

Impact of the Island Mass Effect on Zooplankton Community Composition  
Around the NAM-2 Coral Atoll in the Western Pacific Ocean

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3/14/2025

## Abstract

Phytoplankton acts as the base of the marine food web, providing energy to higher trophic levels such as zooplankton. Zooplankton are an intermediate part of the food chain that can provide evidence of an area with high productivity. The focus of this study was to investigate the Island Mass Effect (IME) and its impact on zooplankton communities around the NAM-2 Atoll located to the southeast of Guam. Data was collected on the TN440 research cruise on the *R/V Thomas G. Thompson* from December 29<sup>th</sup>, 2024, to January 11<sup>th</sup>, 2025. Zooplankton nets were deployed at five stations around the unmapped atoll, NAM-2, (09°08'40''N, 148°07'50'' E), and three stations on the 149°E WOCE line in the open ocean, specifically at latitudes 5°N, 9°N, and 15°N. Zooplankton metrics of abundance and diversity, current direction, temperature, nutrients, and bathymetry were measured around the NAM-2 Atoll and the open ocean to observe the biological productivity of the IME. The highest abundance of zooplankton throughout all of the sites were the calanoid copepods, followed by the cyclopoid copepods, and then the chaetognaths. There was a statistically significant relationship between copepods and their predator, chaetognaths. There was no statistical significance between zooplankton abundance and diversity between the atoll and open ocean sites and among the variables of temperature, nutrients, current direction, and bathymetry. These factors likely still impacted the abundance and diversity of zooplankton. These factors, along with the predator-prey relationship between copepods and chaetognath, may still indicate NAM-2 as a biologically productive area, according to the IME. Also, the varying current directions may bring different compositions of zooplankton to the study stations. Further research is needed to discover the complete picture of this location, which could eventually lead to contributions to Guam's fishing economy.

## Plain Language Summary

Phytoplankton and zooplankton are tiny drifting organisms located close to the surface of the ocean and are involved in the energy transfer among other organisms. Due to their importance in the food web, understanding how many and what types of zooplankton are in a specific area can determine biologically productive locations. Data was collected on the TN440 research cruise on the *R/V Thomas G. Thompson* from December 29<sup>th</sup>, 2024, to January 11<sup>th</sup>, 2025. Zooplankton nets were deployed at five stations around the unmapped atoll, NAM-2 atoll, (09°08'40''N, 148°07'50'' E) and three stations on the 149°E WOCE line in the open ocean, specifically at latitudes 5°N, 9°N, and 15°N. Measurements of zooplankton, nutrients, temperature, current direction, and depth features of the atoll were collected. The highest abundance of zooplankton throughout all the sites were crustaceans called copepods, followed by the cyclopoid copepods, and then the chaetognaths. There was a statistically significant relationship in that an increase in copepods correlated with an increase in their predator, chaetognaths. There was no statistical significance between zooplankton abundance and diversity between the atoll and open ocean sites and among the variables of temperature, nutrients, current direction, and the depth features of the atoll. These factors, along with the predator-prey relationship between copepods and chaetognath, may be able to indicate NAM-2 as a biologically productive area, according to the island mass effect. Further research is needed to discover the complete picture of this location, which could eventually lead to contributions to Guam's fishing economy.

## **Introduction**

Phytoplankton are crucial organisms to the marine ecosystem as they are primary producers that provide organic carbon to high trophic levels as they form the basis of the marine food web. They drive the trophic structure of the entire marine environment, specifically impacting zooplankton distributions and, therefore, larger, highly mobile consumers such as fish (Sheehan et al., 2019). The impact of phytoplankton biomass is profound near atolls, as this oceanic feature predominantly resides in oligotrophic waters. Therefore, understanding the factors that promote nearshore phytoplankton biomass is crucial for determining the health of an ecosystem and its prosperity (Hamner and Hauri, 1981).

The pattern of increased phytoplankton biomass proximate to the atoll and island environments has been termed the Island Mass Effect (IME). According to Gove et al. 2016, researchers described the IME as how atoll flushing, human-derived runoff, riverine outflow, and submarine groundwater outflow to the outer slope of the atoll contribute to increased concentrations of nutrients, which then leads to an increased abundance of phytoplankton.

There are variations in IME between islands and atolls because of geomorphological features, resulting in atolls having higher nearshore chlorophyll concentrations. This is due to atolls having partially enclosed interior lagoons that have a concentrated ecosystem. Wave and tidal-driven flushing of these lagoon ecosystems to surrounding waters can transport nutrients that enhance phytoplankton biomass (Johnson, 1949; Li et al., 2018; Pagano et al., 2017). Specifically, wave forcing is an efficient atoll flushing mechanism that helps with the export of nutrients.

One location that supports the idea of the IME is the Hawaiian Archipelago. The Hawaiian Archipelago consists of nine reef ecosystems, which had the greatest long-term

increase of about 85.6% in total phytoplankton biomass compared to surrounding oceanic waters. This may be due to the region being characterized by islands and atolls with a gradual sloping outer reef bathymetry and high active internal wave generation (Gove et al., 2016).

To observe how nutrients and, therefore, phytoplankton affect the IME of the atoll, it is important to observe zooplankton distributions. Only studying chlorophyll concentration may not provide the best evidence for the IME, as zooplankton communities can overgraze phytoplankton populations, resulting in low chlorophyll concentration. This doesn't indicate that this area has low productivity, but it instead has high productivity due to zooplankton biomass (Levine et al., 1999). Therefore, zooplankton are a crucial aspect to observe as they can provide a more accurate biological productivity analysis through the IME around atolls. Additionally, studying zooplankton concentrations at the deep chlorophyll maximum (DCM) may help indicate productivity. The DCM depth acts as a bottom boundary of the pycnocline in which the mixed layer is located below and where subsurface peaks in chlorophyll-*a* concentration occur. These peaks may coincide with peaks in phytoplankton abundance and, therefore, indicate an area of primary productivity (Moeller et al., 2019).

As waves and tide patterns are important to nutrient transport, observing current direction and speed can provide insight into high-productivity areas (Hasegawa et al., 2004). For example, the Pandora Reef within the Great Barrier Reef lagoon found that zooplankton species distribution correlated with flow patterns. Due to the shape of the reef, there were separations in current flow that impacted the strength of gyres and eddies. These physical forces controlled the distribution of zooplankton. Observing the currents near the atolls can possibly also depict how zooplankton communities are dispersed. There are some possible influential currents like the North Equatorial Current (NEC), which is a broad westward flow that hits the Bifurcation

Region (BR). This geographical area, around 13°N, is where the NEC is split into two separate currents: the southward-flowing Mindanao Current (MC) and the northward-flowing Kuroshio Current. The Subtropical Countercurrent (STCC) is a weak flow within an area of eddies. Subthermocline boundary currents include the Mindanao Undercurrent heading northward and the Luzon Undercurrent (LUC) heading southward. These boundary currents then feed the eastward North Equatorial Undercurrent (NEUC) (Hamner & Hauri, 1981).

