Monsoonal Variation in Phytoplankton Assemblages and Selected Water Physicochemical Parameters in Shark Fin Bay, Taytay, Palawan

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ABSTRACT

Phytoplankton serve as important indicators of water quality and ecosystem condition. This study examined the seasonal variation of phytoplankton communities in Shark Fin Bay, Taytay, Palawan, Philippines, in relation to monsoonal changes. Monthly sampling was conducted from July to December 2025 at six sites within the Shark Fin Bay Marine Protected Area. Phytoplankton composition, abundance, diversity, and harmful genera were assessed together with selected physicochemical parameters, including temperature, salinity, dissolved oxygen, pH, total suspended solids, water transparency, depth, and nutrients. Results showed clear differences between the Southwest and Northeast Monsoons. The Northeast Monsoon recorded higher phytoplankton abundance but lower diversity, indicating dominance by fewer taxa. In contrast, the Southwest Monsoon supported a more diverse community, although overall abundance was lower. Harmful genera, including *Alexandrium* and *Prorocentrum*, were also observed. These findings provide baseline information for phytoplankton monitoring and harmful algal bloom management in Shark Fin Bay, with relevance to fisheries sustainability and coastal conservation.

Keywords: abundance, environmental drivers, harmful algal blooms, marine protected areas, seasonal dynamics

INTRODUCTION

Phytoplankton are fundamental components of marine ecosystems because they serve as primary producers, support aquatic food webs, and respond rapidly to changes in environmental conditions. As major contributors to global primary productivity, phytoplankton influence nutrient cycling, dissolved oxygen dynamics, and the overall ecological functioning of coastal and marine waters (Behrenfeld Randerson 1998; Behrenfeld et al. 2008). Their short generation times and high sensitivity to physical, chemical, and biological changes make them valuable biological indicators of water quality and ecosystem health (Roelke et al. 2003; Yusuf 2020). Variations in temperature, salinity, light availability, dissolved oxygen, nutrient concentrations, rainfall, and hydrodynamic conditions can strongly affect phytoplankton composition, abundance, diversity, and distribution (Wiggert et al. 2005; Behrenfeld & Boss 2014; Deng et al. 2014).

In tropical coastal ecosystems, phytoplankton communities are strongly influenced by seasonal environmental variability, particularly in areas affected by monsoon systems. Monsoonal shifts alter rainfall patterns, wind direction, water circulation, sediment resuspension, freshwater inflow, and nutrient inputs, all of which may contribute to changes in phytoplankton assemblages (Parab et al. 2006; Gatdula et al. 2017; Anutaliya 2023). During periods of increased nutrient availability or water-column stability, certain phytoplankton groups may proliferate rapidly, sometimes resulting in harmful algal blooms (HABs). These blooms can disrupt marine food webs, reduce water quality, affect fisheries productivity, and pose risks to public health through toxin accumulation in seafood (Azanza and Taylor 2001; Wells et al. 2020; Azanza et al. 2024). Therefore, understanding the relationship between monsoonal variability, physicochemical conditions, and phytoplankton community structure is essential for improving coastal monitoring and management strategies.

The Philippines is particularly vulnerable to harmful algal blooms because of its extensive coastline, productive bays, and strong dependence on fisheries and coastal resources. HAB events have been documented in numerous coastal areas of the country, with several bays repeatedly affected by shellfish toxicity and bloom-forming phytoplankton species (BFAR 2021; Azanza et al. 2024). In Palawan, HAB-related concerns have been reported since the first documented occurrence in Malampaya Sound in 1998, indicating the ecological and socioeconomic importance of monitoring phytoplankton dynamics in the province (Furio & Gonzalez 2002; Yñiguez et al. 2020). Because many coastal communities in Palawan depend on fisheries, mariculture, and marine tourism, changes in phytoplankton communities and the possible occurrence of harmful taxa may have direct implications for food security, livelihood stability, and coastal ecosystem health.

Shark Fin Bay in Taytay, Palawan is an ecologically significant coastal area that forms part of a Marine Protected Area network. The area contains productive coastal habitats such as coral reefs, seagrass beds, and mangrove-associated waters, which support fisheries and local biodiversity. It is also influenced by seasonal monsoon patterns and increasing anthropogenic pressures, including coastal runoff, fishing activities, and land-based inputs near protected and non-protected zones (Brun et al. 2024). Previous observations in the area have indicated the presence of potentially harmful phytoplankton, including dinoflagellates associated with bloom development and shellfish toxicity risk (Paalan et al. 2026). These conditions highlight the need for site-specific baseline information on phytoplankton assemblages and their relationship with environmental drivers.

Despite the ecological importance of Shark Fin Bay, baseline information on its phytoplankton community remains limited. Existing conservation initiatives in the area focus largely on habitat protection, fisheries management, and marine biodiversity monitoring, but systematic information on phytoplankton composition, abundance, diversity, harmful genera, and physicochemical drivers is still insufficient. This gap limits the ability of local stakeholders, resource managers, and government agencies to develop early-warning systems and science-based management responses to possible HAB events. Furthermore, while Marine Protected Areas are often expected to contribute to improved ecological conditions, the extent to which phytoplankton assemblages differ between MPA and non-MPA stations in Shark Fin Bay remains unclear.

To address these gaps, this study examined the monsoonal variation in phytoplankton assemblages and selected water physicochemical parameters in Shark Fin Bay, Taytay, Palawan. Specifically, it aimed to: (1) assess the composition, abundance, and diversity of phytoplankton assemblages; (2) assess the seasonal variation in selected water physicochemical parameters between the Southwest and Northeast Monsoon periods; and; and (3) determine the relationship between phytoplankton community structure and environmental gradients across monsoon seasons using redundancy analysis. The findings of this study provide important baseline information for harmful algal bloom monitoring, coastal resource management, and the development of long-term ecological monitoring programs in Shark Fin Bay and other monsoon-influenced tropical coastal systems.

