linking primary producers, such as phytoplankton, to higher trophic levels. This study explains the relationship between zooplankton abundance and phytoplankton availability at different depths and times of day in the water near Guam. Sampling was conducted aboard the R/V Thomas G. Thompson at three stations 9°N, 147 °E; 4°N, 149 °E; and 14°N, 148 °E three different depths, 20, 200, and 600 m using a 1 m ring net with a 211 µm mesh size, and CTD was used to analyze how nutrient availability, chlorophyll-a, temperature, and diel vertical migration (DVM) shape zooplankton communities. While chlorophyll-a and zooplankton abundance showed no correlation (R^2 = -0.106, p = 0.932), temperature showed a strong predictor, with surface layers (0-20 m) exhibiting a significant positive correction (R^2 = 0.568, p = 0.031). Nutrient trends revealed no statistically significant depth-related accumulation ($p > 0.05$ for nitrate, phosphate, and nitrogen). Station 18's low zooplankton abundance, despite midday sampling coinciding with DVM, was linked to food limitation from depleted chlorophyll and nutrients. Calanoid copepods overwhelmingly dominated all stations and depths (mean abundance: 116.4 m^{-3}), underscoring their resilience to variable food and nutrient availability as well as their central role in the ecosystem. Diversity indices highlighted station-specific patterns: Station 8's deep layer (0–600 m) had the highest Shannon diversity (H' = 2.23), while Station 18's surface layer showed the greatest Margalef richness (D = 6.06). These results emphasize the interplay of thermal stratification, localized productivity, and behavioral adaptations in structuring zooplankton communities. Understanding ecosystem dynamics like chlorophyll and nutrients is important for zooplankton responses to environmental change.

Plain Language Summary:

The study explores the relationship between phytoplankton and zooplankton in the ocean. Phytoplankton are the primary food source for zooplankton, and environmental factors like temperature and nutrient levels influence their abundance. Zooplankton moves up and down in the water column in a pattern called diel vertical migration (DVM). They stay deep during the day to avoid predators and come to the surface at night to feed on phytoplankton. This movement affects how phytoplankton and zooplankton are mixed in the ocean, influencing the food web and nutrient cycle. The research was conducted in the Western Pacific aboard the research vessel R/V Thomas G. Thompson. Samples of zooplankton were collected at different depths and times of the day at three stations (7, 8, and 18) by using a net to collect zooplankton and measuring environmental factors like nutrient levels, chlorophyll, and temperature. Stations 7 and 8 had more zooplankton than station 18 due to higher phytoplankton levels. More zooplankton were found near the surface at night, supporting the idea that they migrate to feed when it's dark. Among zooplankton, the most common and dominant species across all sites and depths are copepods. Zooplankton play a critical role in marine ecosystems by linking phytoplankton to larger predators like fish. Their abundance and diversity can indicate changes in ocean health, such as shifts in water quality and climate change impacts. Understanding these relationships helps scientists predict how marine ecosystems might respond to environmental changes.

Introduction:

Phytoplankton, a primary producer, affects the abundance of zooplankton at different depths. Various factors, such as temperature and nutrient availability, also play critical roles in phytoplankton abundance. Zooplankton move through the water column, also known as diel vertical migration (DVM). During the day, they migrate to deeper waters to avoid predators, and at night, they return to the surface to feed on phytoplankton (Courage, 2024).

Studies such as The Georges Bank (Riley & Dean, 1946) suggest that the DVM of zooplankton might lead to differential mixing rates for phytoplankton and zooplankton. Phytoplankton are passive drifters, while zooplankton actively migrate, influencing nutrient cycling and predation patterns (Martin, 1965). The mixing of the two species results in increased consumption of phytoplankton at certain depths (since zooplankton concentration is higher at specific depths).

The distribution of zooplankton diversity, richness, and evenness offers valuable insights into how environmental factors shape these communities. By analyzing these metrics—where diversity indices (Shannon-Weiner and Evenness) reflect species distribution and richness (Margalef's index) quantifies species count—we gain a more comprehensive understanding of zooplankton composition and coexistence (Long et al., 2021). These indicators help reveal the influence of physical and chemical conditions, such as temperature, nutrient availability, and chlorophyll concentration, on zooplankton (Long et al., 2021).

Atolls, ring-shaped coral reefs enclosing shallow lagoons, are dynamic ecosystems where nutrient availability and biotic interactions critically shape ecological processes. Phytoplankton, as primary producers, forms the base of these food webs, converting sunlight and nutrients into biomass, thereby influencing zooplankton abundance across depth gradients (Dufour & Berland, 1999). In oligotrophic atoll lagoons, phytoplankton growth is often co-limited by nitrogen and phosphorus, with nitrogen being the dominant constraint in most systems. However, smaller lagoons, like Reka Reka, exhibit phosphorus limitation due to unique hydrogeomorphic conditions, such as limited oceanic exchange and high sediment-to-water ratios (Dufour & Berland, 1999). These nutrient dynamics directly influence the phytoplankton biomass, which serves as a food source for zooplankton, particularly mesozooplankton (0.2-20 mm), which graze on phytoplankton in the 20-200 µm size range (Liu & Dagg, 2003).

The DVM of zooplankton affects the mixing process, further modifying grazing patterns. Through grazing and the regeneration of nutrients, zooplankton have been shown to maintain nitrogen and phosphorus ratios in the environment (Sterner, 1986). By redistributing nutrients vertically, zooplankton mitigates the impacts of depletion of surface nutrients, enhancing ecosystem stability under varying conditions. I hypothesize that the chlorophyll and nutrient concentrations directly influence the diversity and count of zooplankton, with chlorophyll being a proxy for phytoplankton. This study will address key questions regarding zooplankton abundance trends as chlorophyll availability changes with environmental factors like temperature and nutrient concentration. In the aquatic food web, zooplankton links phytoplankton and large predators like fish, indicating an ecosystem's overall health. A change or dominance of one zooplankton can signal environmental changes like water quality, nutrient levels, and temperature (Lizotte, 2008).