This study observed the IME at the NAM-2 Atoll located to the southeast of Guam. By studying specific atolls and their zooplankton communities, a database of information can be made to further support the notion of IME. The parameters of what biologically productive means is when there is a high abundance and diversity of zooplankton that are also involved in predator-prey relationships. This source could be economically important as zooplankton abundance could be used as an indication of large economic fish communities in pelagic marine ecosystems (Kendall et al., 2019; Long et al., 2021). I hypothesize that there will be a difference in spatial distribution, abundance, and diversity of zooplankton between the outer atoll reef slope and the open ocean because atoll reefs create a “near-island biological hotspot” where there is a significant amount of phytoplankton and therefore zooplankton as atolls usually reside in nutrient impoverished waters. My null hypothesis is that there will be no difference in spatial distribution, abundance, and diversity of zooplankton between the outer atoll reef slope and the open ocean.

## Methods

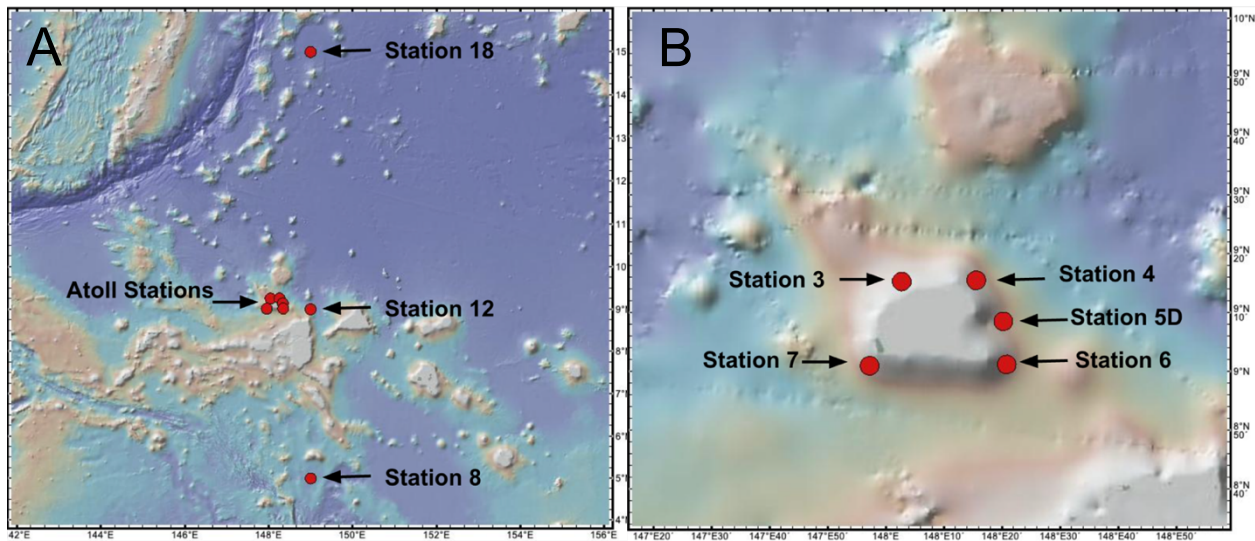


Figure 1. Map of research sites. A) Stations are grouped into atoll stations and open ocean stations: Station 8, Station 12, and Station 18. B) Map of atoll stations: Station 3, Station 4, Station 5D, Station 6 and Station 7.

The 2025 undergraduate research cruise on the *R/V Thomas G. Thompson* left Guam on December 29<sup>th</sup>, 2024, and returned on January 11<sup>th</sup>, 2025. Zooplankton nets were deployed at five stations around the unnamed atoll (09°08'40''N, 148°07'50'' E), and three stations were on the 149°E WOCE line in the open ocean, specifically at latitudes 5°N, 9°N, and 15°N (Figure 1). Since this atoll is unmapped, it was named NAM-2 Atoll. Each island and open ocean site was given a station number to organize the data collected. The open ocean stations at latitudes 5°N, 9°N, and 15°N were chosen due to their latitudes being below, the same, and above the atoll's latitude to act as a control.

Zooplankton samples were collected at each station with one replicate using a 1-meter diameter 200  $\mu\text{m}$  mesh closing plankton net. A flow meter was attached to the net's rim to measure how much water flowed through the deployment. Each net was deployed down to the DCM of each station based on the fluorescence profile from the Seabird SBE-9 CTD of that same station. The net collected samples from the DCM to the surface and then rinsed thoroughly

with seawater. The organisms were collected in the cod end of the net and then preserved in a solution of 5% formalin and seawater to be analyzed in the onboard laboratory.

To count the zooplankton, each sample was split into six 1mL aliquots using a Stemple pipette. Each aliquot was observed under an Eclipse microscope in petri dishes to categorize the species of zooplankton. To ensure that all the zooplankton were counted in the petri dish, a square zig-zag pattern was used.

The taxonomy was determined using Sea Grant's Marine Zooplankton of the Puget Sound guide and *Coastal Marine Zooplankton: A Practical Manual for Students* by C.D. Todd, M.S. Laverack, and G.A. Boxshall. Copepods were specifically split into cyclopoid and calanoid sub-groups based on morphological features. Cyclopoid copepods are rounder with shorter antennae and calanoid copepods are barrel-shaped, with long antennae.

The *R/V Thomas G. Thompson's* temperature salinometer (TSG) was used to measure temperature. Nutrient samples of phosphate, nitrate, and nitrite were collected from Niskin bottles on the CTD rosette at varying depths above the DCM of each station. These samples were then collected with a 60 mL nutrient bottle, which was rinsed three times with the sample before being filled. The bottles were then sent back to the University of Washington Marine Chemistry Lab for analysis. The lab then sent concentration data on nitrate, nitrite, and phosphate.

To determine if a site is biologically productive and follows the IME, factors like high abundance and diversity of zooplankton that are also involved in predator-prey relationships were considered along with temperature, nutrients, current direction, and bathymetry data.

## Data Analysis

Once the zooplankton samples were counted with the Eclipse dissecting microscope, the standard abundance was calculated based on zooplankton counts and dilution factors (Equation 1). The equation, volume of water filtered (1c), was not used because of the inconsistencies with the flowmeter. The equation for the volume of water projected (1d), was used instead. The projected distance was based on the specific depth at which the zooplankton net went at each station.

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

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

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

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

Equation 1. Calculations for abundance (1a) based on dilutions factor (1b) and volume of water (1c, 1d).

The zooplankton metrics were based on Margalef's species richness (D), Shannon-Wiener Diversity Index (H'), species evenness (J), and abundance which will be calculated at each station. The Shannon-Wiener Diversity Index takes into consideration the number of species (S) and the proportion of individuals of each species belonging to the total number of individuals (P<sub>i</sub>), in which values range from 0 to 5, with higher values indicating higher diversity. Margalef's species richness includes the number of species (S) and the total number of individuals (N), where the calculated range should be between 0 to 5, with higher values indicating a more integrated sample. Species Evenness involves the Shannon-Wiener Diversity

Index ( $H'$ ) and the number of species ( $S$ ), where the range of values is between 0 to 1 and higher values indicate a more balanced sample (Long et al., 2021; Equation 2).