METHODS

Study Area and Sampling Design

Phytoplankton sampling was conducted under the Sea Academy Plus Project in Shark Fin Bay, Taytay, Northern Palawan, Philippines, an area characterized by shallow coastal waters, seagrass beds, coral reefs, mangroves, and a network of Marine Protected Areas (MPAs) (Brun et al. 2024). Six sampling stations were established based on the project's monitoring sites, including four stations within the MPA network and two outside its boundaries (Table 1; Figure 1). In December 2023, the toxic dinoflagellate *Pyrodinium bahamense* was recorded across all stations under pre-bloom conditions (Paalan et al. 2026). To better assess temporal variability and potential harmful algal bloom development, sampling frequency was increased from bimonthly to monthly.

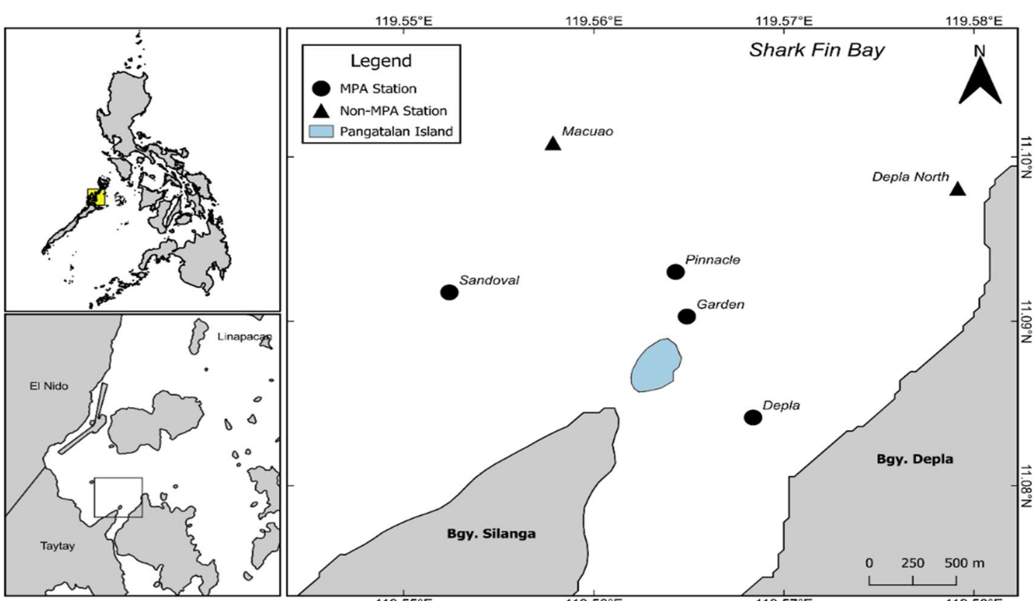

Figure 1. Map of the study area and sampling stations in Shark Fin Bay, Taytay, Palawan, Philippines.

Table 1. Coordinates of sampling stations in Shark Fin Bay, Taytay, Palawan, Philippines.

Station	Longitude (E)	Latitude (N)
Depla	119°34.130’	11°5.049’
Depla North	119°34.747’	11°5.890’
Garden	119°33.894’	11°5.416’
Macuao	119°33.470’	11°6.057’
Pinnacle	119°33.859’	11°5.579’
Sandoval	119°33.143’	11°5.506’

Data Collection

Sampling was conducted monthly from July to December 2025 during the last week of each month, covering both the Southwest Monsoon (Habagat) and Northeast Monsoon (Amihan). Fieldwork was performed between 08:00 and 12:00 to maintain consistency and account for peak phytoplankton surface activity (Kudela, 2010).

Surface water temperature (°C), salinity (ppt), and dissolved oxygen (mg L^{-1}) were measured in situ at 0.5 m depth using a YSI Pro2030 multiparameter meter, while pH was measured using an HT-1202 digital pH meter. All measurements were taken in triplicate. Water transparency was determined using a 20-cm Secchi disk.

Surface water samples were collected for nitrate (NO_3^-), phosphate (PO_4^{3-}), and total suspended solids (TSS) analyses. Nutrient concentrations were measured using Hanna Instruments portable photometers (HI97728 and HI97713) following manufacturer protocols. Due to equipment unavailability, nutrient data for July and August were not obtained. TSS analysis was conducted using vacuum filtration with pre-weighed glass microfiber filters, followed by oven drying at 60°C for 24 h. TSS concentration was expressed in mg L^{-1}.

Phytoplankton Sampling and Analysis

Phytoplankton samples were collected using a 20 µm mesh plankton net (30-cm mouth diameter) vertically towed from 1 m depth to the surface. Sampled water volume was estimated using the cylinder volume equation:

$$V = \pi r^2 L$$

where V is the sampled water volume (m^3), r is the net radius, and L is the tow distance.

Samples were concentrated into 50 mL cod-end containers, preserved with 5% buffered formaldehyde, and analyzed using light microscopy. Phytoplankton were identified to genus level following standard taxonomic references (Thomas 1997; Omura et al. 2012), while harmful taxa were verified using the IOC-UNESCO Harmful Microalgae Reference List. Enumeration was performed using a Sedgewick–Rafter chamber from 1 mL subsamples counted in triplicate under a BA210 microscope (Motic, Germany). Phytoplankton density was calculated following Relox (2002):

$$Density\ (cells\ L^{-1}) = \frac{N \times V_1}{V_s}$$

where N is the number of counted cells, V_1 is the total sample volume, and V_s is the filtered seawater volume. Relative abundance and community indices (Shannon diversity, dominance, richness, and evenness) were also computed.