Methods:

Sampling was done aboard the R/V Thomas G. Thompson along $149\,^{\circ}E$ longitude.

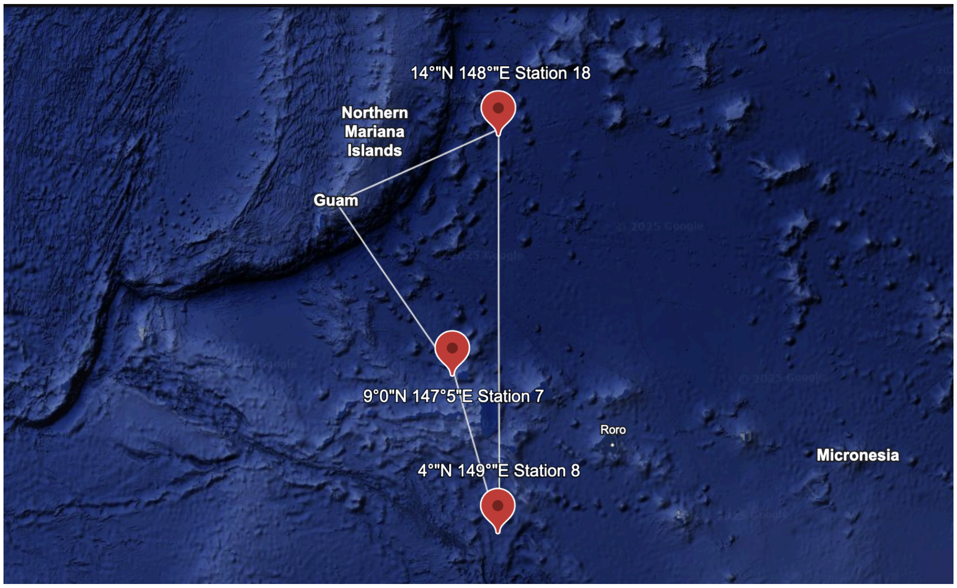


Figure 1: Map of the location of stations 7, 8, and 18 (red) along the cruise transit. The map shows the latitude and longitude coordinates for location reference, and the white line shows a portion of the cruise transit path.

Samples were collected at $9^{\circ}N,\ 147^{\circ}E;\ 4^{\circ}N,\ 149^{\circ}E;$ and $14^{\circ}N,\ 148^{\circ}E$ (Figure 1). Zooplankton was collected at the same depths from the surface to the projected depth, but the time varied across different stations. At station 7 near the atoll, samples were collected at depths 0-20, 0-200, and 0-600 m. The start time was 7:01 pm, and the end time was 11:10 pm. At station 8, samples were collected at depths 0-20, 0-200, and 0-600 m. The start time was 4:00 pm and the end time was 6:30 pm. At station 18, samples were collected at depths of 0-20, 0-200, and 0-600 m. The start time was noon, and the end time was 2:30 pm. A ring net 1 m in diameter and 211 µm mesh size was used to collect zooplankton. After the samples were brought back onto the ship, the net was rinsed throughout with seawater downward to concentrate the sample, then the sample was transferred into a container. Using the 211µm mesh, the content was poured and rinsed into a sample jar. A final concentration of 5% buffered formalin in seawater was added to preserve the zooplankton and kept on board the laboratory fridge. The samples were processed in the ship's lab. A Stempel pipette was used to extract the sample to count the zooplankton and split it into aliquots of 6 mL. Each collected sample was processed separately according to its respective depth (0-20 m, 0-200 m, and 0-600 m). Equal aliquots were extracted from each depth-specific sample to ensure consistent counting, and Equation 1 was used to find the abundance of zooplankton per ml sample, and the total count for each depth was standardized using the dilution factor (Equation 2) and the volume of water filtered or projected (Equations 3 and 4). An Eclipse microscope was used to count and categorize the zooplankton for each station. The taxonomy was determined using Coastal Marine Zooplankton: A Practical Manual for Students by C.D. Todd, M.S. Laverack, and G.A. Boxshall and Sea Grant's Marine Zooplankton of the Puget Sound guide. Under the microscope, each type of zooplankton seen was recorded and counted. A flow meter was used to measure the volume of water filtered. However, the values were not accurate, so the distance traveled was used as the projected distance.

Analysis:

1. $$abundance = \frac{(count * dilution\ factor)}{Volume\ water_{filtered\ or\ projected}}$$

2. $$dilution\ factor = \frac{Total\ volume\ of\ sample}{Volume\ of\ aliquot}$$

3. $$Volume\ water_{projected} = \frac{(diameter_{net})^2}{2} * 26873(flowmeter_{end} - flowmeter_{start}) * 10^{-6} * \pi$$

4. $$Volume\ water_{projected} = \frac{(diameter_{net})^2}{2} * distance_{projected} * \pi$$

5. $$H' = \sum_{i=1}^{S} P_i \log_2 P_i$$

6. $$S = \frac{(S-1)}{ln\ (N)}$$

7. $$J = \frac{H'}{ln\ (S)}$$

Data was analyzed in Excel and Python. Google Colab was used for graphing and plotting the data. Excel was used to calculate the Shannon-Weiner Diversity Index (H') (Equation 5), Margalef's richness index (S) (Equation 6), and Species Evenness (J) (Equation 7).

