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Research Article

Seasonal Shifts in Diatom Species Dominance in the Tidal Mangrove Estuary of Bangladesh

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ABSTRACT

Sustainable estuary management provides fishery resources, supports livelihoods and maintains estuarine food webs. However, these are highly dependent on hydrological factors and nutrients effects of the estuary itself. We studied seasonal phytoplankton quantity and composition of the Pasur River estuary in the Sundarbans mangrove forest, Bangladesh to understand the phytoplankton structure and identify potential indicators of environmental changes. Water and phytoplankton samples were collected at 11 different locations around the study region from January to December 2019 to assess spatial and temporal differences. Significant differences ($p < 0.05$) in the average salinity were observed between the dry and rainy seasons. Elevated phytoplankton (blue-green algae) concentrations were associated with decreased salinity while increased diatom abundance was linked to higher salinity. Phytoplankton succession from blue-green algae (wet season) to diatoms (dry season) occurred due to variations in physicochemical parameters and nutrient factors. Simultaneously, phytoplankton diversity and density were shown to change in response to habitat quality and seasonal variation. This study highlights the potential impacts of both human activities and natural factors on the population structure in these estuarine environments.

Introduction

Estuaries, which are semi-enclosed coastal bodies of water connecting fresh, brackish, and marine waters, are the world's most productive ecosystems (Cameron and Pritchard, 1963). Tropical estuarine environments are particularly interesting for investigating phytoplankton dynamics due to their constantly changing hydrological conditions (Islam et al., 2006). Like other aquatic ecosystems, phytoplankton are the primary producers in estuarine environment, while heterotrophic bacteria play a crucial role as secondary producers (Yuan et al., 2018; Hilaluddin et al., 2020; Cornils et al., 2007). Phytoplankton communities undergo dramatic shifts in species composition and abundance over space and time as a result of biogeochemical processes and fertilizer input from upstream (Collins and Williams, 1981). It has been established that certain types of microalgae, particularly diatoms and blue-green algae, can pose a threat to aquatic and human life (Valenzuela-Sanchez et al., 2021). Diatoms are a type of phytoplankton that can be found in both saltwater and freshwater environments (Hilaluddin et al., 2020). The ability of the phytoplankton community to adapt to seasonal changes is crucial for the health of aquatic environments. All characteristics associated with the photosynthesis, development, composition, and variety of phytoplankton will be impacted by shifts in

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environmental parameter, monsoon patterns, rainfall intensity, water flow, tidal changes, waves, and outwelling (Valenzuela-Sanchez et al., 2021; Hilaluddin et al., 2020; Lisitsyn, 1995; Gebhardt et al., 2005). Since water turbidity and transparency both increased during the rainy season due to heavy precipitation and increased surface runoff, light intensity and diatom density both dropped. It was reported that diatom growth was stunted because of suspended sediments that blocked the sunlight. A number of species of Chlorophyceae and Cyanophyceaea, however, thrive under conditions of high turbidity due to their exceptional tolerance of shade (Hilaluddin et al., 2020; Krishnan et al., 2020).

Located on the southwestern coast of Bangladesh, the Pasur River estuary (PRE) is the primary estuary for the mangrove ecosystem (Islam and Gnauck, 2011). Although there is published data on coastal phytoplankton (Zinat et al., 2021; Uddin et al., 2021; Shefat et al., 2020; Chowdhury, 2019; Rahaman et al., 2013; Shah et al., 2008). However, these studies did not find evidence of seasonal phytoplankton changes in the interconnected aquatic ecosystems. Thus, the current study was conducted to examine the variations of key phytoplankton species across the seasons in connection to physico-chemical parameters in the tidal mangrove estuary.

Materials and Methods

Study Area

The PRE is located in the Sundarbans, the largest mangrove habitat on Earth (Uddin et al., 2021; IUCN, 1997). Six sampling stations are located in river channels (Dangmari, Koromjal, Jongra, Morapasur, Gandhabala, and Joymoni) and five are located in the estuary (E1, E2, E3, E4, and E5). The study area comprises a total of eleven sampling stations (Fig. 1). Location was a major factor in selecting these study areas.