Data Analysis

Normality and homogeneity of variance were tested using Shapiro–Wilk and Levene’s tests, respectively. Spatial and temporal differences in environmental parameters and phytoplankton density were analyzed using one-way ANOVA or Kruskal–Wallis tests, depending on data distribution. Relationships between phytoplankton abundance and environmental variables were assessed using Redundancy Analysis (RDA). Diversity indices were calculated in PAST version 4.17, and all statistical analyses were performed in R software at $\alpha = 0.05$.

RESULTS

Phytoplankton Composition across sampling areas and Monsoon seasons

The data showed that phytoplankton observed across the six sampling areas of Shark Fin Bay is summarized in Table 2. A total of 66 genera belonging to four major functional groups were identified. Among these, diatoms comprised the most diverse group with 46 genera, followed by dinoflagellates with 18 genera. Cyanobacteria and silicoflagellates were represented by one genus each. Variations in genus composition were observed among sampling stations. Garden, Pinnacle, and Sandoval recorded the highest phytoplankton composition, with 51 genera each, followed by Depla with 48 genera. Macuao had 44 genera, while Depla North showed the lowest composition with 40 genera. Phytoplankton composition also varied between monsoon seasons. A total of 53 genera were shared between the Southwest Monsoon (SWM) and Northeast Monsoon (NEM) periods. Genera present in both monsoons included the diatoms *Bacteriastrum, Chaetoceros, Coscinodiscus, Diploneis, Ditylum, Guinardia, Hemialus, Licmophora, Odontella, Pleurosigma, Rhizosolenia,* and *Thalassionema*. Dinoflagellate genera included *Akashiwo, Alexandrium, Dinophysis, Gonyaulax, Prorocentrum, Protoperidinium,* and *Tripos*. The cyanobacterial genus *Oscillatoria* and the silicoflagellate genus *Dictyocha* were likewise recorded in both monsoon periods. A total of 11 genera were found exclusively during the Southwest Monsoon, namely *Amphidinium, Amphora, Biddulphia, Craticula, Entomoneis, Gomphonema, Goniodoma, Podolampas, Rhodomonas, Thalassiosira,* and *Ulnaria*. In contrast, only two genera were unique to the Northeast Monsoon: *Detonula* and *Skeletonema* (Figure 2).

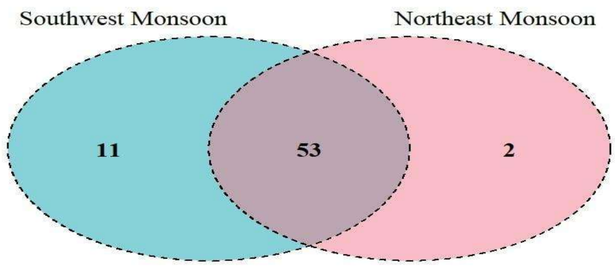

Figure 2. Venn diagram showing the number of phytoplankton genera unique to each monsoon season and shared between the southwest and northeast monsoons in Shark Fin Bay, Taytay, Palawan, Philippines.

Table 2. Phytoplankton composition across sampling sites and months."+" denotes the presence of genera, while "–" indicates their absence at the respective sampling sites and months.

Genus	Station					
	Depla	**Depla North**	**Garden**	**Macuao**	**Pinnacle**	**Sandoval**
Diatom						
Amphisolenia	+	+	-	+	+	+
Amphora	-	-	+	-	-	-
Asterionellopsis	-	-	-	+	+	+
Asteromphalus	-	-	-	-	-	+
Bacillaria	+	+	+	+	+	+
Bacteriastrum	+	+	+	+	+	+
Biddulphia	-	-	+	-	-	-
Campylodiscus	+	-	+	+	+	+
Cerataulina	+	+	+	+	+	+
Chaetoceros	+	+	+	+	+	+
Corethron	+	+	+	+	+	+
Coscinodiscus	+	+	+	+	+	+
Craticula	-	-	+	-	+	+
Cylindrotheca	+	-	+	-	+	+
Dactyliosolen	+	-	+	+	-	+
Detonula	+	-	-	-	+	-
Diploneis	+	+	+	+	+	+
Ditylum	+	+	+	+	+	+
Entomoneis	-	-	-	-	+	-
Eucampia	+	+	+	-	-	-
Fragilaria	-	+	-	-	+	+
Gomphonema	-	-	-	-	+	-
Guinardia	+	+	+	+	+	+
Hemialus	+	+	+	+	+	+
Lauderia	+	+	+	+	+	+
Leptocylindricus	+	-	-	+	+	+
Licmophora	+	+	+	+	-	+
Lyrella	-	+	+	+	+	+
Melosira	+	-	+	+	+	+
Navicula	+	+	+	-	+	+

Genus	Station					
	Depla	Depla North	Garden	Macuao	Pinnacle	Sandoval
Nitszchia	+	+	-	-	+	+
Odontella	+	+	+	+	+	+
Pinnularia	+	+	+	+	+	+
Pleurosigma	+	+	+	+	+	+
Proboscia	+	+	+	+	+	+
Pseudo-nitszchia	+	+	+	+	+	+
Rhizosolenia	+	+	+	+	+	+
Rhodomonas	-	-	+	-	-	-
Skeletonema	-	-	-	+	-	-
Synedra	+	-	+	+	+	-
Thalassionema	+	+	+	+	+	+
Thalassiosira	-	-	-	-	-	-
Thalassiothrix	+	-	+	+	+	-
Triceratium	+	+	+	+	+	+
Tropidoneis	+	+	+	+	+	+
Ulnaria	-	-	-	-	-	+
Dinoflagellates						
Akashiwo	+	-	+	-	-	+
Alexandrium	+	+	+	+	+	+
Amphidinium	-	-	+	-	-	+
Dinophysis	+	+	+	+	+	+
Diplopsalis	-	-	+	-	+	+
Goniodoma	-	-	+	-	-	-
Gonyaulax	+	+	+	+	+	+
Gymnodinium	+	+	+	+	+	+
Gyrodinium	+	-	+	+	+	+
Noctiluca	+	+	+	-	+	+
Ornithocercus	-	+	-	-	-	-
Peridinium	+	+	+	+	+	+
Phyrophacus	+	+	+	+	+	+
Podolampas	-	-	-	+	-	-
Prorocentrum	+	+	+	+	+	+
Protoperidinium	+	+	+	+	+	+
Pyrocystis	+	+	+	-	+	-
Tripos	+	+	+	+	+	+
Cyanobacteria						
Oscillatoria	+	+	+	+	+	+
Silicoflagellate						
Dictyocha	+	-	+	+	+	+
Total	**48**	**40**	**51**	**44**	**51**	**51**