A CTD rosette was used to collect temperature, salinity, and nutrient concentrations. Nutrient samples were collected from Niskin bottles on the CTD rosette at multiple depths. Niskin bottles were rinsed three times, and the water from the rosette was filled in it. Then, samples were placed in a cooler to be shipped back to the University of Washington Marine Chemistry Laboratory for analysis. At the lab, nutrients were processed, and data was produced. Levels of Nitrate, Phosphate, Orthosilicic acid, Nitrogen dioxide, and Ammonium from the nutrient data were analyzed.

Results:

The analysis of zooplankton abundance across different stations and depths (Figure 2) provides insights into their distribution and variability.

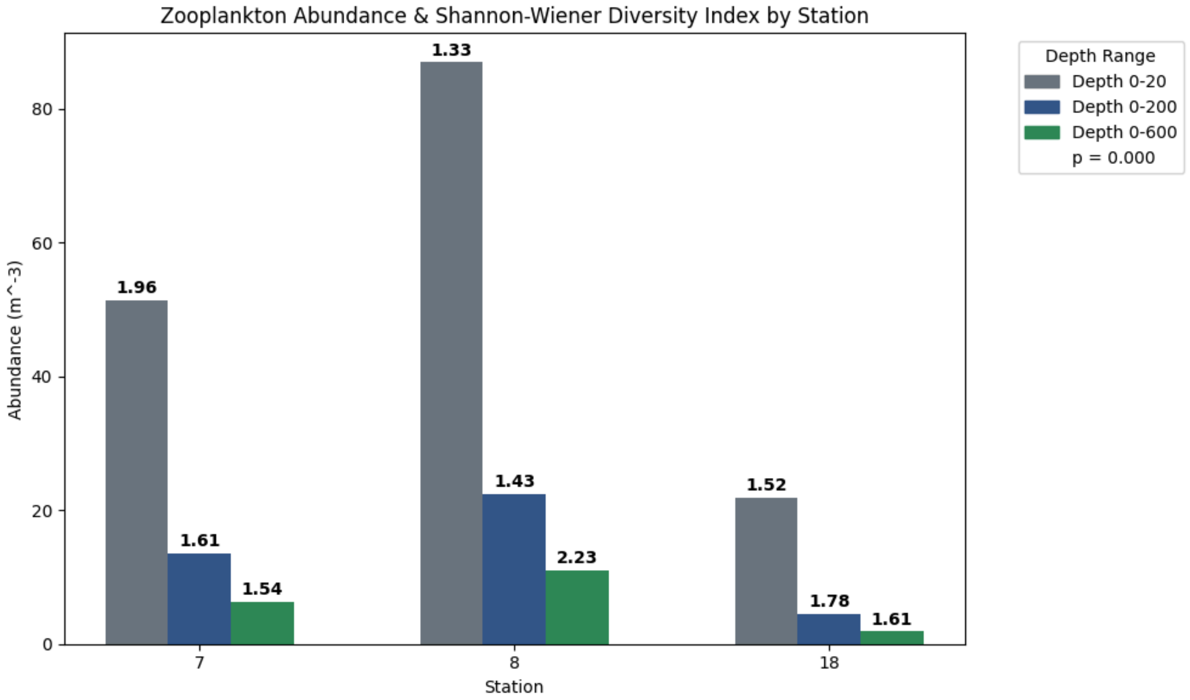


Figure 2: The abundance of zooplankton (measured in individuals per cubic meter) across three stations (7, 8, and 18) at varying depths. The number above each graph shows the Shannon-Wiener Diversity.

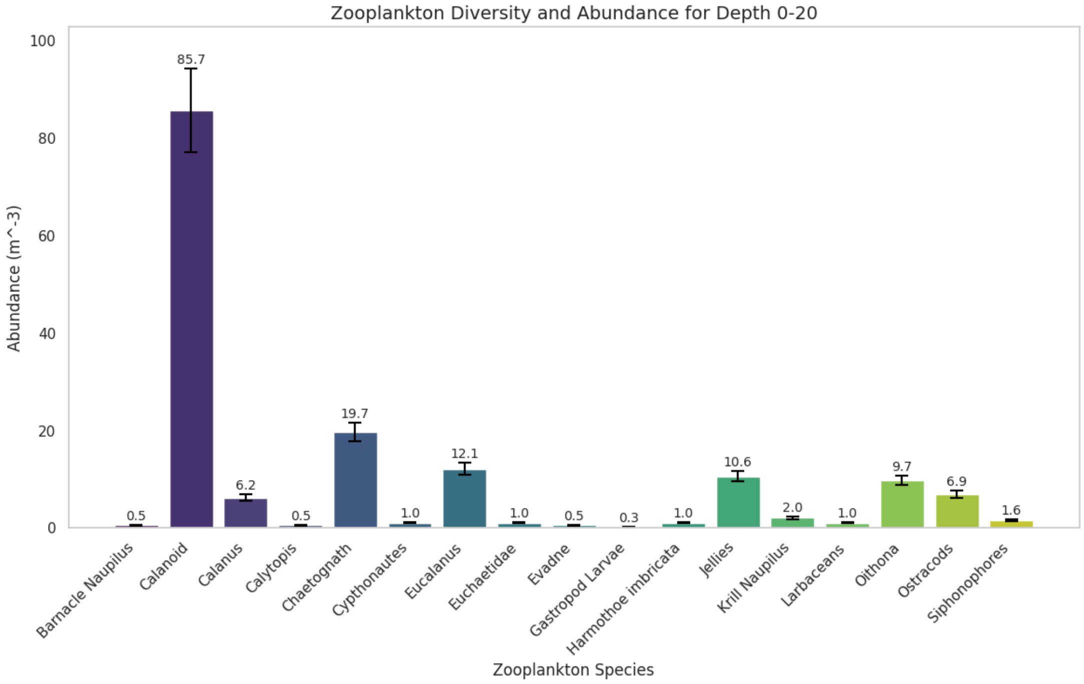
Significant variation in zooplankton distribution was observed across stations and depths. Zooplankton abundance was significantly higher at Station 7 (located at the atoll) and Station 8 (south of Station 7) compared to Station 18, as indicated by the Two-Way ANOVA results (p = 0.000). At shallower depths (0-20 m), abundance was consistently higher than at deeper depths, with Station 8 exhibiting the highest zooplankton abundance in the 0-20 m depth range (approximately 90 individuals m^3). In contrast, Station 18 recorded the lowest abundance across all depths. A general trend of decreasing zooplankton abundance with increasing depth was observed at all stations. The Shannon-Wiener diversity index (H') values, displayed above each bar in Figure 1, further highlighted differences in species diversity. The highest diversity (H' = 2.23) was recorded at Station 8 within the 0-600 m depth range, while the lowest diversity (H' = 1.33) was observed at the same station but within the 0-20 m depth range. These findings suggest that both spatial location and depth significantly influence zooplankton abundance, with shallower waters and specific stations supporting higher zooplankton populations and varying levels of species diversity.