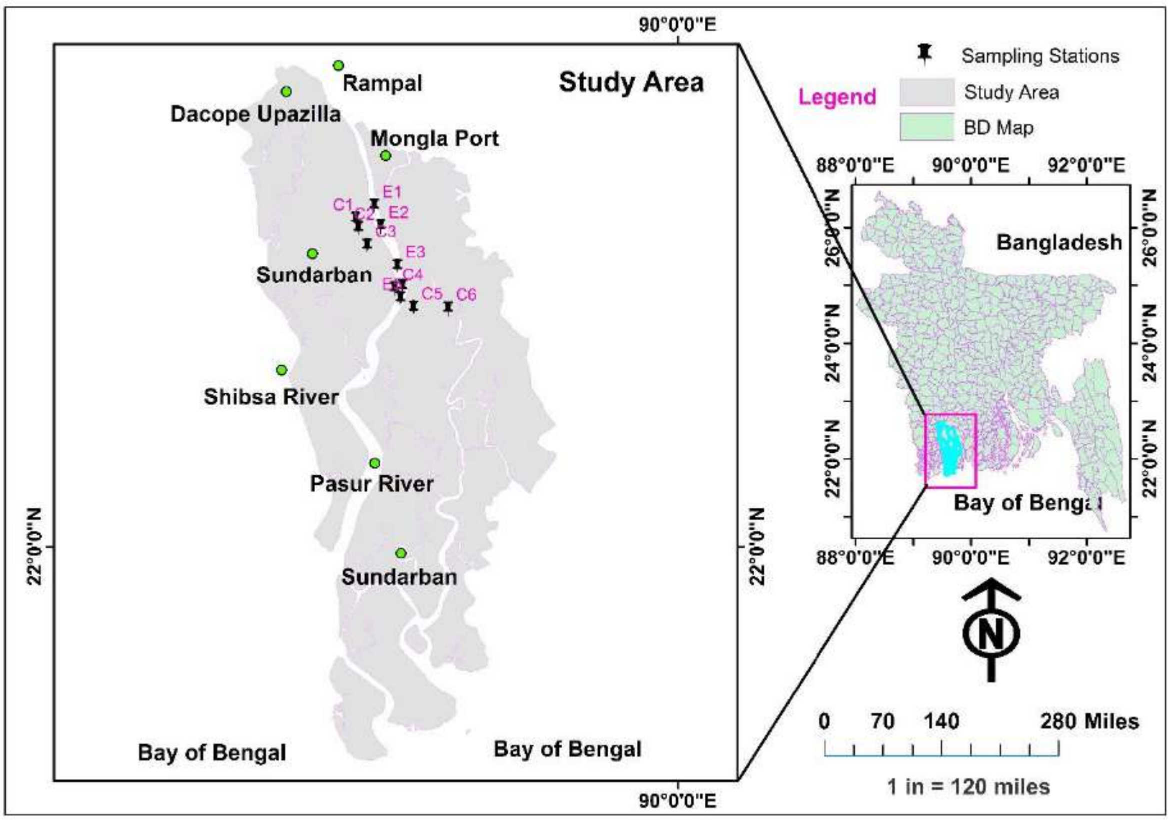

Figure 1. Study area and sampling locations [Mangrove creeks: C1, C2, C3, C4, C5 and C6; Pasur River estuary: E1, E2, E3, E4 and E5].