Phytoplankton Composition across stations and sampling months

The phytoplankton assemblage in Shark Fin Bay was dominated by *Thalassionema*, with a mean density of ($\bar{x}$ = 27,685 cells/L), and *Chaetoceros*, with ($\bar{x}$ = 19,801 cells/L). These two genera consistently represented the largest proportion of the community across both sampling months and stations, with a total mean density of ($\bar{x}$ = 47,486 cells/L) (Figure 3 and Figure 4). Other notable genera contributing to the community composition included *Bacteriastrum* ($\bar{x}$ = 9,016 cells/L), *Tripos* ($\bar{x}$ = 1,153 cells/L), *Protoperidinium* ($\bar{x}$ = 746 cells/L), *Prorocentrum* ($\bar{x}$ = 639 cells/L), *Lauderia* ($\bar{x}$ = 3,073 cells/L), and *Cerataulina* ($\bar{x}$ = 880 cells/L).

Across the six sampling stations, *Thalassionema* was the most dominant genus at most sites, followed by *Chaetoceros*. While the proportional contributions of minor taxa varied among stations, the overall community structure remained relatively consistent throughout the study area (Figure 3). At stations such as Depla, Garden, and Pinnacle, *Thalassionema* and *Chaetoceros* consistently constituted the majority of the phytoplankton assemblage, while other genera, such as *Bacteriastrum* and *Protoperidinium*, were present in smaller proportions. However, there was noticeable variation in the relative abundance of these minor taxa across stations, suggesting site-specific environmental factors influencing community composition.

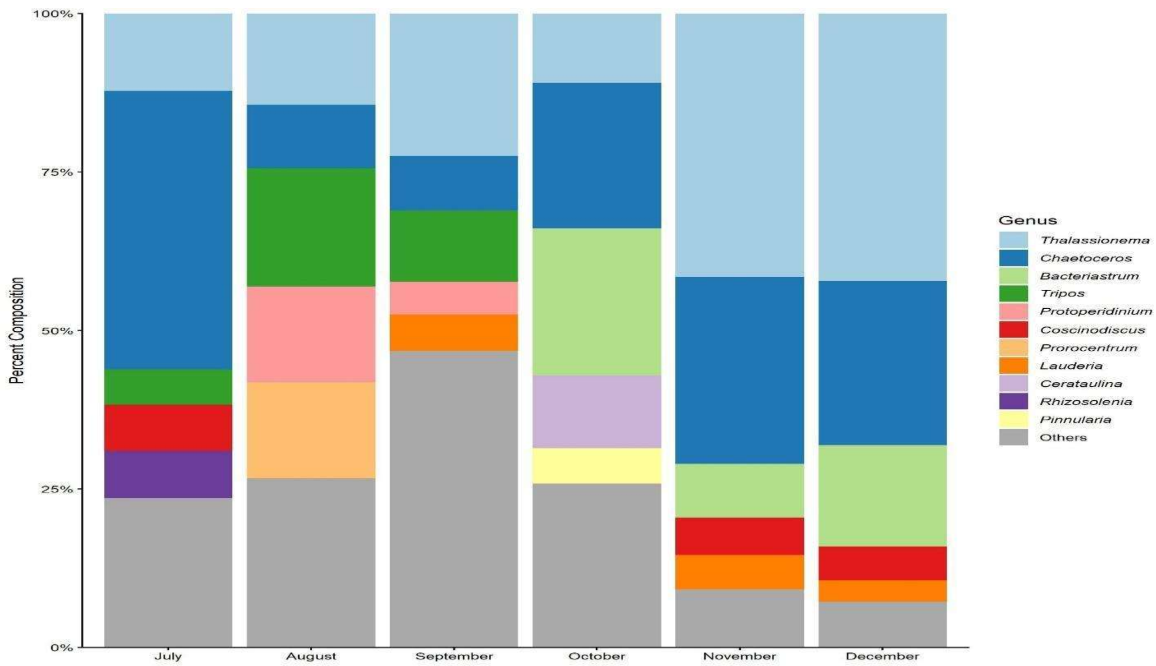

Figure 3. The percentage contribution of the dominant phytoplankton genera to the total abundance. Among sampling stations in Shark Fin Bay, Taytay, Palawan, Philippines.

Additionally, the monthly percent composition showed distinct trends, particularly during the Southwest Monsoon from July to September. In July, the assemblage was primarily dominated by *Chaetoceros* ($\bar{x}$ = 731 cells/L). August exhibited a more balanced distribution across several genera, with *Tripos* ($\bar{x}$ = 625 cells/L) and *Protoperidinium* ($\bar{x}$ = 506 cells/L) contributing significantly. In September, the community displayed greater taxonomic diversity, indicating an increase in community complexity. Conversely, November and December were marked by a notable increase in *Thalassionema* ($\bar{x}$ = 26,064 cells/L) abundance, suggesting a seasonal shift towards a more uneven assemblage characteristic of the Northeast Monsoon period (Figure 4).

