Spatial Distribution and Assemblages of Zooplankton during the Northeast Monsoon in Shark Fin Bay, Taytay, Palawan, Philippines

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ABSTRACT

Marine Protected Areas (MPAs) are vital for biodiversity conservation, yet monitoring often focuses on larger species, neglecting microscopic organisms that form the marine food web's foundation. This research determined the spatial distribution and community assemblages of zooplankton within Shark Fin Bay. Field sampling was conducted at six stations: four within MPAs (Depla, Garden, Pinnacle, and Sandoval) and two in non–MPAs (Depla North and Macuao). Zooplankton were collected via five–minute horizontal surface tows using a 200–micron mesh plankton net. Laboratory analysis involved the displacement method to determine biomass and identification using a Bogorov counting chamber. The highest–abundance station recorded a wet weight of 49.5 ml/m³, density of 1,249.79 ind/m³, and diversity index of 1.808, while Depla North showed the lowest abundance. The Wilcoxon signed–rank test revealed no significant differences between MPA and non–MPA stations ($p > 0.05$). Taxonomic composition was dominated by Calanoid copepods and Cyclopoida, indicating a stable but localized community structure. Garden station was notably dominated by Appendicularia, which constitutes a significant portion of many nekton species' diet. The findings demonstrate that Shark Fin Bay supports a robust zooplankton community. This research provides critical baseline data for MPA management, suggesting that conservation efforts must account for these "invisible" foundational species to ensure long–term sustainability of the bay's fisheries and marine productivity. Further temporal studies are recommended to assess zooplankton variability in the bay.

Keywords: appendicularia, diversirty, marine protected area, plankton

INTRODUCTION

Marine Protected Areas (MPAs) are specific regions where human activities are limited to protect essential ecosystems and conserve marine biodiversity. By safeguarding diverse habitats, MPAs contribute to the restoration of ocean productivity, the mitigation of environmental degradation, and the preservation of ecosystem services. As the pressures from overfishing, pollution, and climate change intensify, MPAs are increasingly vital in maintaining ocean health and ensuring the long–term protection of marine biodiversity (Gennari 2024).

Recently, the Marine Conservation Institute and the Sulubaai–Environmental Foundation have announced that the Shark Fin Bay MPA Network is now a Blue Spark marine protected area collaboration. This network protects tropical reefs, seagrass meadows, and mangrove forests, which support a high diversity of species. The area provides habitat for an array of threatened and endangered species, including black–tip reef sharks, hawk bills, green turtles, and several endangered tropical fish, including napoleon wrasse. The local communities of Shark Fin Bay are committed to revitalizing the coastal and marine ecosystems upon which they rely on food and their livelihoods (Daily Tribune 2025).

Zooplankton, a subset of the broader planktonic community, are heterotrophic organisms that inhabit both freshwater and marine environments. The term "plankton" encompasses a diverse array of organisms that float or drift within aquatic realms. Among these, zooplankton are distinguished by their heterotrophic nature, signifying their reliance on external organic matter for sustenance, as opposed to autotrophic organisms that can synthesize their own food (BNO Team 2024). Changes in zooplankton communities over time may indicate subtle environmental changes to their habitats. Zooplankton play a crucial role in not only the material transport and energy flow through the food web but also in the control of the community structure and population size in different aquatic biomes via upward and downward effects (Sun X., et al. 2021). Therefore, indices of zooplankton abundance and species diversity can be used to determine the health of an ecosystem. Many local councils and water managers collect phytoplankton and zooplankton samples as indicators of water quality, often in response to the increasing incidence of algal blooms in rivers and estuaries (Queensland Government 2018). Profiling helps understand the structure of the zooplankton community and how it relates to environmental factors and other organisms in the ecosystem (Duarte et al. 2014).

The aim of this study was to determine the zooplankton diversity of Shark Fin Bay, Palawan. Specifically, the study aimed to (1) determine the composition, abundance, and diversity of the zooplankton community, (2) map the distribution of dominant taxa, and (3) compare the assemblages between stations within and outside the MPAs.