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

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

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

Equation 2. Equations used to analyze the zooplankton data.  $H'$ : Shannon-Weiner Diversity Index with number of species ( $S$ ) and the proportion of individuals of each species belonging to the total number of individuals ( $P_i$ ).  $D$ : Margalef's richness index with the number of species ( $S$ ) and the total number of individuals ( $N$ ).  $J$ : Species Evenness with the Shannon-Weiner Index ( $H'$ ) and the number of species ( $S$ ).

Data was analyzed and compiled in Excel. Statistical tests such as t-tests and regression modeling were performed to determine any significance between zooplankton metrics, nutrients, temperature, and bathymetry.

## Results

The total zooplankton species abundance was the greatest at Station 7 of the atoll sites and Station 8 of the open ocean sites. At each site, the species with the highest abundance were the calanoid copepods, followed by the cyclopoid copepods and then the chaetognaths. The Shannon-Weiner Index was the greatest at Station 3 of the atoll sites and Station 8 of the open ocean sites. Station 8's Shannon-Weiner Index value was comparable to the indexes of the atoll sites (Figure 2). There was no statistically significant difference in total zooplankton abundance

between the atoll and open ocean sites, so the null hypothesis that there was no difference between the two groups of sites cannot be rejected (t-test,  $p = 0.13$ ).

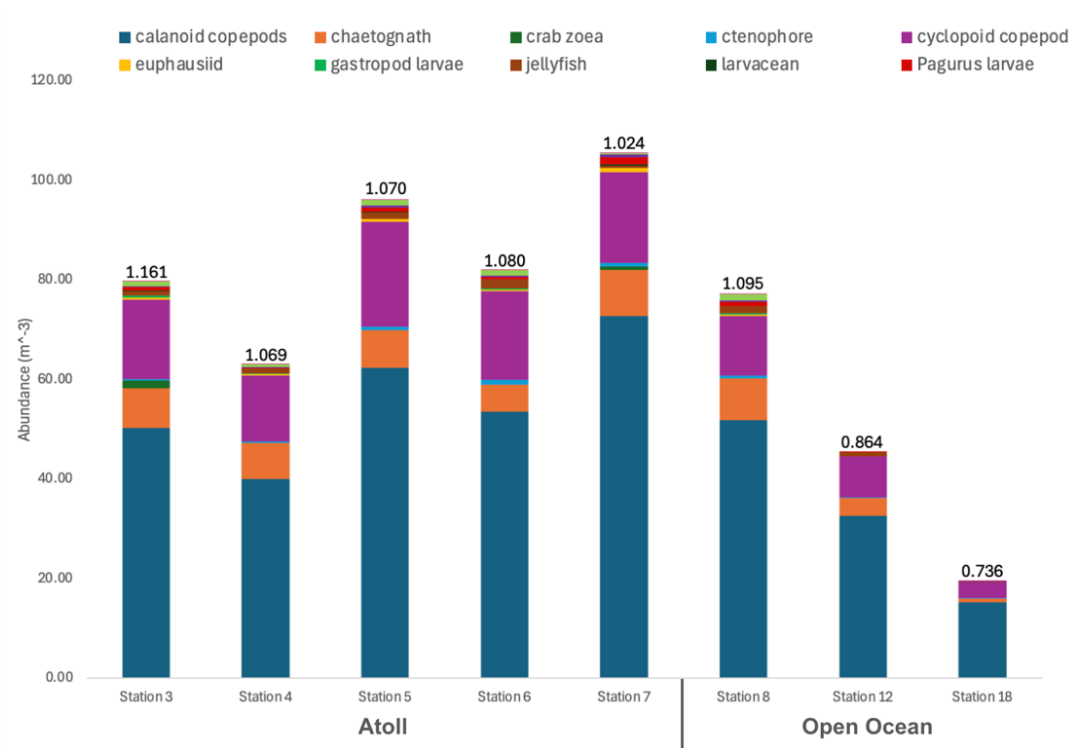


Figure 2. Zooplankton species abundance ( $m^{-3}$ ) and composition at each station. A legend of all zooplankton included with color-coded keys. The number above each bar represents the Shannon-Weiner Diversity Index.

To observe species diversity of less abundant zooplankton, the dominant group of calanoid copepods was excluded from the analysis. The total zooplankton species abundance was still the greatest at station 7 of the atoll sites and station 8 of the open ocean sites. The Shannon-Weiner Index was also the greatest at Station 3 of the atoll sites and Station 8 of the open ocean sites. However, Station 8 had the highest Shannon-Weiner Index of all sites. The abundance of the cyclopoid copepods and the chaetognaths was also greater than the other species of zooplankton (Figure 3). There was no statistically significant difference in total zooplankton abundance, excluding the calanoid copepods, between the atoll and open ocean sites. Therefore,

the null hypothesis that there was no difference between total abundance among the atoll and open ocean stations when excluding calanoid copepods, cannot be rejected (t-test,  $p = 0.14$ ).

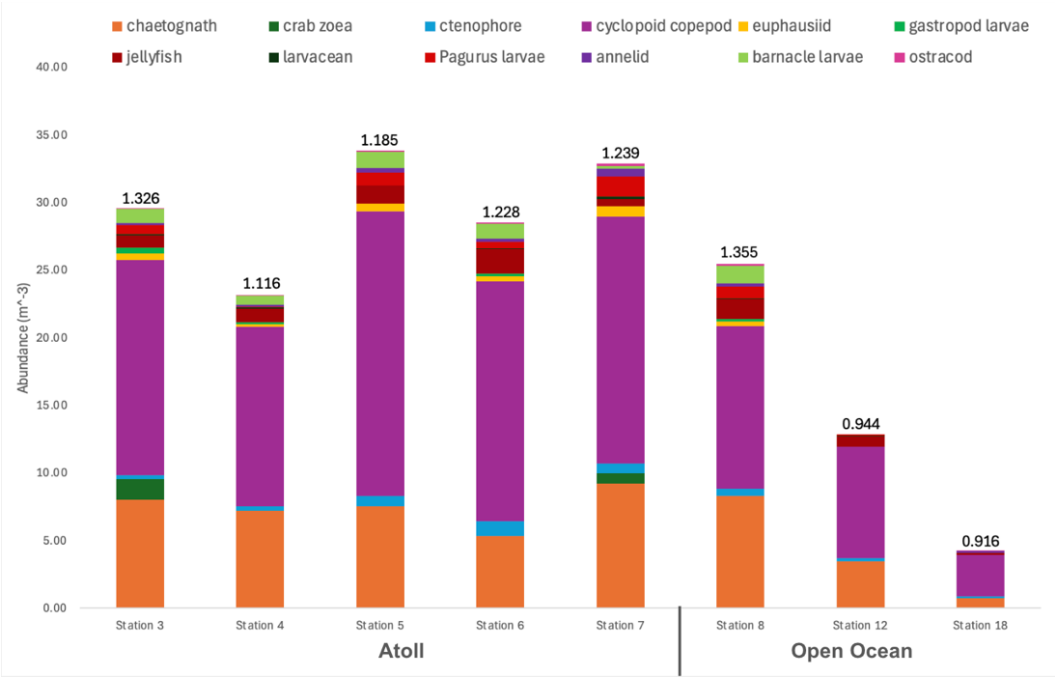


Figure 3. Zooplankton species abundance and composition, not including calanoid copepods, at each station. A legend of all zooplankton included with color-coded keys. The number above each bar represents the Shannon-Weiner Diversity Index.