Sample Collection and Laboratory Analysis

Between January and December of 2019, seven water samples were collected: two during the dry season (2019-01-28) and five during the wet season (2019-03-13, 2019-03-25, 2019-06-23, and 2019-12-31) seasons. The sampling times and dates were provided by the Bangladesh Inland Water Transport Authority. Each sampling site had unique GPS coordinates. An Aqua TROLL 200 (USA) conductivity-temperature-depth (CTD) profiler was used to measure the water's depth in the estuary. Wildco-1520 water samplers were used to collect surface water from a depth of 0 to 0.5 meters (the euphotic layer) at each of the 17 stations. The samples were then filtered through Whatman GF/F (0.45 micron) filter paper using a vacuum machine and stored in the refrigerator until laboratory analysis. Dissolved oxygen (DO) and pH (sensION+ EC71) were measured using a DO meter (HACH HQ30d) after calibration. Nutrient concentrations were determined via spectrophotometric analysis (HACH, DR-6000, Germany) in a laboratory setting (HACH, 2012; APHA, 1998). Phytoplankton samples were collected through horizontal trawling with a plankton net having a mesh size of 25 µm and stored unprocessed in Lugol's solution in a 150 mL black plastic bottles. These samples were stored in a cool, dark place. Phytoplankton cells or colonies were identified and counted to their highest resolved taxonomic rank using a Sedgewick-Rafter counting chamber (Guiry and Guiry, 2022; Stirling, 1995) and a phase-contrast microscope (Carl Zeiss Microscopy, Primo Star, Germany).

Statistical Analysis

Boxplots were analysed using R 4.0.3 (Galili et al., 2018). All physical, chemical, and nutritional variables' descriptive statistics were computed using SPSS v. 20. Following the Shapiro-Wilk and Levene tests for normality and homogeneity of variance, SPSS 22.0 ran a two-way ANOVA to determine the spatio-temporal variation, and a student t-test for independent samples to determine whether or not environmental factors differed. Principal component analysis (PCA) was used on raw data from an investigation into the connections between phytoplankton and physicochemical characteristics in R version 4.0.3. The PAST programme was used to conduct an ANOSIM (Analysis of Similarities). Non-metric multidimensional scaling (NMDS) was originally used to compare the community structure of different samples. It was determined using cluster analysis implemented in PRIMER 7.

Results

Physico-chemical parameters

The average salinity concentration was 8.34 psu with the highest concentration of 11.43 psu recorded in in the dry season and the lowest concentration of 0.62 psu recorded in the wet season (Fig. 2). During the dry season, salinity was 12.26 psu, 9.46 psu and 0.87 psu and 0.29 psu, respectively in the mangrove creeks and PRE (Fig. 2). The average dissolved oxygen (DO) concentration across the study sites was 6.54 mg/L, ranging from 4.62 to 8.77 mg/L. DO concentrations were higher in the dry season compared to the wet season in both the tidal mangrove creeks and the PRE (5.96±0.13 mg/L, $p < 0.057$) (Fig. 2). DO levels in the mangrove creeks were 7.1 mg/L (dry), 6.03 mg/L (wet) while in the PRE, they were 6.65 mg/L (dry), 5.92 mg/L (wet). The post-monsoon winter months brought low water temperatures, while the wet season brought higher temperatures. Tidal mangrove streams had significantly warmer water temperatures ($p < 0.015$) than the PRE during the dry season (25.6°C) (Fig. 2). The water temperature in the PRE was higher (30.03°C) during the rainy season than in the tidal mangrove creeks (29.4°C) (Fig. 2).

The average concentration of dissolved inorganic nitrogen (DIN) was 0.65 mg/L across the study sites, with values ranging from 0.07 to 2.32 mg/L. The average DIN concentrations were significantly higher ($p < 0.05$) in the PRE (0.57 mg/L) compared to the mangrove creeks (Fig. 2). DIN levels in mangrove creeks and the PRE were 1.02 mg/L (dry) and 0.18 mg/L (wet) and 0.62 mg/L (dry) and 0.20 mg/L (wet), respectively (Fig. 2). Fig. 2 shows that the concentration of dissolved inorganic phosphate (DIP) in the sampling sites that ranged from 0.06 to 8.44 mg/L, with the greatest average concentration being found in the mangrove creeks, at 1.35 mg/L, followed by the PRE, at 1.25 mg/L. The concentration of DIP in the water samples was 3.20 mg/L during the wet season, significantly greater than the value of 0.48 mg/L during the dry season.