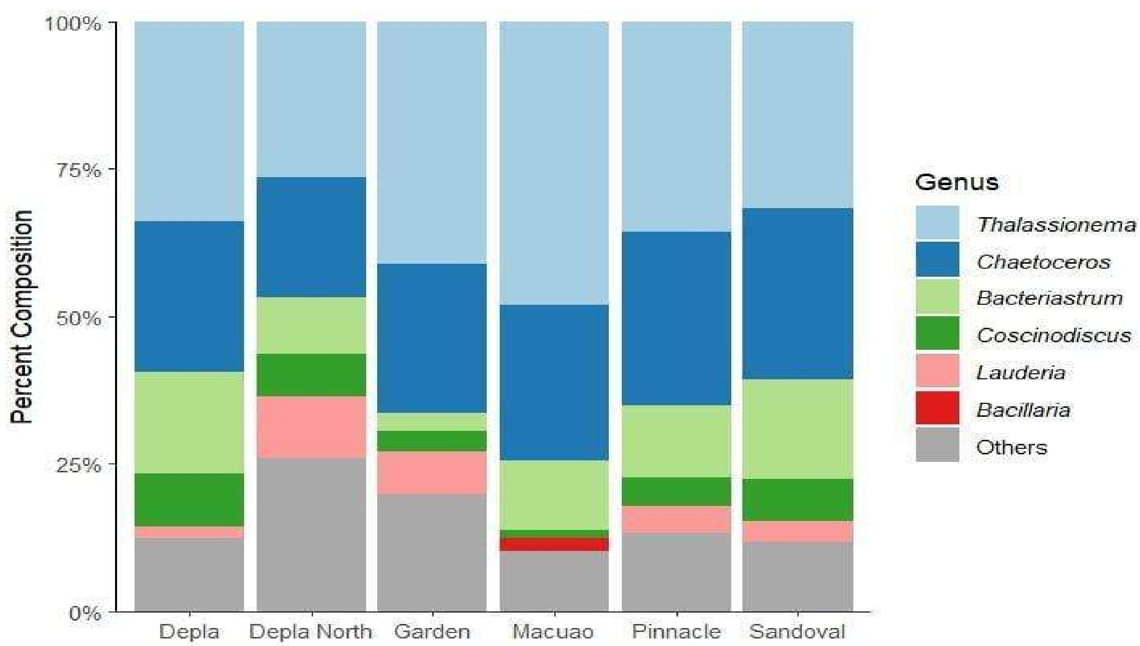

Figure 4. The percentage contribution of the dominant phytoplankton genera to the total abundance. Among sampling months in Shark Fin Bay, Taytay, Palawan, Philippines.

Seasonal Variation in Phytoplankton Abundance and Diversity Indices

Seasonal comparison showed that phytoplankton community attributes differed significantly between the Southwest and Northeast Monsoon periods (Figure 5). Phytoplankton abundance was significantly greater during the Northeast Monsoon, as shown by the higher median and broader distribution of values relative to the Southwest Monsoon (Figure 5). In contrast, the Shannon–Wiener diversity index was significantly higher during the Southwest Monsoon, indicating that this period supported a more diverse phytoplankton assemblage. Additionally, richness and evenness were both significantly higher during the Southwest Monsoon, suggesting greater taxonomic representation and a more equitable distribution of individuals among genera. The Northeast Monsoon, although characterized by higher abundance, exhibited reduced diversity, richness, and evenness, reflecting the increasing dominance of a limited number of taxa. These findings demonstrate that monsoonal variation strongly influenced phytoplankton community structure, with the Southwest Monsoon favoring a more diverse and balanced assemblage, and the Northeast Monsoon promoting higher biomass but lower community complexity.

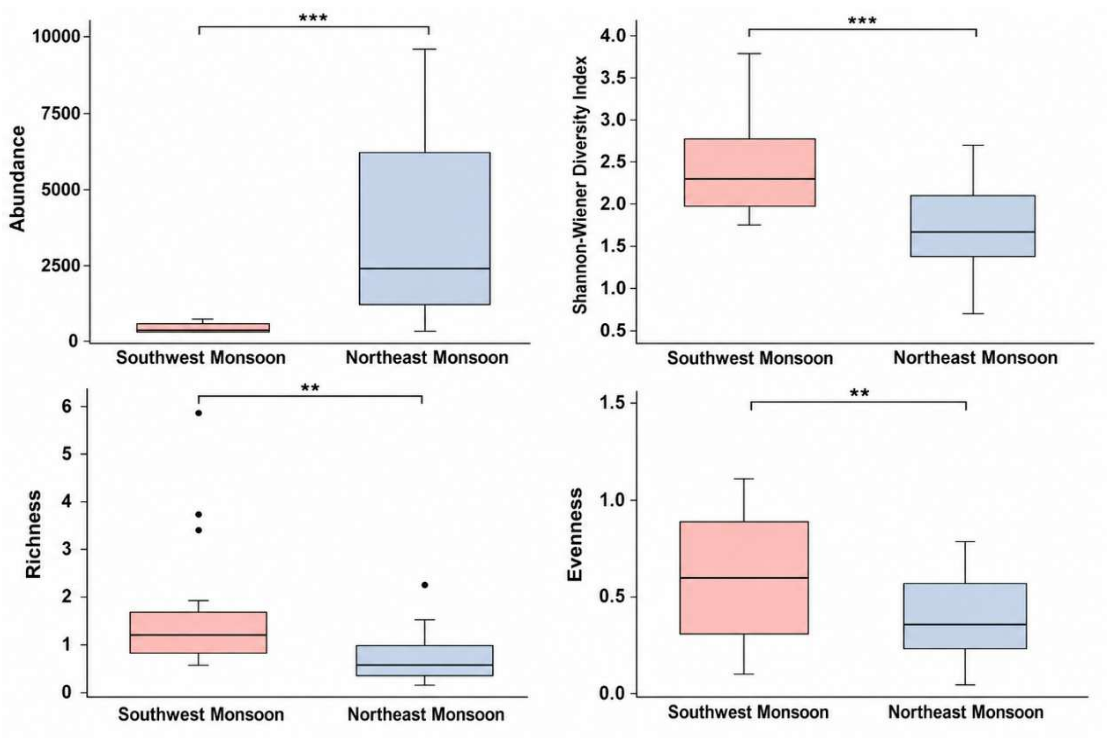

Figure 5. Phytoplankton abundance, diversity, richness, and evenness in Shark Fin Bay during Monsoon season.