There was a positive linear pattern between the abundance of copepods compared to the abundance of their predator, chaetognaths. The abundance of calanoid and cyclopoid copepods were combined under the category of copepods. The slope was 0.1066 copepod abundance/chaetognath abundance. The  $R^2$  value was 0.75. There was statistical significance between the abundance of copepods and chaetognaths ( $p = 0.005$ ), so the null hypothesis can be rejected (Figure 4, Figure 5).

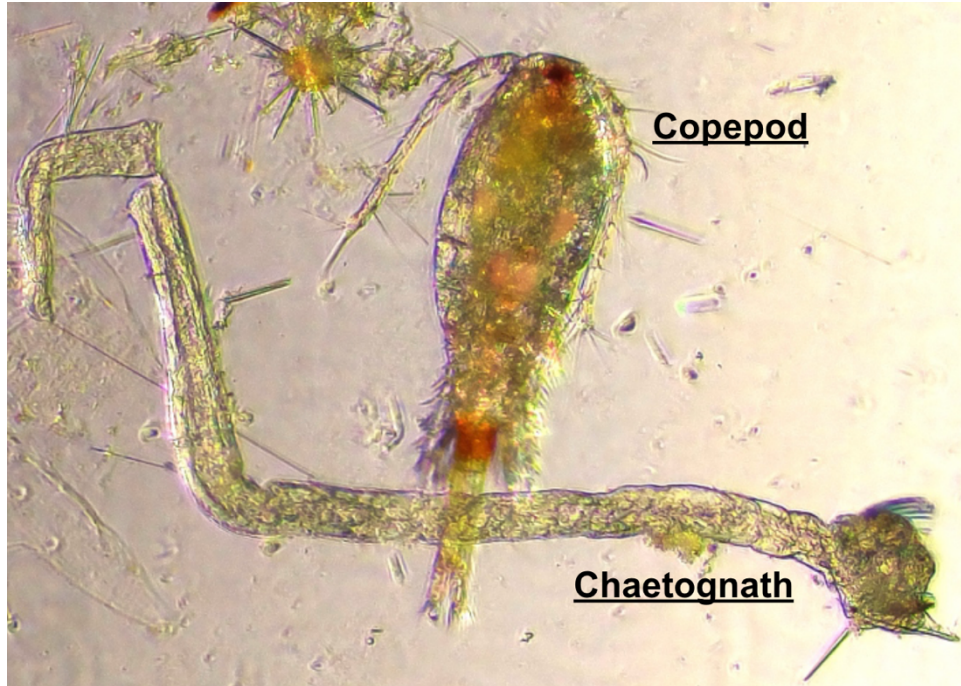


Figure 4. Photo from Eclipse microscope of chaetognath and copepod.

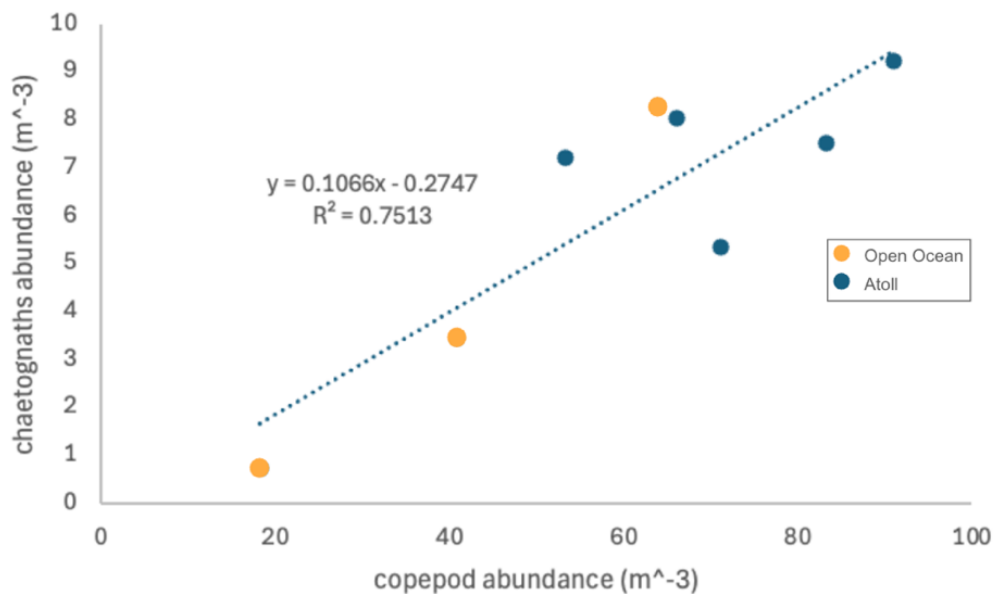


Figure 5. The relationship between copepod abundance (m<sup>-3</sup>) and the abundance (m<sup>-3</sup>) of their predator, chaetognaths. Orange dots represent open ocean stations and blue dots represent atoll stations.

Zooplankton evenness values were mainly between about 0.4 to 0.45 across both the atoll and open ocean stations, except it decreased at Station 12 and Station 18. There was no statistically significant difference in evenness between the atoll and open ocean sites (t-test, p =

0.23) (Figure 6a). Zooplankton richness was also relatively similar amongst all stations, however, at Station 12 and Station 18, the richness increased. There was no statistically significant difference in evenness between the atoll and open ocean sites (t-test,  $p = 0.16$ ) (Figure 6b). Similar to the pattern of species evenness, the Shannon-Weiner Index values were between about 1 to 1.2 among all stations, except for open ocean stations of Station 12 and Station 18, where it decreased. There was no statistically significant difference in diversity in terms of the Shannon-Weiner Index between the atoll and open ocean sites, so the null hypothesis cannot be rejected (t-test,  $p = 0.23$ ) (Figure 6c).