Temporal variations in DIN ($F = 43.214$, $p < 0.05$) and DIP ($F = 8.385$, $p < 0.0001$) were both substantially different from zero, whereas spatial variations were not. In the mangrove creeks and the PRE, the maximum and lowest dissolved silica concentrations were 3.24 mg/L and 2.84 mg/L, respectively. Fig. 2 shows that during the dry season, the dissolved silica concentrations in the tidal mangrove creeks were 2.84±0.05 mg/L, which is significantly higher than the PRE's value of 1.64±0.03 mg/L ($p < 0.0001$). While dissolved silica concentrations in tidal mangrove creeks were lower than in the PRE during the dry season, they were greater than in the PRE at 4.02±0.44 mg/L (Fig. 2). There were temporal and regional variations in dissolved silica concentrations between PRE and the tidal mangrove streams that were statistically significant ($p < 0.0001$).

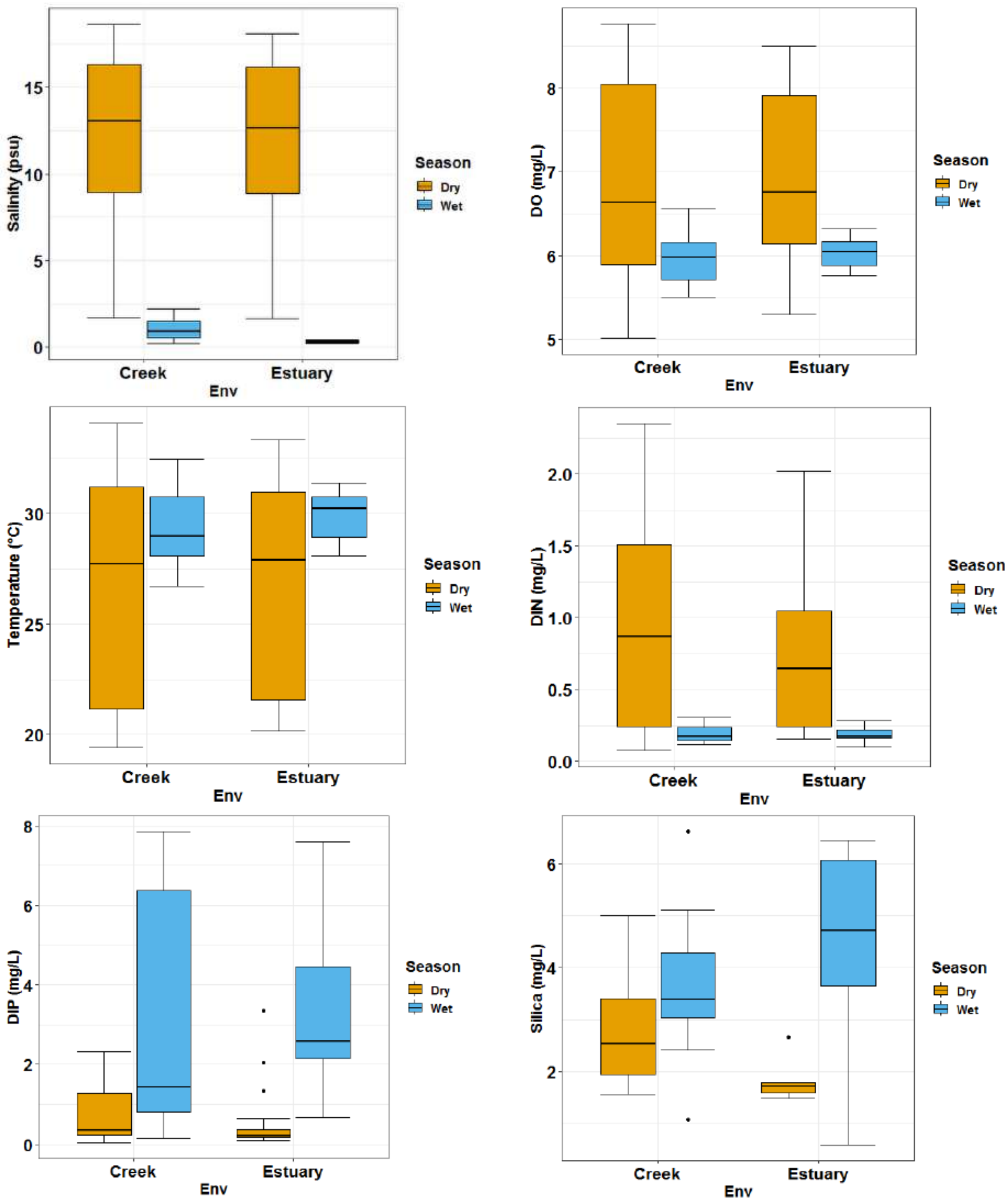

Figure 2. Spatial and temporal variation of major hydrochemical parameters.