Monsoonal Variation in Selected Water Physicochemical Parameters

The analysis of selected water physicochemical parameters revealed notable differences between the Southwest and Northeast Monsoons. As shown in Figure 6, temperature and dissolved oxygen concentrations were significantly higher during the Southwest Monsoon. In contrast, pH and total suspended solids were significantly elevated during the Northeast Monsoon. It is important to note that phosphate and nitrate data were unavailable for July and August (SWM); consequently, these parameters appeared higher due to the lack of data for two months during the Southwest Monsoon. However, salinity, water transparency, and water depth did not show significant variations between the two monsoon periods. These findings suggest that distinct environmental conditions characterize each monsoon. The Southwest Monsoon is associated with warmer, more oxygenated waters, whereas the Northeast Monsoon is characterized by higher suspended solids and pH levels, with minimal nutrient concentrations. These seasonal fluctuations in water physicochemical parameters likely influenced the observed changes in phytoplankton community composition between the two monsoonal periods.

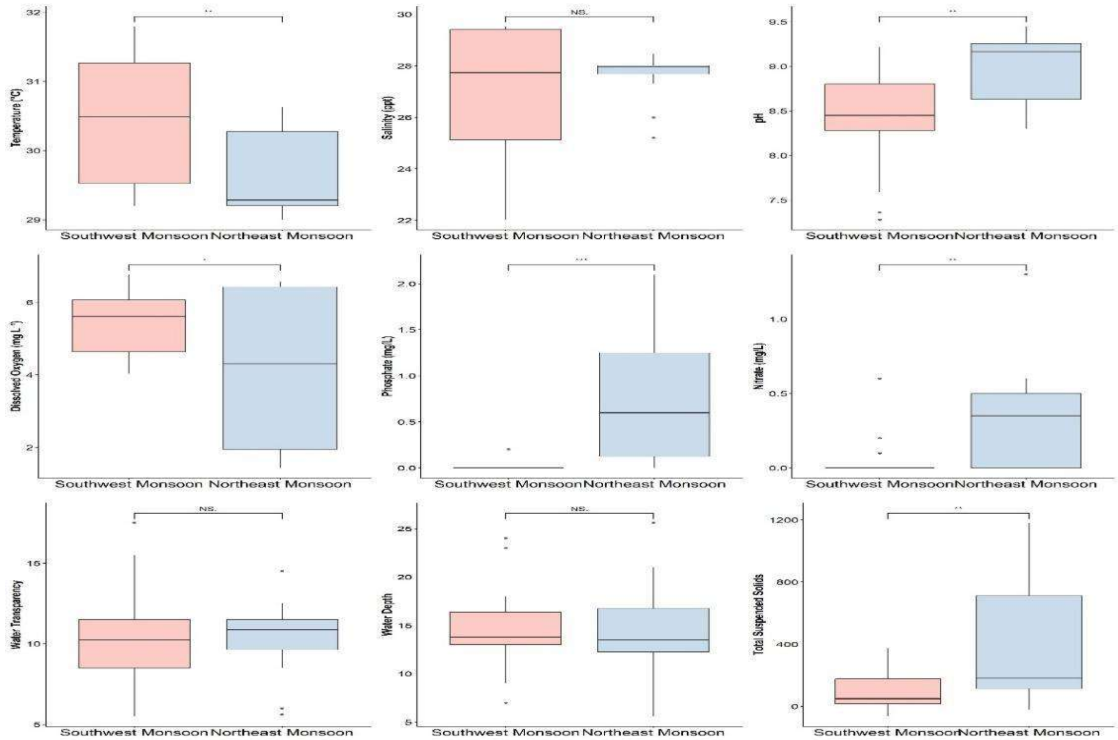

Figure 6. Comparison of water physicochemical parameters between Monsoon periods.

Phytoplankton Distribution and Environmental Gradients Across Monsoon Periods

The redundancy analysis (RDA) revealed distinct relationships between phytoplankton genera and environmental variables across monsoon periods. The first two canonical axes explained 78.79% of the phytoplankton–environment variation, with RDA1 accounting for 64.92% and RDA2 for 13.87% (Figure 7). Temperature and dissolved oxygen (DO) emerged as the dominant gradients on the positive side of RDA1, indicating their strong influence under warmer and more oxygenated conditions associated with the Southwest Monsoon. In contrast, the negative side of RDA1 was associated with higher nitrite, phosphate, salinity, pH, and total suspended solids (TSS), which were more characteristic of the Northeast Monsoon. Water transparency and depth showed moderate influence, as indicated by their vectors positioned closer to the center of the ordination plot.

The RDA ordination also demonstrated a clear separation between monsoon periods. Southwest Monsoon samples were mostly distributed along the positive side of RDA1, reflecting higher temperature and DO levels that favored phytoplankton taxa adapted to warmer and oxygen-rich waters. Conversely, Northeast Monsoon samples were positioned along the negative side of RDA1, suggesting stronger associations with nutrient-enriched, saline, alkaline, and more turbid conditions. This separation indicates that seasonal hydrographic shifts, particularly changes in temperature, oxygen availability, nutrient concentration, and suspended solids, were important drivers of phytoplankton community structure in the study area.