Station	Depth	Shannon-Weiner diversity index	Margalef's Richness Index	Species Evenness
7	0-20	1.95711533	5.086405121	0.587333498
7	0-200	1.605310453	4.461269364	0.481756281
7	0-600	1.544483478	4.045975488	0.463502007
8	0-20	1.33447115	5.269357886	0.400476965
8	0-200	1.425624392	4.452664313	0.427832202
8	0-600	2.226152721	3.928321898	0.668072057
18	0-20	1.517157133	6.061494132	0.455301326

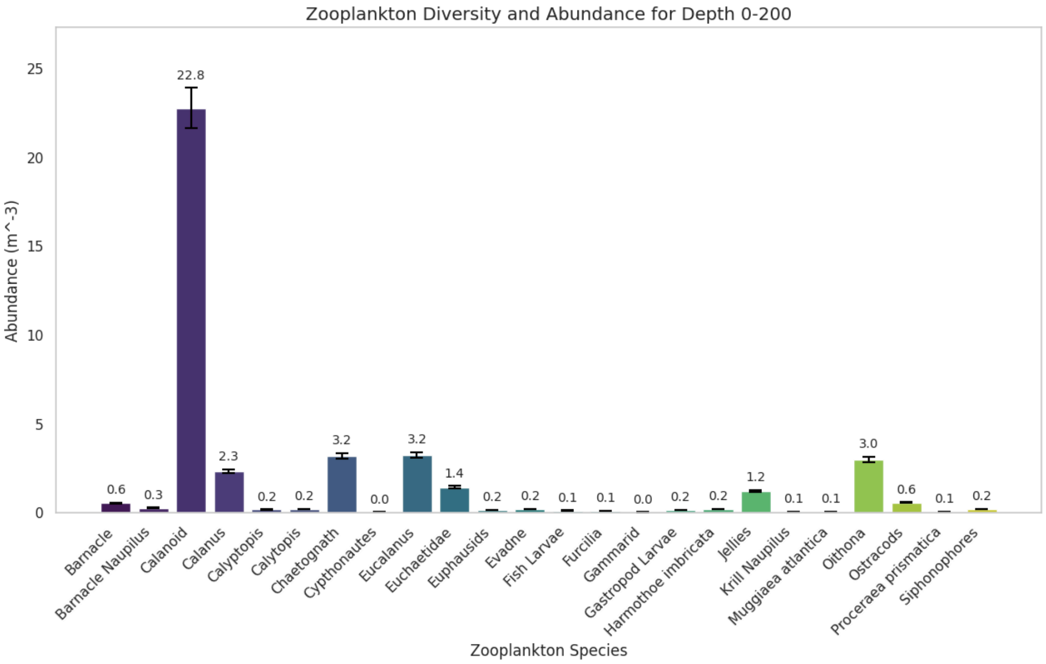
18	0-200	1.775292418	5.53823737	0.532768146
18	0-600	1.612013289	5.333233218	0.483767813

Table 1: The Shannon-Wiener Diversity Index, Margalef’s Richness Index, and Species Evenness at three sampling stations (7, 8, and 18) across varying depth ranges (0–20 m, 0–200 m, and 0–600 m). These indices provide insights into species diversity, richness, and evenness in the sampled marine environments.

a.


Zooplankton Diversity and Abundance for Depth 0-20
Abundance (m^-3)
100
80
60
40
20
0
85.7
6.2
0.5
19.7
1.0
12.1
1.0
0.5
0.3
1.0
10.6
2.0
1.0
9.7
6.9
1.6
0.5
Barnacle Naupilus
Calanoid
Calanus
Calytopis
Chaetognath
Cypthonautes
Eucalanus
Euchaetidae
Evadne
Gastropod Larvae
Harmothoe imbricata
Jellies
Krill Naupilus
Larbaceans
Oithona
Ostracods
Siphonophores
Zooplankton Species

b.


Zooplankton Diversity and Abundance for Depth 0-200
Abundance (m^-3)
25
20
15
10
5
0
0.6
0.3
22.8
2.3
0.2
0.2
3.2
0.0
3.2
1.4
0.2
0.2
0.1
0.1
0.0
0.2
0.2
1.2
0.1
0.1
3.0
0.6
0.1
0.2
Barnacle
Barnacle Naupilus
Calanoid
Calanus
Calyptopis
Calytopis
Chaetognath
Cypthonautes
Eucalanus
Euchaetidae
Euphausids
Evadne
Fish Larvae
Furcilia
Gammarid
Gastropod Larvae
Harmothoe imbricata
Jellies
Krill Naupilus
Muggiaea atlantica
Oithona
Ostracods
Proceraea prismatica
Siphonophores
Zooplankton Species

c.