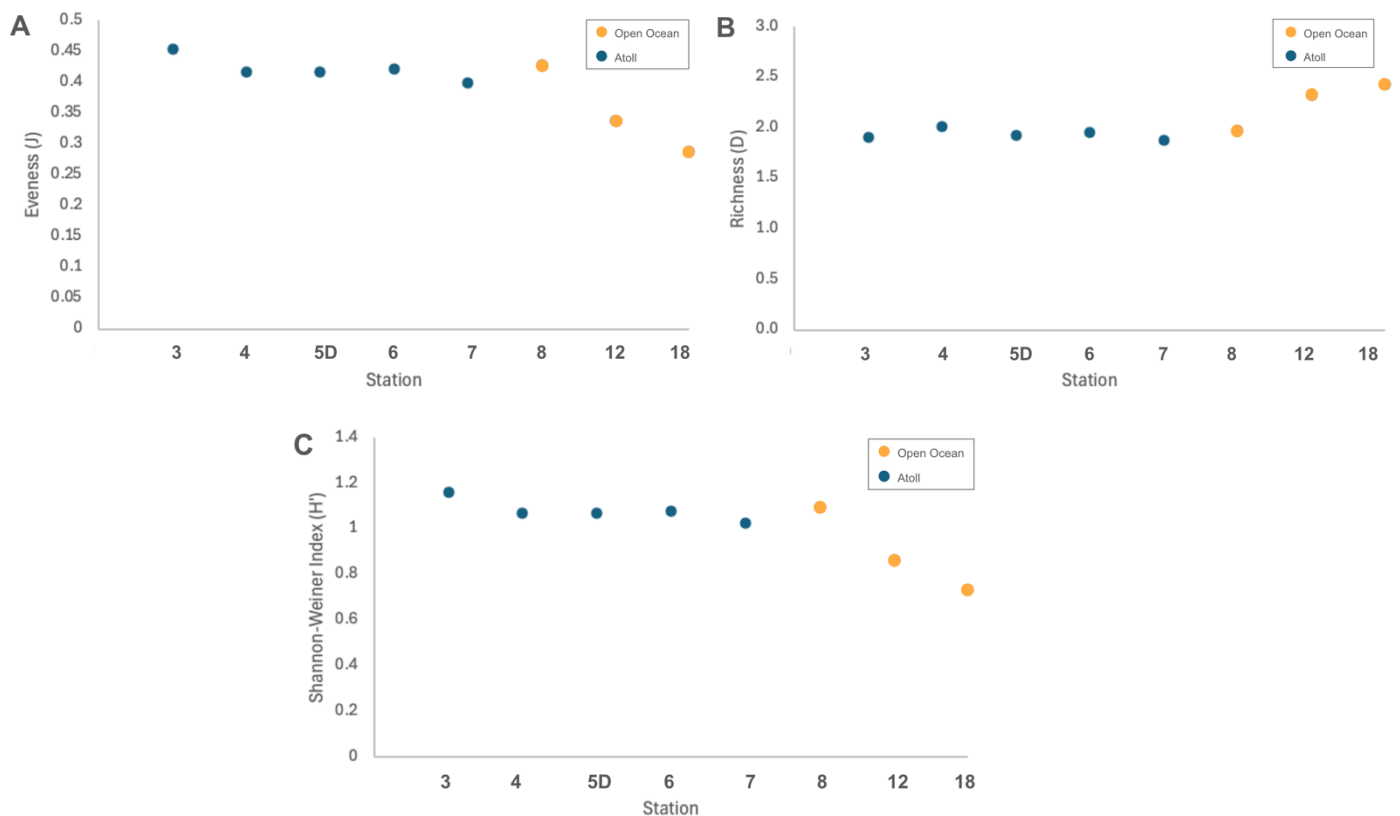


Figure 6. Zooplankton Community Composition metrics from each station. Orange dots represent open ocean stations, and blue dots represent atoll stations. A) Species Evenness, B) Species Richness, C) Shannon-Weiner Diversity Index.

There was a positive pattern between temperature and the total abundance of zooplankton among the atoll and open ocean stations. The  $R^2$  value was 0.1834, and the temperature does not significantly affect diversity among all of the stations ( $p = 0.29$ ) (Figure 7a). There was a

positive pattern between total chlorophyll and total abundance at each atoll and open ocean station. The  $R^2$  value was 0.1544, and the total chlorophyll concentration does not significantly affect diversity among all of the stations, so the null hypothesis cannot be rejected ( $p = 0.34$ ) (Figure 7b). The nutrient concentrations of phosphate and nitrate + nitrite did not include Station 4 and Station 7 because there wasn't any data collected at those locations. There was a positive pattern between the concentration of phosphate and the total abundance of zooplankton at each station. The  $R^2$  value was 0.496, and the phosphate concentration does not significantly affect diversity among all the stations, therefore, the null hypothesis cannot be rejected ( $p = 0.18$ ) (Figure 7c). There was a negative pattern between Nitrate + Nitrite concentrations and total abundance. The  $R^2$  value was 0.0825, and the nitrate + nitrite concentration does not significantly affect diversity among all of the stations ( $p = 0.64$ ) (Figure 7d).

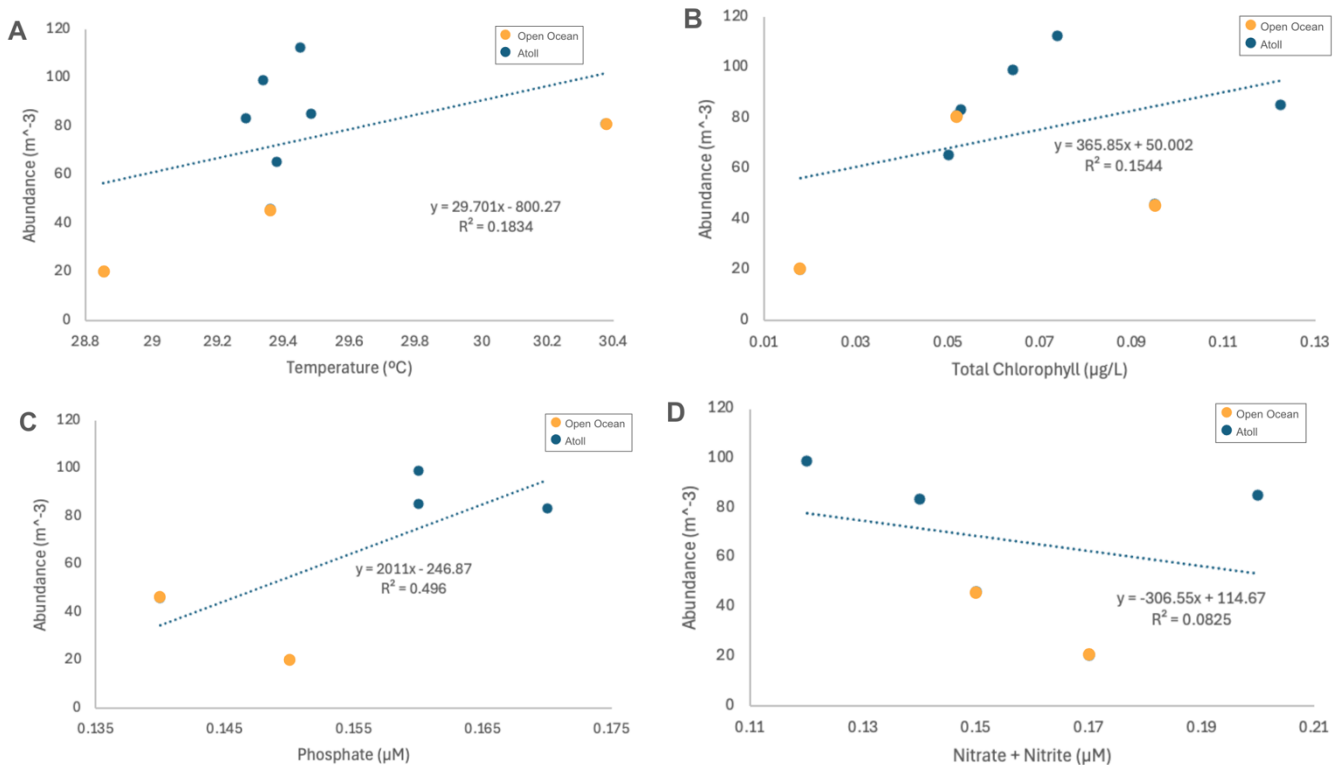
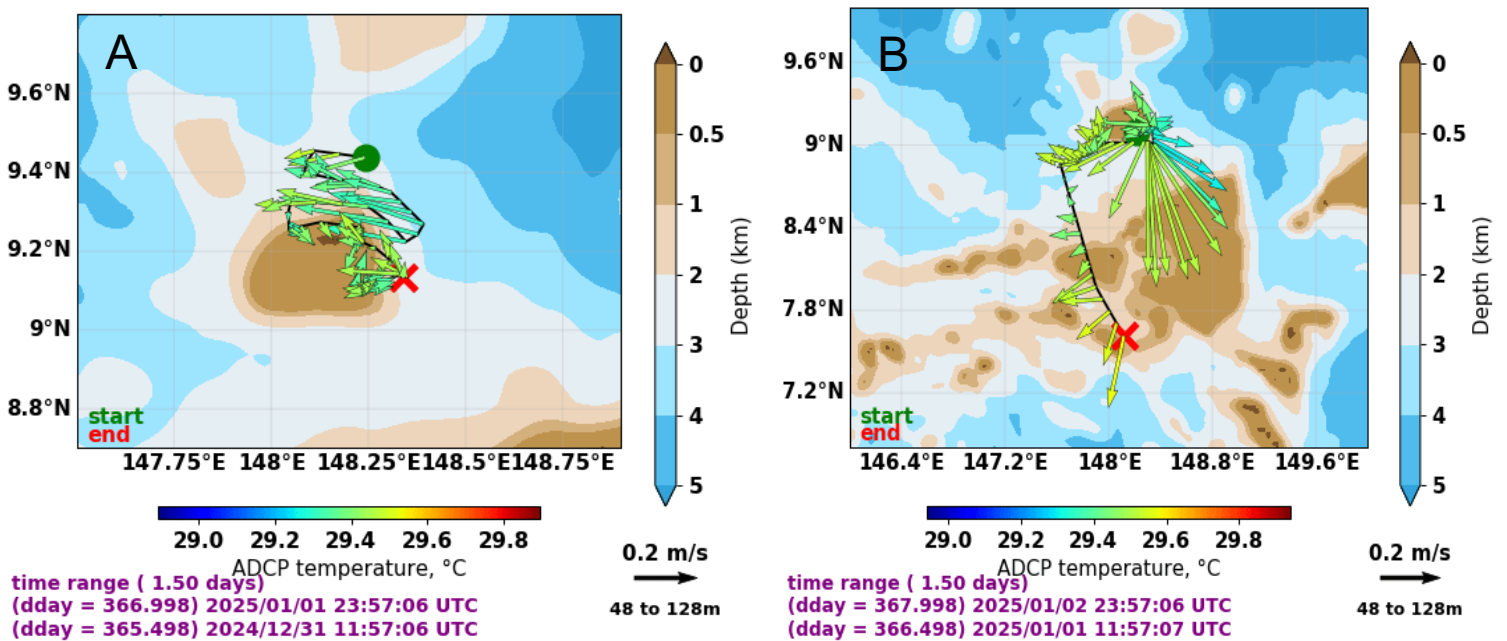