METHODS

Study Site

This study was conducted in Shark Fin Bay situated at the northern east coast of mainland Palawan, Philippines. The sampling stations were based on the established monitoring sites for fish eDNA project of the Sea Academy (**Table 1**). The sampling stations were composed of four (4) stations within Marine Protected Area (MPA) and two stations outside MPA area (**Figure 1**). In recent years, the bay has been impacted by illegal and destructive fishing practices, which have disrupted the marine ecosystem and biodiversity.

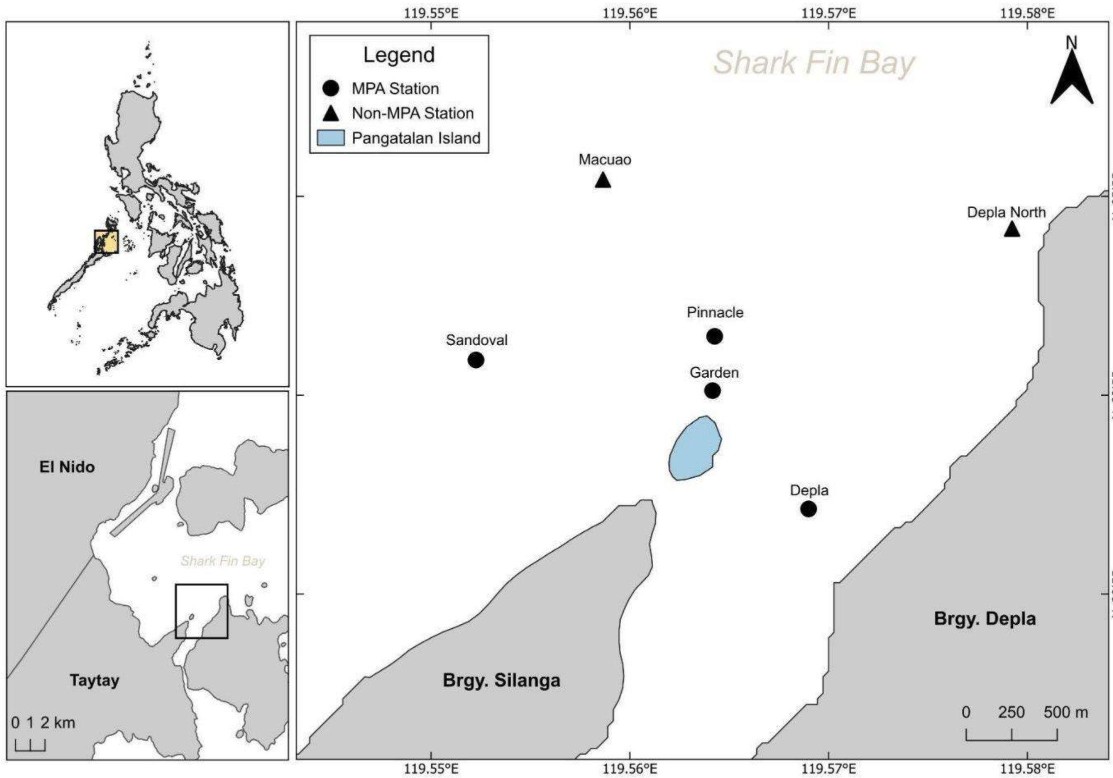

Figure 1. Map of the study area and location of sampling stations in Shark Fin Bay, Taytay, Palawan.

Table 1. Coordinates of the designated sampling stations including longitude and latitude measurements.

Station	Longitude	Latitude
Depla N	119.57923	11.09838
Macuao	119.55866	11.10084
Depla	119.56898	11.084263
Garden	119.564172	11.09021
Pinnacle	119.564273	11.092943
Sandoval	119.552252	11.091739

Sampling procedure

Zooplankton samples were collected using a plankton net with a mesh size of 200 microns and a mouth diameter of 50 cm. The collection process involved horizontal towing, with the net affixed to the side of a boat moving at a constant speed of one knot. Upon retrieval, the plankton net was sprayed to concentrate the samples at the cod end. The concentrated samples were then sieved to remove large debris and transferred to pre–labeled bottles. Preservation of the samples was achieved by using 10% formalin, and the bottles were sealed with parafilm to prevent leakage. The samples were placed in an ice box and promptly transported to the Microbiology

Laboratory at the Aquatic, Biodiversity, Biotechnology and Aquaculture R&D building, Western Philippines University, Puerto Princesa Campus.