Specific genera showed distinct environmental associations. *Tripos*, *Protoperidinium*, *Prorocentrum*, and *Dinophysis* were associated with the positive side of RDA1, suggesting affinity for Southwest Monsoon conditions. In contrast, *Chaetoceros* and *Bacteriastrum* were linked to the negative side, indicating stronger association with nutrient-rich and higher-salinity conditions during the Northeast Monsoon. *Lauderia*, *Ditylum*, and *Thalassionema* were closely related to nutrient and TSS gradients, suggesting tolerance or preference for more turbid and nutrient-enriched waters. Meanwhile, *Ceratulina* and *Thalassiothrix* were positioned near the center of the ordination, indicating broader ecological tolerance and weaker dependence on specific environmental gradients.

These results showed that the spatial distribution of stations reflected environmental heterogeneity across the study area. Stations on the positive side of RDA1 were characterized by warmer and more oxygenated waters, whereas those on the negative side were influenced by higher nutrients, salinity, and suspended solids. These findings emphasize the role of monsoon-driven environmental variability and local station conditions in shaping phytoplankton distribution and community composition.

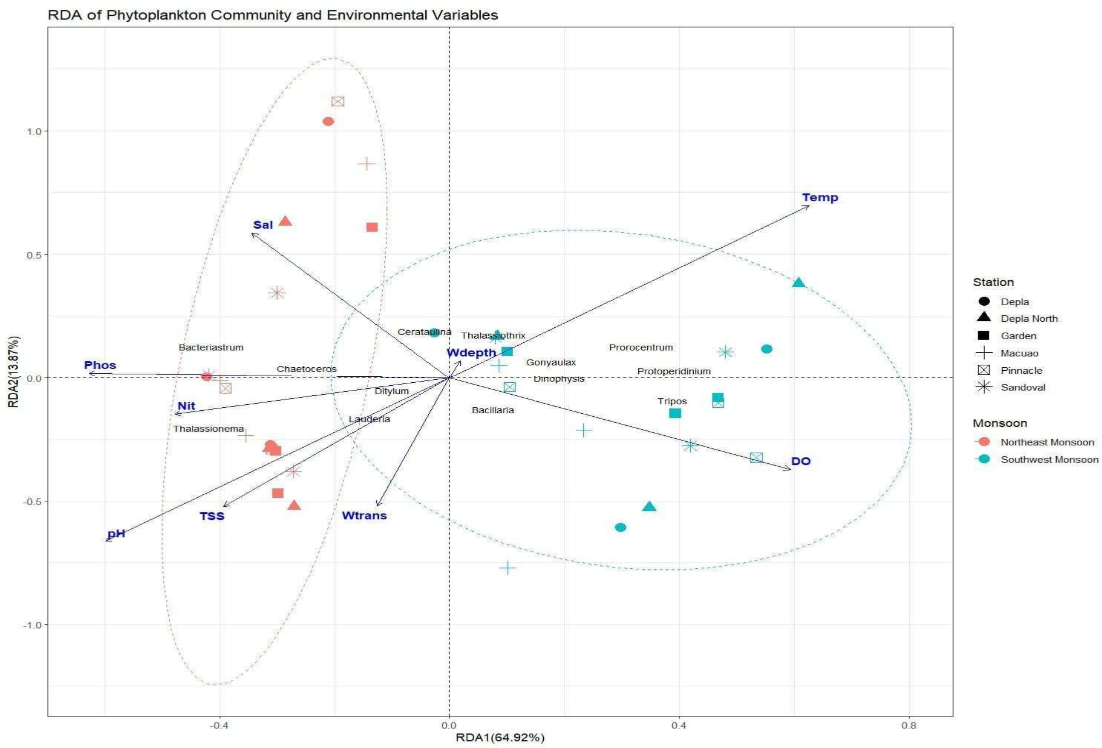

Figure 7. Redundancy analysis (RDA) of phytoplankton community and environmental variables in Shark Fin Bay, Taytay, Palawan, Philippines,

DISCUSSION

Phytoplankton Composition, Abundance, and Diversity

In this study we observed diatoms are the most diverse phytoplankton group, comprising 46 genera, followed by dinoflagellates with 18 genera. Cyanobacteria and silicoflagellates were the least represented, with only one genus each. This result supports previous studies emphasizing the dominance of diatoms in tropical marine ecosystems (Malviya et al. 2016; Fu et al. 2022). In Philippine coastal waters, diatoms are often abundant because of their adaptability to changes in temperature, salinity, and nutrient availability (Ravelo et al. 2022). Similarly, Liu et al. (2022) reported that phytoplankton richness in relatively homogenous coastal environments is influenced more by temporal fluctuations than by spatial differences.

Although less diverse, dinoflagellates were also well represented and widely distributed across the study area. Genera such as Alexandrium, Gonyaulax, Prorocentrum, and Protoperidinium occurred in all sampling stations, suggesting broad ecological tolerance. Their coexistence with diatoms indicates a dynamic coastal system where nutrient enrichment and water column stratification may occur intermittently (Gao et al. 2025). Such patterns are common in tropical coastal areas affected by seasonal monsoon cycles, where changes in water stability and nutrient conditions favor different phytoplankton groups (Parab et al. 2006).

The presence of dinoflagellates is also notable because some genera have been associated with harmful algal bloom events in Malampaya Sound, including those recorded in 1998 and 2000 (Borja et al. 2000; Furio & Gonzalez 2002). In this study, potentially toxic genera were observed, particularly Alexandrium, with a mean density of 80.7 cells/L. This genus is associated with paralytic shellfish poisoning, which results from toxins accumulating in filter-feeding shellfish and moving through the food web to humans and other animals (Etheridge, 2010; Barua et al. 2024). Dinophysis was also recorded at a mean density of 180.3 cells/L and has been linked to diarrhetic shellfish poisoning, although it rarely forms dense blooms (Reguera et al. 2014; Borja et al. 2000).