Figure 7. Water chemistry data against on total abundance of each station. A) Temperature, B) Total Chlorophyll, C) Phosphate, D) Nitrate + Nitrite. Orange dots represent open ocean stations, and blue dots represent atoll stations.

The main direction of the surface current around the atoll was directed to the west. The ADCP temperature range was between 29.5°C to 29.3°C (Figure 8a, Figure 8b). The main directions of the surface currents on the WOCE line between 4.5°N to 10.5°N were directed to the east. The ADCP temperature range was between 30.4°C to 29.6°C (Figure 8c). The main direction of the surface currents on the WOCE line between 10.5°N to 16.5°N was to the west. The ADCP temperature range was between 29.5°C to 20°C (Figure 8d). The open ocean samples were collected at different latitudes on the WOCE line to determine if different latitudes varied in current speed and direction, which could impact zooplankton concentration. The ADCP temperature range was between 29.5°C to 29.0°C (Figure 8d).



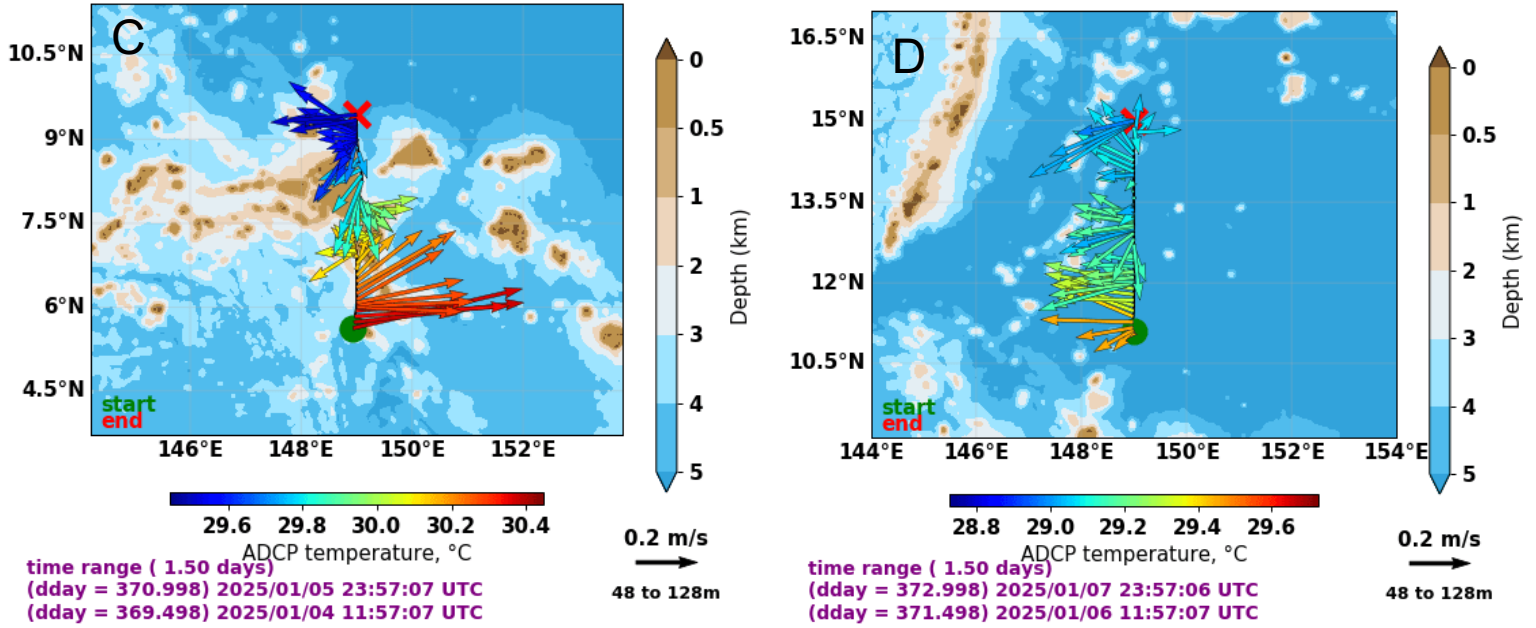


Figure 8. ADCP current direction and temperature ( $^{\circ}\text{C}$ ) measured by os75nb sensor. A. ADCP data of the northern and northeastern side of NAM-2 Atoll. B. ADCP data of eastern and southern sides of NAM-2 Atoll. C. ADCP data of WOCE line. Figure creation by *R/V Thomas T. Thompson* software of UHDAS+CODAS provided by the University of Hawaii.