Phytoplankton community structure

The study identified 38 phytoplankton species, including 11 Bacillariophyceae (diatoms), 8 Cyanophyceae (blue-green algae), 5 Chlorophyceae, 3 Coscinodiscophyceae, 3 Mediophyceae, 2 Zygnematophyceae, 2 Dinophyceae (Dinoflagellates), 2 Ulvophyceae, 1 Xanthophyceae, and 1 Euglenophyceae. Diatoms (Bacillariophyceae and Coscinodiscophyceae) dominated during the rainy season at 25% and the dry season at 68% (Figs. 3 and 4). However, during the wetter months, the proportion of blue-green algae (Cyanophyceae) increased from 4% to 36%. In the dry season, chlorophyceae (green algae) made up 7% of all algae, whereas in the wet season, that number jumped to 23%. During the dry season, diatoms predominated, but during the wet season, blue-green algae (Cyanophyceae) took over. Diatom predominance was not observed at all study sites. During the dry season, however, diatoms diverge noticeably from other types of phytoplankton in the region. As a result, the phytoplankton seasonal succession was most noticeable in the PRE and the tidal mangrove creeks. Diatoms, blue-green algae, and green algae were all roughly equally abundant within the time frame of our study.

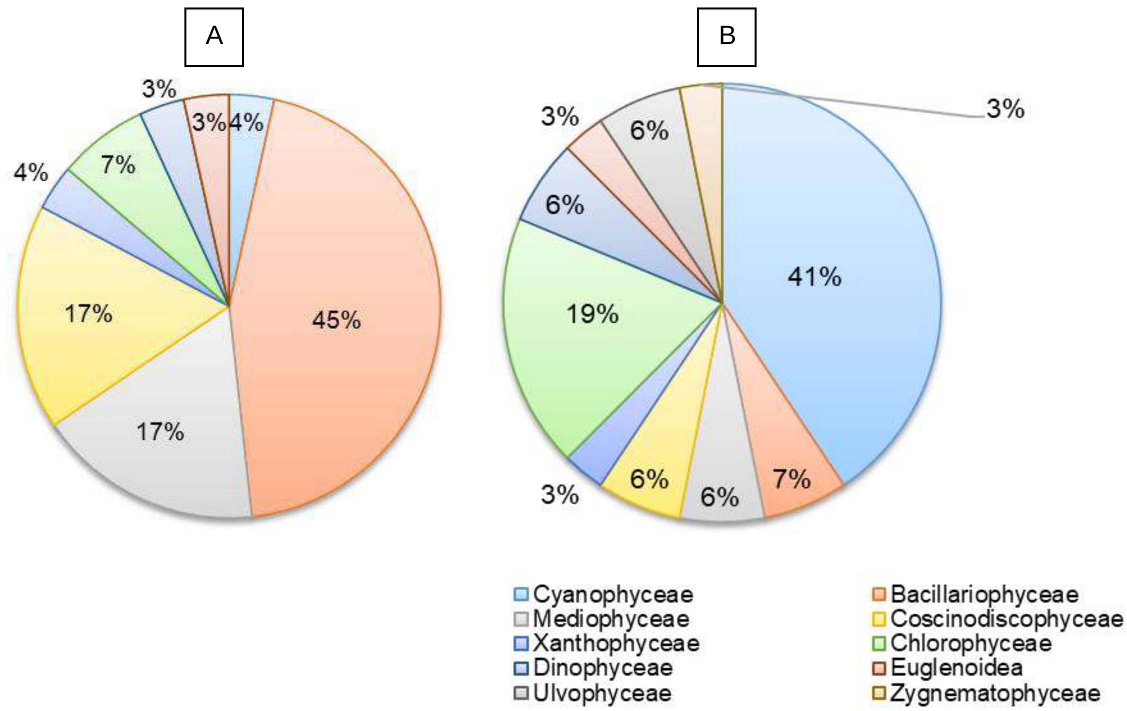

Figure 3. Percent composition of phytoplankton during the dry (A) and wet season (B) in the mangrove creeks.