Seasonal Differences Between the Southwest and Northeast Monsoons

The comparison of phytoplankton communities between the Southwest Monsoon (SWM) and Northeast Monsoon (NEM) revealed significant differences in abundance, diversity, richness, and evenness. Phytoplankton abundance was significantly higher during the NEM (~6,800 cells L^{-1}). In contrast, the SWM exhibited significantly higher Shannon–Wiener diversity values (~2–3), along with greater richness and evenness, indicating a more diverse and evenly distributed community during this period. The present study revealed the comparison effects of the Northeast Monsoon (NEM) and Southwest Monsoon (SWM) on phytoplankton communities, highlighting the significant role of seasonal shifts in environmental conditions. During the Northeast Monsoon, increased phytoplankton biomass was observed, but this was accompanied by a notable reduction in diversity and evenness. Furthermore, the community became dominated by a fast-growing or opportunistic taxa such as *Thallasionema and Chaetoceros* (Canini et al. 2013; Gatdula et al. 2017). In contrast, although the SWM was associated with lower overall phytoplankton abundance, it supported a more diverse and well-balanced community (Canini et al. 2013. These results support our hypothesis that changes in environmental factors such as water temperature, salinity, and nutrient availability are key drivers of phytoplankton community structure (Parab et al. 2006; Gatdula et al. 2017).

Selected Water Parameter Profile in Shark Fin Bay

The comparison between the Southwest Monsoon (SWM) and Northeast Monsoon (NEM) showed significant differences in selected physicochemical parameters. Temperature and dissolved oxygen (DO) were higher during the SWM, with temperature ranging from 29.2°C to 31.8°C and DO from 1.4 to 6.7 mg L^{-1}. These values are consistent with monsoonal patterns reported in tropical coastal waters (Jacinto et al. 2011; Villanoy et al. 2011; Nisha & Achyuthan 2014). However, the low DO value of 1.4 mg L^{-1} also indicates possible oxygen stress, similar to previous observations in Manila Bay where hypoxic conditions were reported during the SWM (Jacinto et al. 2011; Gatdula et al. 2017).

In contrast, the NEM recorded higher pH and total suspended solids. The increase in suspended solids may be linked to stronger winds, rainfall, runoff, and water-column mixing during this season (Wiggert et al. 2020; Unnithan et al. 2025). The higher pH values observed during NEM, ranging from 8.40 to 9.45, may also be associated with daytime phytoplankton photosynthesis, which reduces dissolved CO_2 in the water, together with enhanced vertical mixing (Wiggert et al. 2020).

A major limitation of the study was the absence of phosphate and nitrate data for July and August during the SWM. This gap may have affected the comparison by making nutrient concentrations appear higher during the NEM, as shown in Figure 15. Despite this limitation, the available data suggest that nutrient enrichment, particularly nitrate and phosphate, was more evident during the NEM and may have contributed to algal growth and changes in the aquatic food web (Jacinto et al. 2011; Avenido 2023).

Water transparency and depth did not differ significantly between the two monsoon periods. This suggests that these parameters were less affected by seasonal changes compared with temperature, DO, pH, nutrients, and suspended solids. The relatively stable transparency also indicates that other processes, including suspended particles and phytoplankton abundance, may have varied without strongly altering overall light penetration (Wu et al. 2016; PEMSEA 2023).

Relationship Between Water Parameters and Phytoplankton Assemblage

The Redundancy Analysis (RDA) showed that temperature and salinity were significantly related to phytoplankton assemblages during both the Southwest and Northeast Monsoons, with both variables recording a significance value of 0.001. This indicates that these two factors are important drivers of phytoplankton distribution in the study area. During the Southwest Monsoon, temperature and dissolved oxygen explained 64.92% of the variation, suggesting that changes in water-column conditions, such as stratification, mixing, and water-mass movement, influenced the observed community patterns (Jacinto et al. 2011; Araujo et al. 2016).

Seasonal differences were also reflected in the dominant phytoplankton groups. Warmer conditions during the Southwest Monsoon were associated with armored dinoflagellates, including *Prorocentrum*, *Protoperidinium*, *Gonyaulax*, *Dinophysis*, and *Tripos*. This agrees with previous studies showing that higher temperatures can favor dinoflagellates, especially in more stratified waters where their motility gives them an advantage over diatoms (Xiao et al. 2018; Wei et al. 2024). In contrast, during the Northeast Monsoon, higher salinity and nutrient availability supported the abundance of diatoms such as *Bacteriastrum*, *Chaetoceros*, and *Thalassionema*, which are known to thrive under nutrient-enriched and well-mixed conditions (Ravelo et al. 2022; Bharathi et al. 2026).

In general, the results showed that seasonal changes in temperature, salinity, and nutrients strongly shape phytoplankton community composition. The increasing trend in sea surface temperature may further favor dinoflagellates over diatoms, which could have ecological consequences, including a higher risk of harmful algal blooms in coastal waters (Gobler et al. 2017; Develi et al. 2022; Mutshinda et al. 2025). These findings highlight the importance of continued monitoring of phytoplankton communities and environmental conditions, particularly in areas affected by monsoon variability, warming, and local pollution.

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GENERATIVE AI STATEMENT

OpenAI's ChatGPT was used only as a writing support tool to improve grammar, clarity, and reference formatting. All content generated with the assistance of AI was carefully reviewed, revised, and verified by the authors to ensure accuracy, originality, and alignment with academic standards.

ETHICAL CONSIDERATIONS

No animals were harmed, and no human subjects were involved during this study.

DECLARATION OF COMPETING INTEREST

The authors declare that theres no competing interests to any authors.

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