A negative relationship exists between bathymetric slope in degrees and total abundance ( $\text{m}^{-3}$ ). The slope was  $-1.7656/\text{m}^{-3}$  with an  $R^2$  value of 0.4112. The slope angle in degrees does not significantly affect the total abundance of zooplankton around the atoll stations ( $p = 0.2$ ), so the null hypothesis cannot be rejected (Figure 9).

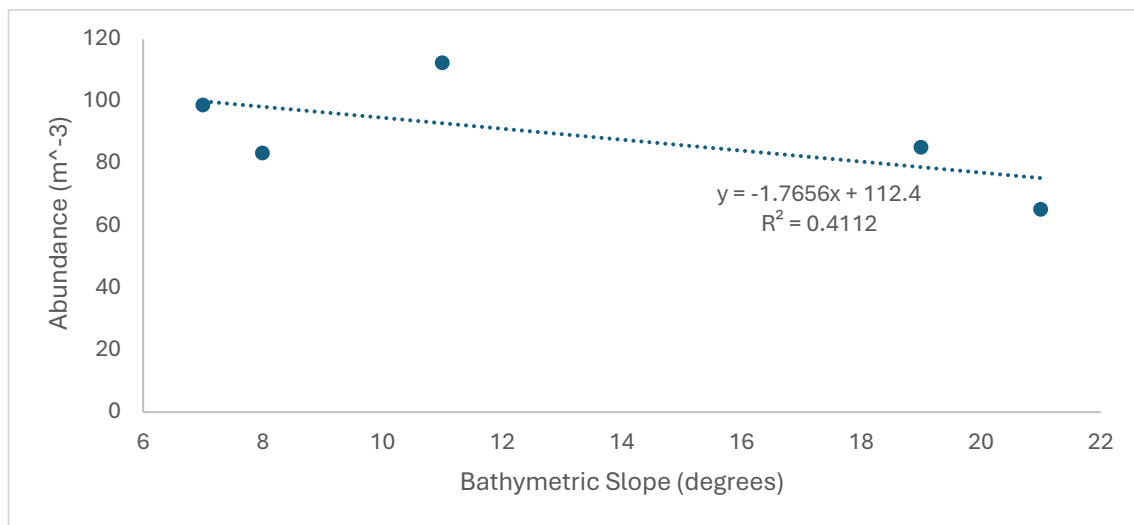


Figure 9. Bathymetric slopes around NAM-2 Atoll. Total Abundances from net tows at Stations 3, 4, 5d, 6 and 7.

## **Discussion**

### **Abundance and Diversity**

The total zooplankton species abundance varied across all station locations. Station 7 had the highest total abundance out of the atoll and open ocean stations. Station 8 had the highest total abundance of all the open ocean stations (Figure 2, Figure 3). The total abundance was based on the DCM depth and was calculated from the CTD profile. The DCM depth varied at each station, so different volumes of water containing the zooplankton samples were filtered through the net. Even with different volumes of water filtered through the zooplankton net, by following the depth of the DCM, each sample should represent an accurate depiction of the zooplankton composition. Therefore, many factors, including currents and nutrients, may have contributed to the different abundances across all locations.

Both species of copepods, calanoid and cyclopid, had the highest species abundance at each station, indicating a higher degree of survival compared to zooplankton species like larvae and jellyfish (Figure 2, Figure 3). This may be due to copepods' higher tolerance to temperature and pH (Long et al., 2021; Sasaki & Dam, 2021). However, there was no statistically significant difference in terms of total abundance versus the atoll and open ocean sites. This indicates that factors like nutrients, temperature, bathymetry, and currents may have impacted the total abundance of zooplankton.

When specifically looking at the composition of zooplankton species, chaetognaths were the second most common species after the copepods. Chaetognaths are known predators of copepods, so their abundance may be correlated with the high amount of copepods seen (Baier & Terazaki, 2005). Specifically, chaetognaths use mechanoreceptors to sense the water movements of copepods (Ball & Miller, 2006). Among the atoll and open ocean stations, there was a positive

linear relationship with statistical significance, implying that when copepod abundance increases, chaetognath abundance also increases (Figure 5). Predator-prey relationships play a crucial role in shaping community dynamics, so due to this correlation, there is evidence of a dynamic ecosystem in which energy is transferred through trophic levels (Schmitz, 2017).

The Shannon-Weiner Diversity Index implies that there is higher species diversity with a greater index value. The index values were the highest around the atoll stations as well as the open ocean site, Station 8 (Figure 6c). However, there was no statistically significant difference in diversity between the atoll and open ocean stations, which further indicates that factors like nutrients, temperature, current direction, and bathymetry may have been impactful. Evenness and richness are factors of the Shannon-Weiner diversity index in that greater values of evenness indicate that the species present are distributed relatively equally in terms of population size, and greater richness values indicate a larger number of different species. The highest value for evenness was at Station 3, which may imply that the zooplankton in the sample are more resilient to environmental change (Figure 6a). Richness was the greatest at Station 18, which describes this sample as a possible representative of a complex and healthy ecosystem (Figure 6b). Even though the evenness or richness value may indicate what may be occurring in the sample, the difference between the atoll and open ocean sites of these metrics was not statistically significant, which implies that the hypothesis that the atoll stations would have higher diversity may not be proven. This further indicates that factors like nutrients, temperature, currents, and bathymetry are needed to understand the relationship between abundance and diversity among all the stations.

## Water Chemistry

With temperature, there was a positive linear pattern when measured against total abundance among all the stations (Figure 7a). However, there was no statistical significance, so the null hypothesis cannot be rejected. Zooplankton are poikilothermic, which means that their physiological processes, like ingestion and respiration, are sensitive to temperature in that the rate increases when temperature rises. However, this relationship may not apply to specific zooplankton and their optimal temperature ranges as some prefer colder water over warm. As each organism has an optimum temperature range, a relationship between total abundance and temperature may hold until the optimum temperature range is reached (Richardson, 2008). A factor like temperature may not be the best indicator to explain the abundance and diversity of the zooplankton among the stations, however, the warmest site was an open ocean station, Station 8, which had similar value to the atoll stations' abundance and diversity which may provide some evidence for these unpredicted higher values in a known oligotrophic area.