Sample preparations

The zooplankton were extracted from the container and placed in a 200–micron sieve to eliminate any phytoplankton present. Large debris were manually removed using forceps. Following this cleaning process, the sieve was employed to concentrate the zooplankton using a wash bottle. Once concentrated, a spatula was utilized to transfer the samples into a tube for the measurement of their wet weight. Subsequently, the volume (ml) of water containing the zooplankton was measured. The mixture was then transferred to another tube using a sieve to separate the zooplankton from the water, and the volume was measured again. The volume of water was subtracted from the zooplankton mixture with water to determine the total wet weight of the sample. This type of procedure is called displacement method because this method (submersion, or dunking method) can be used to accurately measure the volume of the human body and other oddly shaped objects by measuring the volume of fluid displaced when the object is submerged (Choi, J. H. et al. 2024). Measuring the zooplankton biomass is also done by having the formula of $A= pi(r^2)D$ and Biomass= Wet weight/Total filtered seawater (m^3).

Microscopic examination of samples

Following the determination of the sample's biomass, the zooplankton were placed in a Bogorov counting chamber. This type of chamber is utilized in limnology and oceanography for the quantification of plankton, particularly zooplankton, under a stereomicroscope. These chambers accommodate a small volume of the sample for examination under a dissecting microscope. The design and configuration of the shallow etched grooves facilitate the identification of specific areas within the chamber. The straight sides maintain a consistent focus, while the rounded edges prevent the specimens from becoming ensnared.

Statistical Analysis

Diversity and richness indices were computed using Shannon–Weiner diversity and Margalef's richness, respectively. Wilcoxon statistics was used to determine significant differences between MPA and non–MPA stations, since test for normality of data was not satisfied.

RESULTS

Phytoplankton Composition, Abundance, and Diversity

A total of 14 zooplankton taxa were recorded across the six sampling stations: Depla North, Macuao, Depla, Garden, Pinnacle, and Sandoval . The total zooplankton density varied considerably among stations, ranging from 194.40 ind/m^3 at Depla North to 1249.79 ind/m^3 at Sandoval. Relatively low densities were also observed in Macuao (202.63 ind/m^3) and Depla (218.12 ind/m^3), whereas much higher densities were recorded at Garden (729.92 ind/m^3) and Pinnacle (1091.52 ind/m^3) as shown in **Figure 2**.

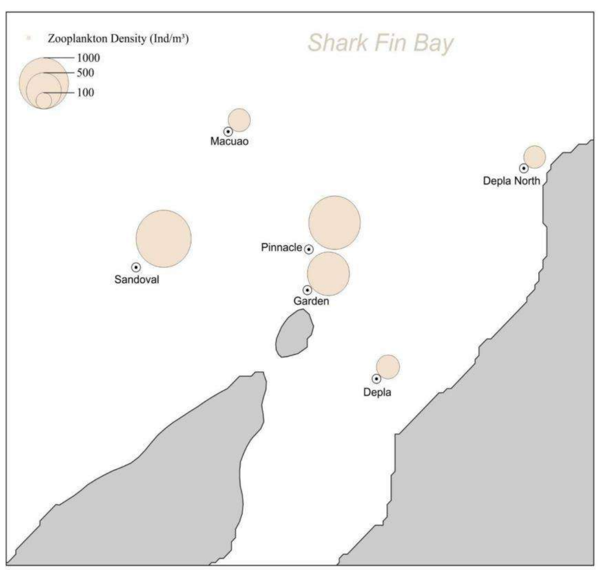

Figure 2. Spatial map of zooplankton total abundance (density: Ind/m^3) in Shark Fin Bay, Palawan.