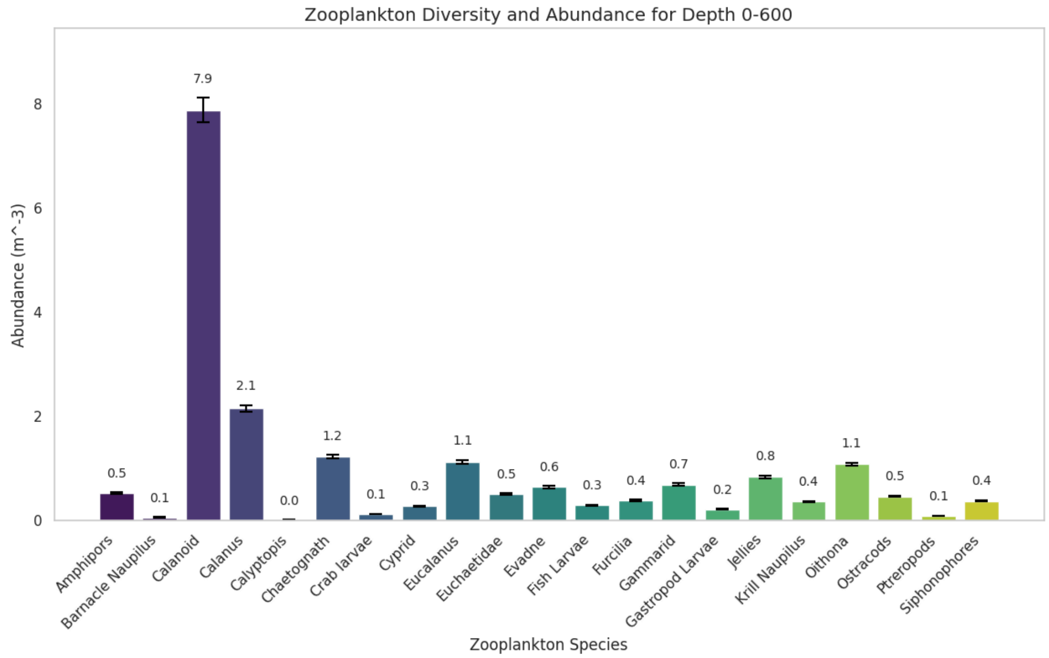


Figure 3: Zooplankton diversity, with calanoid being the most abundant. Eucalanus and Chetognath contribute significantly. 3a depth ranges from 0-20, 3b ranges from 0-200, and 3c ranges from 0-600.

Figure 3 illustrates the diversity across all three stations. There are three separate graphs, each representing data for one of the three depths: 0-20, 0-200, and 0-600. Calanoid copepods are the most dominant zooplankton species across all stations and depths. The second most abundant group, Chaetognaths, recorded a much lower abundance, followed by a few more copepod species like Eucalanus, Oithona, and Calanus. Other species, such as Jellies, Ostracods, and Krill Nauplius, were present in relatively lower concentrations. The remaining zooplankton taxa exhibited even smaller population densities, with some species like Gammarid and Crab larvae. These findings show that copepods are a key component of the zooplankton community, likely playing a major role in the food web dynamics of the region.

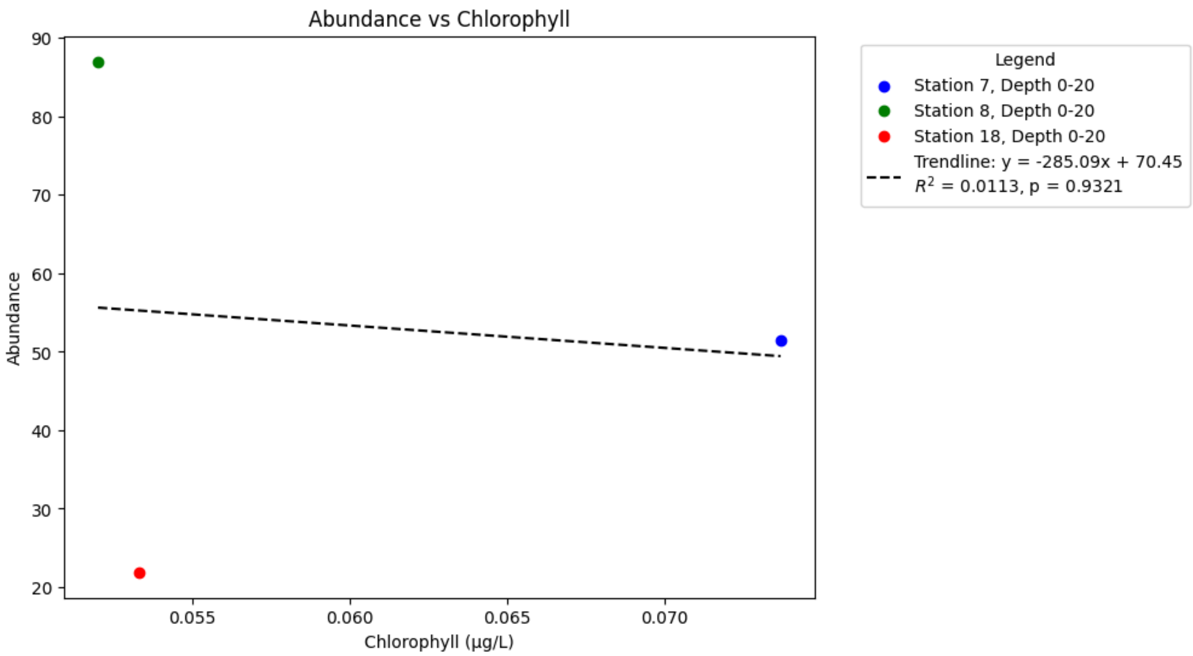
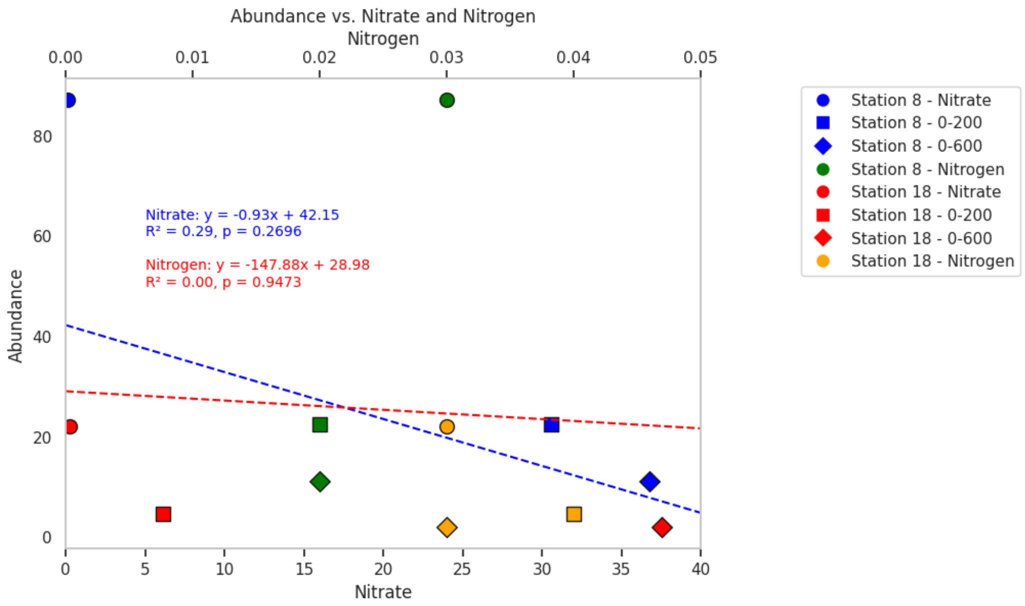