Total chlorophyll also had a similar pattern as temperature as there was a positive linear pattern with total zooplankton abundance, but there was no statistical significance indicating that the null hypothesis that there was no difference in total abundance in relationship to total chlorophyll between the atoll and open ocean stations cannot be rejected (Figure 7b). Chlorophyll is used as a proxy for phytoplankton abundance, in which high concentrations indicate a high abundance of phytoplankton. Zooplankton are consumers of phytoplankton, so high amounts of chlorophyll may indicate high abundances of zooplankton. However, the station with the highest concentration of chlorophyll did not have the highest total abundance of zooplankton, which goes against this idea. This may be due to a possible delay in high zooplankton abundances when high amounts of phytoplankton are seen in an area, which occurs

when zooplankton is located farther from the phytoplankton production location (Roman et al., 2002). Also, even in areas with low concentrations of chlorophyll, there still may be high abundances of zooplankton due to zooplankton overgrazing the amount of phytoplankton (Levine et al., 1999). Due to the multiple contradicting explanations about the meaning behind chlorophyll concentration, it may not be the best indicator for understanding the patterns between the abundance and diversity of zooplankton among the stations. Therefore, data on nutrients may provide a better explanation.

There was a positive linear relationship between phosphate concentration and total abundance of zooplankton (Figure 7c). However, there was no statistical significance between these two variables, so the null hypothesis cannot be rejected. Zooplankton receive the nutrient, phosphate, through grazing on phytoplankton, so a high concentration may indicate more phytoplankton activity and, therefore, a high abundance of zooplankton (Wijaya & Elfiansyah, 2022). The concentrations of phosphate ranged from 0.14  $\mu\text{M}$  to 0.20  $\mu\text{M}$  among all the stations, which is a relatively small concentration when compared to deeper nutrient-rich water. These similar values then go against the idea that the atoll station would have higher concentrations compared to the oligotrophic water of the open ocean. The nutrient samples were taken in the mixed layer, which generally has lower nutrient concentrations compared to deeper water due to nutrients accumulating at deeper depths from the decomposition of organic matter. The mixed layer is where most of the nutrients are consumed by phytoplankton and zooplankton, which are readily available (Diaz et al., 2021). This may indicate that the open ocean sites are still considered oligotrophic as they are overall nutrient-poor throughout the water column. Therefore, observing nutrients at the mixed layer near the surface may not provide the best evidence for found patterns.

There was a positive linear relationship between nitrate + nitrite concentrations and total abundance of zooplankton (Figure 7d). However, there was no statistical significance between these two variables, so the null hypothesis cannot be rejected. Nitrate + Nitrite are essential nutrients gained from feeding on phytoplankton that zooplankton use for growth processes as it's the most common form of nitrogen (Wijaya & Elfiansyah, 2022). Following the pattern with phosphate concentrations, the concentrations of nitrate + nitrite from the mixed layer were similar among both the atoll and open ocean sites. This then also implies that the open ocean can still be considered oligotrophic, as concentrations of nutrients at the surface are generally less than at deeper depths. Additionally, observing nutrients within the mixed layer may not provide a large enough range of different concentrations to determine if there is a pattern among zooplankton abundance and diversity.

#### **ADCP**

At the atoll sites, the main direction of the surface current is from the east to the west (Figure 8a, Figure 8b). This follows the North Equatorial Current, which is directed from the east to the west due to being primarily driven by the Northeast Trade Winds. Currents carry different compositions of zooplankton species from different origin areas (Keister et al., 2011). Even with the current around the atoll having the same direction, the zooplankton composition depends on how the current is interrupted by the morphology of the atoll. This may explain why there was a difference in abundance and diversity among the atoll stations, as different zooplankton species could have settled based on whether the current was interrupted by the atoll. The high abundance of copepods may also be explained by their higher resilience to temperature and pH regimes created by the North Equatorial Current compared to more delicate organisms like jellyfish and larvae. The current on the WOCE line between 10.5°N to 16.5°N was also directed from the east

to west, therefore following the North Equatorial Current (Figure 8d). However, between 4.5°N and 10.5°N on the WOCE line, the current was directed from the west to the east (Figure 8c). This different direction suggests that there are two different bodies of water passing each other on the WOCE line. This may explain the high total abundance at Station 8, which is located between 4.5°N and 10.5°N as this body of water may be comprised of a different composition of zooplankton (Alldredge & Hamner, 1980).

### **Bathymetry**

A negative linear relationship was determined by comparing the total abundances from Stations 3, 4, 5d, 6, and 7 around the atoll to the bathymetric slopes around the atoll (Figure 9). However, there was no statistical significance between the bathymetric slopes and total zooplankton abundance, indicating that the null hypothesis cannot be rejected. Through observing the negative linear slope, there is an indication that around a more gradual sloping bathymetry, there was a higher abundance of zooplankton and, therefore, a stronger IME. This is a similar pattern found in Gove et al. 2016, where atoll ecosystems around the South Pacific that have a gradual slope indicated a stronger IME. Bathymetry does affect ocean currents in that it can force vertical transport of subsurface nutrient-rich waters to fuel nearshore biological productivity. Another factor is that internal waves generated from tidal currents can interact with bathymetry, which also drives stratification that delivers cooler and nutrient-rich waters to the near-surface, resulting in increased nearshore abundance (Gove et al., 2016).

### **Conclusion**

By observing zooplankton abundance and diversity, morphological features like atolls can be associated with the IME, which could indicate an area as biologically productive. There was no statistical significance among abundance and diversity against various factors, including

temperature, nutrients, current direction, and bathymetry. However, there was statistical significance in the relationship between copepod and chaetognath abundance.

Even with an observed predator-prey relationship, the non-statistically significant factors cause the null hypothesis to not be rejected in that the NAM-2 Atoll follows the IME and is more biologically productive than different areas in the open ocean. Due to not being able to isolate these factors, it is difficult to determine which one or a combination impacted the abundance and diversity of the zooplankton the most. Another aspect to consider when determining if an area follows the IME is that this idea includes that there are land masses above the sea surface that could provide additional nutrients through runoff, which could be consumed and, therefore, cause an increase in the abundance of zooplankton. With this, even though the notion of an IME usually indicates a biologically productive area, this doesn't mean that the NAM-2 atoll is not biologically productive.

The goal of this study was to identify an unmapped atoll that could be considered biologically productive. As this area is not commonly known, it might be a missed location that could be a source of fishing that could provide economic support to Guam. Over 12 year period, Guam was a driver of 148 tons/year or 1.5 million USD of reef-fish trade (Cuetos-Bueno & Houk, 2018). Fishing is a major part of their economy, so the hope of this study was to provide another location that could support Guam.

Further studies may include whether these stations were experiencing a top-down or bottom-up effect, which could give insight into whether there was not enough phytoplankton to support the zooplankton or if the zooplankton was overgrazing the phytoplankton, resulting in low concentrations of chlorophyll. Another aspect of future studies is observing more locations around the atoll. Specifically, observations in the center of the atoll may be influential due to a

possible impact from lagoons or other factors. More study sites around the atoll can provide a more complete picture of its biological productivity in terms of zooplankton abundance. More sites might even be able to support the relationships found with the stations in this research project.

## **Acknowledgments**

I would like to acknowledge the captain and crew of the *R/V Thomas G. Thompson* during the TN440 cruise. Particularly, I want to thank the marine technicians Liz and Jen for assisting me with my data collection. I would also like to thank my mentors, Ginger Armbrust and Kathy Newell, for helping me throughout this project. My mentor groups should also be acknowledged for the support they gave me throughout the cruise and paper. Finally, I would like to thank the University of Washington School of Oceanography for providing the influential opportunity to conduct research.

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