Copepods constituted the dominant zooplankton group across all stations (Figure 3). Among them, Calanoida showed the highest densities in most stations, particularly at Sandoval (407.57 ind/m³) and Pinnacle (377.71 ind/m³), followed by Garden (131.98 ind/m³), Depla North (129.47 ind/m³), Macuao (105.36 ind/m³), and Depla (105.29 ind/m³). Cyclopoida was the second most abundant copepod group, with densities increasing toward the latter stations, reaching 354.33 ind/m³ in Sandoval and 268.59 ind/m³ in Pinnacle. Harpacticoida occurred in lower densities but were present in all stations, with the highest value observed at Sandoval (64.34 ind/m³). Among non–copepod taxa, Appendicularia exhibited notable abundance, particularly at Pinnacle (368.07 ind/m³) and Garden (355.91 ind/m³), indicating a strong contribution to the overall zooplankton density at these stations. Other groups such as Ostracoda, Chaetognatha, fish eggs, and nauplii were also recorded across most stations but generally occurred in moderate to low densities. Nauplii were particularly abundant at Sandoval (80.85 ind/m³).

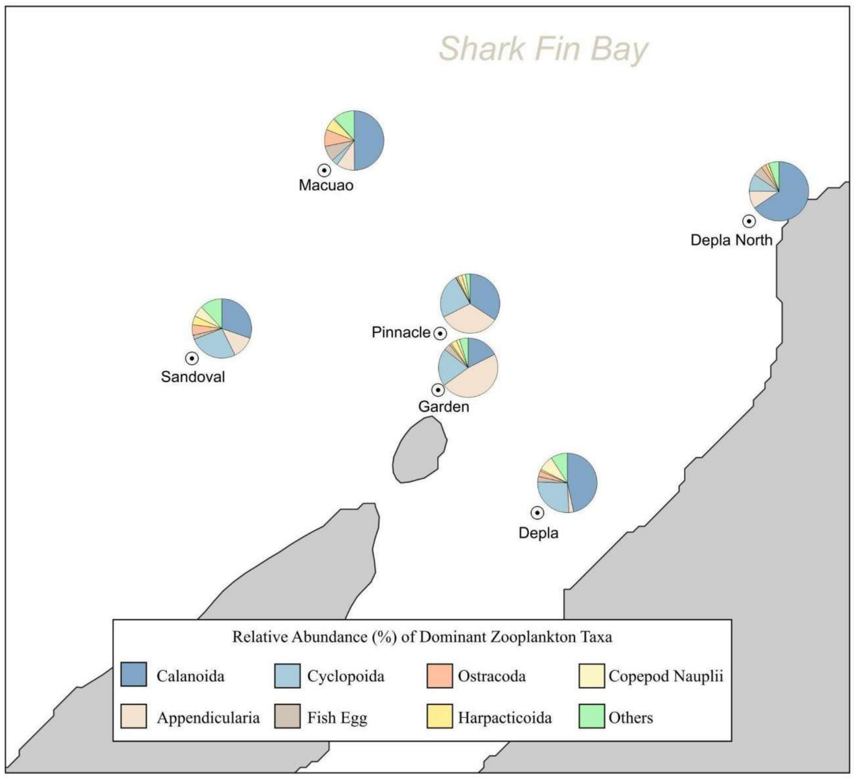

Figure 3. Spatial distribution map and relative abundance (%) of dominant zooplankton taxa.

Larval forms including crab zoea, euphausiids, mysids, and polychaete larvae were present in relatively low densities across stations. Rare taxa such as gastropod larvae and foraminiferans were only observed in Macuao, with very low densities. Moreover, the results indicate a higher zooplankton density in the stations within MPAs (Garden, Pinnacle, Depla and Sandoval) compared to the non–MPAs (Depla North, Macuao), with copepods, particularly Calanoida and Cyclopoida, dominating the zooplankton community structure.