Figure 4: The scatter plot shows the relationship between total chlorophyll concentration (µg/L) and abundance at three stations (7, 8, and 18) at a depth of 0–20 m. Different colors represent different stations for comparison.

A classmate who was working with chlorophyll data provided the data. The graph depicts no correlation between total chlorophyll concentrations and abundance. A Pearson correlation test was conducted to determine the significance of the association. The analysis revealed no correlation between chlorophyll and zooplankton abundance (r = -0.106, p = 0.932). This aligns with linear regression results (y = -285.09x + 70.45, R^2= 0.0113, p = 0.9321), where the minimal R^2value indicates that chlorophyll explains only ~1% of the variability in zooplankton abundance. The lack of statistical significance suggests that chlorophyll levels alone do not strongly predict zooplankton abundance.

a.



b.

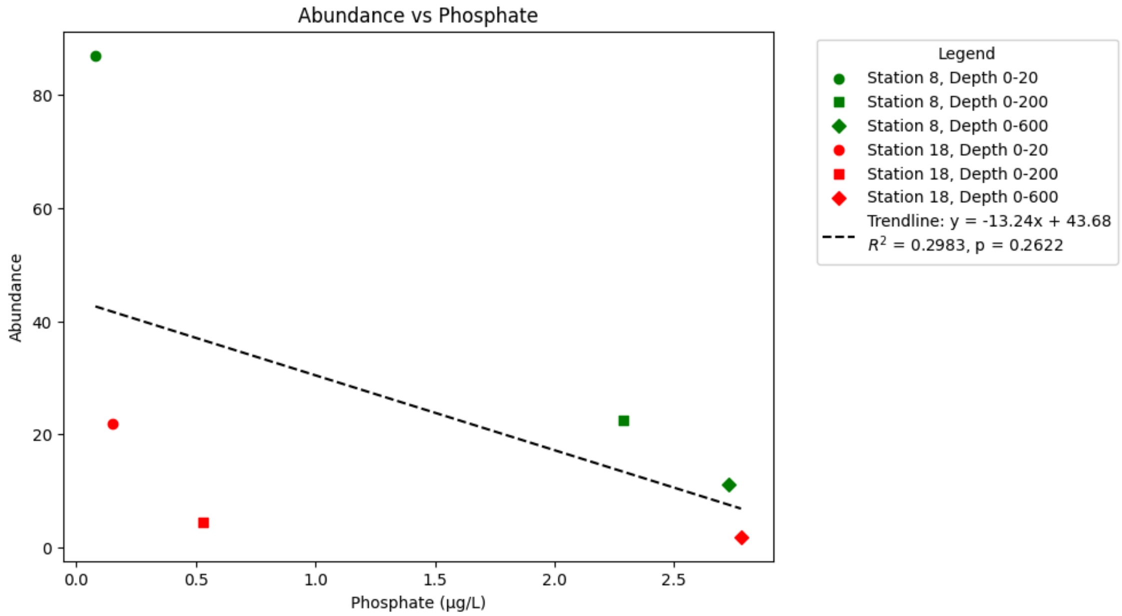


Figure 5a: The nitrate and nitrogen concentrations on species abundance at different stations and depths. The blue trendline represents the relationship between nitrate and abundance, showing a weak negative correlation. The red trendline represents the relationship between nitrogen and abundance

5b: Zooplankton abundance versus phosphate concentration (µg/L) at different depths for Station 8 and Station 18. Different markers represent depth ranges (0–20 m, 0–200 m, and 0–600 m) for each station.