Figure 4 shows the spatial distribution of zooplankton biomass (ml/100 m³) across the six sampling stations in Shark Fin Bay. Biomass was highest at Sandoval with 49.54 ml/100 m³, this was followed by Pinnacle with 36.33 ml/100 m³, Garden with 19.82 ml/100 m³, and Depla with 16.51 ml/100 m³. In contrast, Macuao and Depla North recorded the lowest zooplankton biomass with 3.63 ml/100 m³ and 2.97 ml/100 m³, respectively. Consistently, the distribution pattern suggests that stations within MPAs (Sandoval, Pinnacle, Garden, and Depla) supported higher zooplankton biomass compared with the stations outside MPAs (Macuao and Depla North).

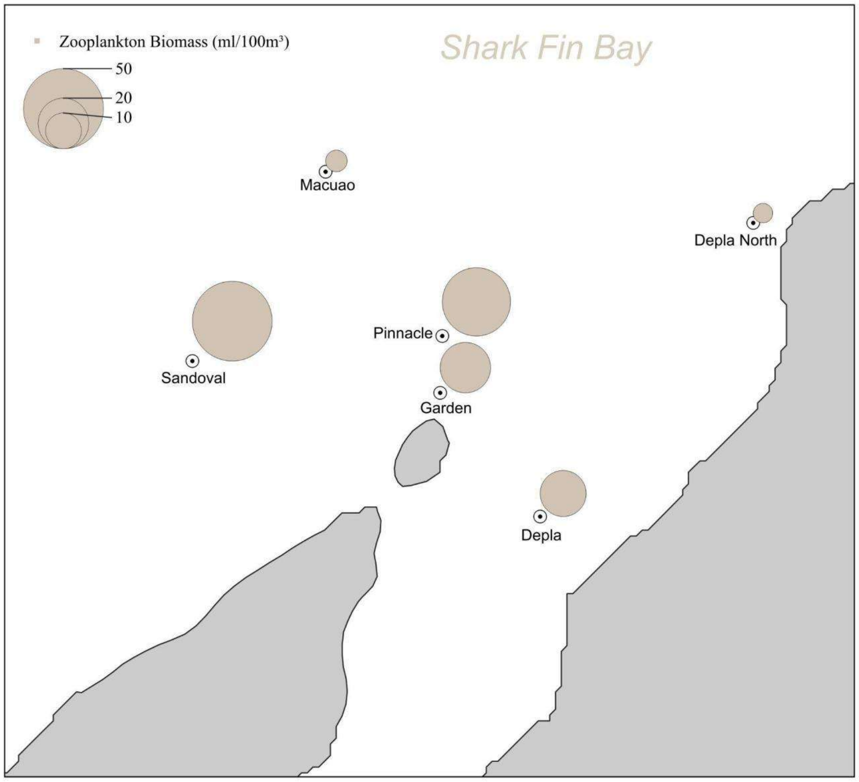

Figure 4. Spatial map of zooplankton total biomass (wet weight: ml/100m^3) in Shark Fin Bay, Palawan.

The Shannon diversity index (H') ranged from 1.232 to 1.808 across stations as show in Table 2. The highest diversity was recorded at Sandoval (H' = 1.808), indicating a relatively more diverse zooplankton assemblage at this station. This was followed by Macuao (H' = 1.642) and Depla (H' = 1.526). Moderate diversity values were observed at Garden (H' = 1.45) and Pinnacle (H' = 1.385), while the lowest diversity occurred at Depla North (H' = 1.232).

The evenness index ranged from 0.2858 to 0.5081, suggesting moderate variation in the distribution of individuals among taxa. Sandoval exhibited the highest evenness (0.5081), indicating a more balanced distribution of zooplankton individuals among species. In contrast, Depla North recorded the lowest evenness (0.2858), suggesting that a few taxa dominated the zooplankton community at this station. The remaining stations such as Depla (0.3833), Macuao (0.3689), Garden (0.3554), and Pinnacle (0.333) showed moderate levels of species distribution.

The Margalef richness index values ranged from 1.044 to 1.491, reflecting relatively similar species richness among stations. Macuao had the highest richness (1.491), followed by Depla North (1.267) and Depla (1.251). Lower richness values were observed at Garden (1.1), Pinnacle (1.057), and Sandoval (1.044). The results indicate that Sandoval exhibited the highest zooplankton diversity and evenness, while Macuao showed the greatest species richness. In contrast, Depla North had the lowest diversity and evenness, suggesting a more uneven distribution of zooplankton taxa at that station.

Table 2. Diversity Indices of zooplankton communities among sampling stations.

Diversity Index	Depla North	Macuao	Sandoval	Pinnacle	Depla	Garden
Shannon–Weiner (H')	1.232	1.642	1.808	1.385	1.526	1.45
Eveness_ (e^H/S)	0.2858	0.3689	0.5081	0.333	0.3833	0.3554
Margalef's Richness	1.267	1.491	1.044	1.057	1.251	1.1

Comparison between MPA and Non–MPA stations

The comparison between Marine Protected Areas (MPA) and Non–Marine Protected Areas (NMPA) showed no statistically significant differences across all measured metrics based on the Wilcoxon test ($p > 0.05$) at $\alpha = 0.05$ (Figure 5). Similarly, the Shannon–Wiener diversity index showed slightly higher values in MPA

(1.55) than in NMPA (1.45), but this difference was also not significant ($p > 0.05$). Margalef's richness index followed a different trend, with NMPA (1.35) slightly higher than MPA (1.10), yet again with no significant difference ($p > 0.05$).

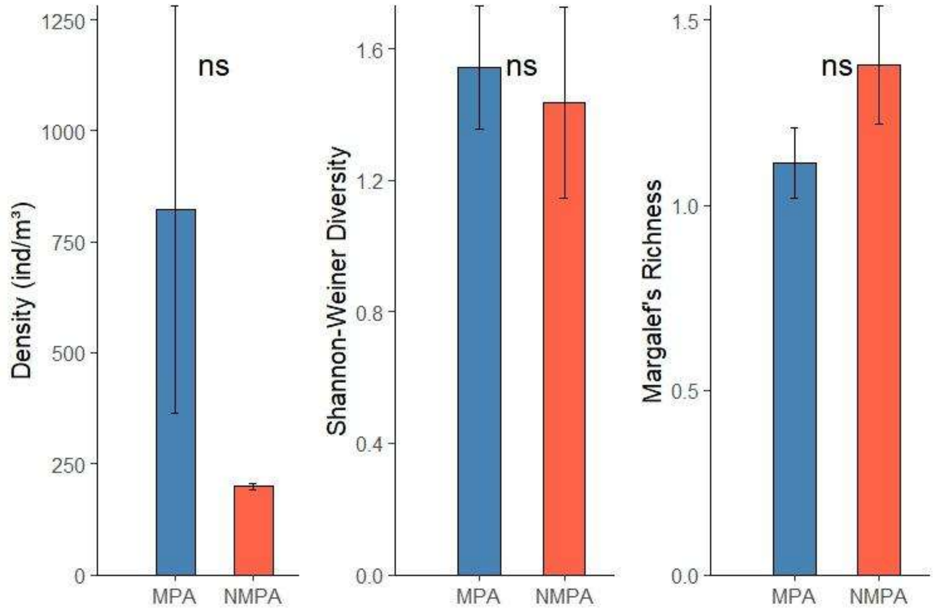

Figure 5. Comparison between Marine Protected Area and Non–Marine Protected Area in terms of density, diversity, and richness.

DISCUSSION

Phytoplankton Composition, Abundance, and Diversity

The present study revealed spatial variation in the composition, abundance, and diversity of zooplankton across the six sampling stations in Shark Fin Bay. A total of 14 zooplankton taxa were recorded, indicating a moderately diverse zooplankton community within the study area. The differences observed among stations suggest that environmental conditions may influence zooplankton distribution and abundance. Zooplankton community structure is influenced by environmental variables such as temperature, salinity, and nutrient availability, which can vary within Marine Protected Areas (MPAs) due to localized protection and management strategies (Gao et al. 2025). For example, in the Coiba National Park MPA, zooplankton abundance was linked to favorable oceanographic conditions (Olivera EB et al. 2023). Similarly, in the Iroise Sea MPA, seasonal and inter–annual variations in zooplankton abundance were observed, driven by phytoplankton composition and abiotic factors (Benedetti et al. 2019).