Nutrient concentrations(nitrate + nitrogen and phosphate) did not statistically tend to increase with depth. While surface layers (0-20) displayed slightly lower nutrient levels, consistent with phytoplankton uptake. Both nitrate and nitrogen showed a weak, non-significant decline with (y = -0.93x + 42.15, R^2= 0.29, p =0.270) and nitrogen (R^2= 0.00, p = 0.947). Similarly, a negative trend with depth was observed for phosphate (y = -13.24x + 43.68, R^2= 0.298, p = 0.262). Despite the regression slope suggesting lower phosphate in deeper layers, the relationship was not statistically significant, and variability across stations obscured clear depth-related trends.

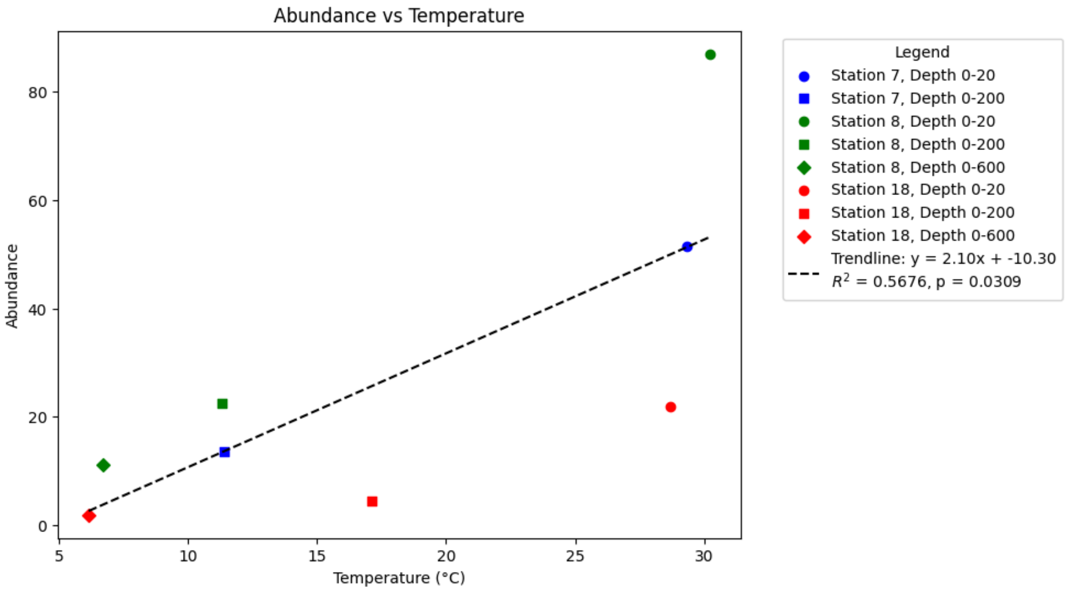


Figure 6: The correlation between species abundance and temperature (°C) across different stations and depths. Different markers and colors represent data from various stations and depth ranges.

A significant positive correlation was observed between temperature and zooplankton abundance (y = 2.10x - 10.30, R^2= 0.568, p = 0.031). Higher temperatures in surface layers (0-20 m) corresponded to greater zooplankton densities due to enhanced phytoplankton productivity in these warmer, sunlit zones. The moderate R^2 value (56.8%) suggests that temperature explains a substantial portion of the variability in abundance, though other factors (e.g., nutrient availability, predation) likely also influence zooplankton abundance.

Discussion:

The diel vertical migration (DVM) of zooplankton is a behavioral adaptation where organisms ascend to surface water at night to feed and descend to deeper layers during daylight to avoid predators (Courage, 2004). At stations 7 and 8, after sunset, sampling captured zooplankton at the surface during nocturnal time, exploiting phytoplankton-rich zones (Figure 2). However, midday sampling at station 18 agreed with their deeper daytime refuge, resulting in lower observed surface abundance. This aligns with the predation-avoidance hypothesis (Liu et al., 2004), where DVM balances feeding opportunities with predation risk. However, samples were not collected at the same station day and night, leading to the inability to test the DVM hypothesis.

Calanoid copepods dominated zooplankton communities across all stations (Figure 3), a pattern reflecting their flexibility and tolerance to variable nutrients (Chang, 2004). Despite station 18's low temperature, copepods, even at reduced densities, highlight their resilience and adaptability. Their dominance plays a key role in species in marine food webs, transferring energy from primary producers to higher trophic levels (Karakus et al., 2022).

The relationship between chlorophyll (phytoplankton biomass) and zooplankton abundance showed no significance (R^2 = -0.106, p = 0.932). However, since chlorophyll data was not collected at deeper depths, a direct comparison with zooplankton abundance is not possible. Instead, temperature showed as a strong driver: the significant positive correlation between temperature and zooplankton abundance (R^2= 0.568, p = 0.031) indicated that warmer surface layers enhance metabolic rates and phytoplankton productivity, indirectly boosting zooplankton population (Figure 6). This aligns with global patterns where thermal stratification concentrates resources in sunlit zones (Williams & Murdoch, 1966). Similar trends have been observed, where temperature is a key structuring factor in the marine ecosystem, influencing nutrient availability and zooplankton abundance (Richardson, 2008).