Zooplankton density varied considerably among stations, ranging from 194.40 ind/m³ at Depla North to 1,249.79 ind/m³ at Sandoval. These spatial variations suggest that environmental heterogeneity within Shark Fin Bay influences zooplankton distribution. Notably, four of the six sampling stations, Sandoval, Pinnacle, Garden, and Depla, were located within MPAs and recorded higher densities compared to the two non–MPA stations, Depla North and Macuao. However, statistical analysis revealed no significant differences in density between MPA and non–MPA stations, suggesting that the observed variation in abundance cannot be definitively attributed to protection status alone. This finding indicates that other environmental factors, such as hydrodynamics, nutrient availability, and habitat structure, may be equally or more important drivers of zooplankton abundance in the bay than MPA designation.

The dominance of copepods, particularly Calanoida and Cyclopoida, across all stations is consistent with typical zooplankton community structures in tropical marine ecosystems. Copepods are widely recognized as the most abundant and ecologically important zooplankton group because they play a critical role in transferring energy from primary producers to higher trophic levels such as fish larvae and small pelagic fishes. The high abundance of Calanoida observed in Sandoval and Pinnacle may indicate favorable feeding conditions since many calanoid copepods are efficient grazers of phytoplankton. Calanoida copepods are often used as indicators of good water quality and are associated with reduced anthropogenic impact (Belmonte 2021; Choi et al. 2024). Similarly, the variable density of Cyclopoida across stations may reflect differences in food availability or environmental conditions. Cyclopoida are highly adaptable to a wide range of environmental conditions, including eutrophic and hypoxic environments. Their ability to tolerate adverse conditions, such as high salinity or low oxygen, enhances their dominance in diverse habitats (Ladhar et al. 2015; Xu et al. 2015; Min et al. 2021; Choi et al. 2023; Rocha–Diaz et al. 2024).

Among non–copepod taxa, Appendicularia showed notably high densities at Pinnacle and Garden, contributing significantly to the overall zooplankton density at these stations. Appendicularians are known to thrive in nutrient–rich environments because of their ability to efficiently filter small particles, including picoplankton and detritus. Their high abundance may indicate areas of elevated productivity or localized nutrient enrichment within the bay. Appendicularians act as a critical link in marine food webs, bridging primary producers and higher trophic levels through their eggs, trunks, and filtering houses, which serve as food for copepods, chaetognaths, ctenophores, and fish larvae (Costalago et al. 2012; Capitanio et al. 2018; Alves et al. 2025). The presence of Ostracoda, Chaetognatha, fish eggs, and nauplii underscores the dynamic and multi–trophic nature of planktonic ecosystems, which are vital for sustaining marine food webs (López et al. 2007; Costa et al. 2020; Peter et al. 2020; Dinç et al. 2026).

The occurrence of larval forms, including crab zoea, euphausiids, mysids, and polychaete larvae, although in relatively low densities, highlights the role of Shark Fin Bay as a potential nursery or spawning ground for various marine organisms. Larval dispersal connects different habitats, such as estuaries, coastal zones, and open oceans, ensuring genetic exchange and population connectivity (Able et al. 2011; Simith et al. 2014; Dvoretsky and Dvoretsky 2022). The presence of fish eggs across several stations further supports the ecological importance of the area for fish reproduction and early development. Fish eggs are foundational to the recruitment and sustainability of fish populations, and their abundance and spatial distribution directly impact larval survival and early recruitment success, which are critical for maintaining fishery stocks (Rajeesh et al. 2022; Utami et al. 2025; Wu et al. 2025). In contrast, rare taxa such as gastropod larvae and foraminiferans, which were only recorded at Macuao, may reflect localized environmental conditions or sporadic plankton dispersal patterns influenced by water currents. Foraminiferans contribute to nutrient cycling and carbon sequestration, while gastropods act as decomposers and nutrient providers in coastal ecosystems (Supusepa et al. 2023; Isfaeni et al. 2024; Islam et al. 2025).

Spatial Distribution of Zooplankton

The spatial distribution of zooplankton biomass exhibited considerable variation across stations. Sandoval recorded the highest biomass (49.54 ml/100 m^3), followed by Pinnacle (36.33 ml/100 m^3), Garden (19.82 ml/100 m^3), and Depla (16.51 ml/100 m^3). In contrast, Macuao (3.63 ml/100 m^3) and Depla North (2.97 ml/100 m^3) recorded the lowest biomass values. The high biomass observed in certain stations may be linked to the combined presence of abundant copepods and appendicularians, both of which significantly contribute to total plankton biomass.

The Shannon diversity index indicated moderate diversity overall, ranging from 1.232 to 1.808 across stations. Sandoval exhibited the highest diversity (1.808) with the most balanced distribution of taxa (evenness = 0.5081), suggesting a more stable and diverse zooplankton community. In contrast, Depla North recorded the lowest diversity (1.232) and evenness (0.2858), indicating that the zooplankton community at this station was dominated by a few taxa. The Margalef richness index revealed that Macuao had the highest species richness (1.491), despite its relatively low density and biomass, suggesting a greater variety of taxa but fewer individuals. Sandoval and Pinnacle, in contrast, exhibited lower species richness but substantially higher abundance, indicating that a few dominant taxa (particularly copepods and appendicularians) contributed substantially to total zooplankton density, a pattern commonly observed in productive marine plankton communities.

Comparison between MPA and Non–MPA stations

Statistical analysis revealed no significant differences between MPA and non–MPA stations in any of the measured metrics: density ($p > 0.05$), biomass ($p > 0.05$), Shannon diversity index ($p > 0.05$), evenness ($p > 0.05$), or species richness/Margalef index ($p > 0.05$). The absence of significant differences suggests that MPA designation may not be the primary driver of zooplankton community structure in Shark Fin Bay. Instead, multiple factors likely exert greater influence on zooplankton dynamics, including abiotic variables (temperature, salinity, nutrient availability, oxygen concentration), water mass connectivity and hydrodynamic exchanges that homogenize communities between protected and unprotected areas, predation by fish species that move freely across boundaries (Toruan 2021), and temporal variability in zooplankton composition driven by seasonal environmental changes (Du et al. 2019; Serafim–Júnior et al. 2019; Prasertphon et al. 2023). Additionally, the scale of this study, six stations sampled at a single time point, may be insufficient to capture the temporal and spatial dynamics necessary to detect MPA effectiveness. The comparable community metrics between MPA and non–MPA stations indicate that both environments support functionally similar zooplankton communities, suggesting that assembly and maintenance processes operate similarly across protection categories. These findings highlight that evaluating MPA effectiveness requires longer–term, multi–seasonal monitoring coupled with comprehensive assessment of physical and biogeochemical variables.

This study revealed clear spatial variation in zooplankton composition, abundance, biomass, and diversity across the six sampling stations in Shark Fin Bay. Copepods, particularly Calanoida and Cyclopoida, dominated the community structure across all stations, highlighting their ecological importance in the area. Zooplankton density, biomass, diversity, richness, and evenness varied among individual stations, but statistical analysis indicated no significant differences between MPA and non–MPA stations. This finding suggests that factors other than MPA status, such as localized hydrodynamics, nutrient availability, habitat heterogeneity, predation, and temporal variability, are primary drivers of zooplankton community structure in Shark Fin Bay. These results underscore the complexity of evaluating MPA effectiveness and highlight the need for longer–term, multi–seasonal monitoring coupled with comprehensive assessment of physical and biogeochemical variables to elucidate the mechanisms governing zooplankton ecology in the bay.

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GENERATIVE AI STATEMENT

There were no AI tools incorporated in the making of this manuscript.

ETHICAL CONSIDERATIONS

The study did not involve human and animal subjects as it is focused on the Spatial Distribution and Assemblages of Zooplankton during the Northeast Monsoon in Shark Fin Bay, Taytay, Palawan, Philippines.

DECLARATION OF COMPETING INTEREST

The authors declare that there is no competing interests to any authors.

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