A study by Dufour and Berland (1999) found that nitrate-nitrogen has the biggest effect on phytoplankton growth. Their findings indicate that in most lagoons, nitrogen availability has the strongest impact on phytoplankton biomass, while in certain cases, phosphorus (P) also plays a significant role. Notably, in lagoons such as Reka-Reka, phosphorus had a greater effect on primary production during specific periods, highlighting the variability in nutrient limitation as phytoplankton serves as the primary food source for many zooplankton species. The relationship between nutrient concentrations and phytoplankton abundance observed in their study aligns with the idea that nitrogen-driven phytoplankton blooms can directly impact zooplankton abundance. Variations in nitrogen and phosphorus concentrations correspond with changes in zooplankton diversity and abundance. The data from the cruise showed no significant depth-related trends for phosphate ($p = 0.262$), nitrate ($p = 0.270$), or nitrogen ($p = 0.947$). Stations 7 and 8 displayed surface nutrient depletion consistent with active phytoplankton uptake, but the high chlorophyll levels (Figure 4) suggest rapid nutrient recycling. At station 18, low nitrogen (Figure 5) likely restricted phytoplankton growth, cascading into zooplankton food limitation. Nitrogen's role as a primary limiting nutrient (Dufour & Berland, 1999) was evident here. The weak statistical trends emphasize the complexity of nutrient, chlorophyll, and zooplankton interactions. Furthermore, higher temperatures play a role in the feeding behavior of zooplankton (Figure 6). Increased phytoplankton concentrations during high temperatures, meaning a higher abundance of light, result in increased zooplankton abundance. Additionally, essential nutrients like nitrates, nitrogen, and phosphate are important in phytoplankton and zooplankton populations. Zooplankton grazing can indirectly contribute to nutrient cycling by releasing nutrients through excretion. The abundance of nutrients at times with high light can fuel phytoplankton blooms, which in turn support the growth of zooplankton populations (Riley & Dean 1946). Therefore, it can be concluded that zooplankton abundance is high at these stations.

The observed patterns in zooplankton diversity, richness, and evenness across stations and depths (Table 1) provide critical insights into how environmental gradients structure these communities. Evaluating these metrics is essential for understanding community structure, as diversity indices (Shannon-Weiner and Evenness) assess species distribution, while richness (Margalef's index) measures species count. Collectively, these offer a comprehensive view of zooplankton composition and coexistence under varying conditions. These metrics help reveal how physical and chemical factors, such as temperature, nutrient availability, and chlorophyll concentration, influence zooplankton assemblages. Additionally, they help explain how species compete for resources, share habitats, and interact as predators and prey. For example, station 7, located near an atoll, had the highest Shannon-Weiner diversity index (H' = 1.96) and Mergalef's richness (D = 5.09) in the 0-20 m layer aligned with elevated chlorophyll concentrations (Figure 4) and warmer surface temperatures (Figure 6). The atoll's proximity likely enhances nutrient input subsurface upwelling, fueling phytoplankton productivity and supporting a diverse zooplankton community. This synergy of high chlorophyll (food availability) and optimal temperatures promotes metabolic efficiency and niche partitioning (when different species of zooplankton use resources to minimize competition and allow multiple species to coexist in the same environment), fostering both richness and evenness. Station 8, which exhibited the highest diversity in the 0–600 m depth layer, recorded the greatest Shannon diversity (H’ = 2.23) and evenness (0.67) among all stations. Zooplankton aggregate to a deeper depth during the daytime to avoid visual predators, but this behavior also redistributes nutrients through excretion, potentially enhancing deep-layer microbial loops. The study by Gittins et al. (2022) demonstrates that microbial activity in deep marine sediments is tightly linked to nutrient transport mechanisms, such as geological seepage and burial. While their work focuses on geologically mediated loops, it underscores the importance of nutrient availability in sustaining deep-layer microbial processes. Zooplankton-mediated nutrient redistribution could similarly stimulate microbial activity in these zones, complementing the subsurface dispersal loop described here. However, the low richness (D = 3.93) at this depth suggests only a subset of taxa tolerates harsh conditions (e.g., colder temperatures, limited light) (Gittins et al. 2022). Notably, Station 8’s surface layer (0–20 m) had the lowest diversity (H’ = 1.33), likely due to competitive exclusion (species rely on the same limited resources) by dominant copepods (Figure 3) in resource-rich surface waters—a reminder that DVM is not solely predator-driven but also shaped by resource competition and niche specialization. Station 18 had the highest Margalef’s richness (D = 6.06) in its 0-20 m layer. Despite its low chlorophyll and nutrient levels (Figure 4-5), this station’s richness highlights the potential for transient species adapted to extreme conditions. The lower evenness (0.46-0.53 across depths) compared to station 8 further underscores how resource limitation may favor a subset of resilient taxa, such as copepods, over a balanced community. These findings underscore the complex interplay between environmental gradients, species interactions, and adaptive strategies in shaping zooplankton community structure across different stations and depths.

Conclusion:

This study highlights the complex interactions between chlorophyll as a proxy for phytoplankton and zooplankton abundance. Zooplankton varied across stations and depths, with higher concentrations near the surface and the atoll. Diel vertical migration played a key role, as zooplankton moved upward at night to feed and descended during the day to avoid predators. No significant correlation was found between chlorophyll concentration and zooplankton abundance, suggesting that other factors influence populations. However, data limitations for chlorophyll, nutrient concentrations, and DVM measurements may have affected the ability to thoroughly test their relationship with zooplankton abundance. Instead, temperature emerged as a key driver, with higher temperatures linked to increased zooplankton abundance, likely due to enhanced phytoplankton productivity. Nutrient concentrations showed no strong depth-related trends, though surface depletion occurred at some stations. The dominance of calanoid copepods across all stations highlights their crucial role in marine food webs. Further research is needed to account for how seasonal variations affect zooplankton abundance, as well as the long-term effects of environmental changes such as rising ocean temperatures and nutrient shifts. Understanding these dynamics is essential for predicting how zooplankton populations may respond to future environmental changes, with broader implications for marine food webs and ecosystem stability.

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