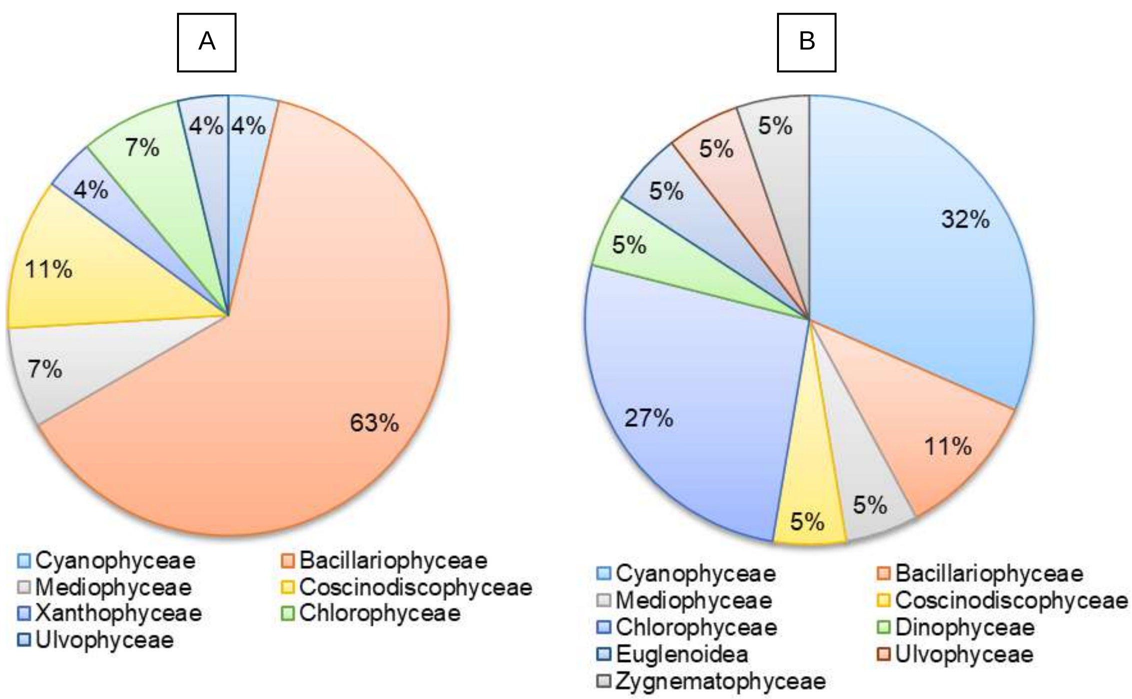

Figure 4. Percent composition of phytoplankton during the dry (A) and wet season (B) in the PRE.

Principal component analysis (PCA) revealed that four principal components accounted for 70.5% of the total variance (Fig. 5). The major factors in PC1 were the families of Bacillariophyceae, Coscinodiscophyceae, Mediophyceae, and Xanthophyceae (Fig. 5). PC2's primary parameters accounted for 20.7% of the total variation, and these were the phyla Cyanophyceae, Chlorophyceae, and Ulvophyceae. The remaining cumulative variation in PC3 (11.9%) and PC4 (9.4%) was accounted for by Chlorophyceae, Zygnematophyceae, Dinophyceae, and Ulvophyceae (Fig. 5). Four distinct seasonal groups were identified in the hierarchical clustering of environmental factors and phytoplankton abundance (Fig. 6). Fig. 6 is a dendrogram depicting the separation of environmental characteristics into dry, wet, creek, and estuarine groupings. NMDS displays the variation in environmental factors and phytoplankton across the various study sites (Fig. 7). ANOSIM analysis revealed a significant difference between dry and wet seasons ($p < 0.05$, R = 0.59), but no significant difference between sampling sites ($p > 0.05$, R = 0.002).

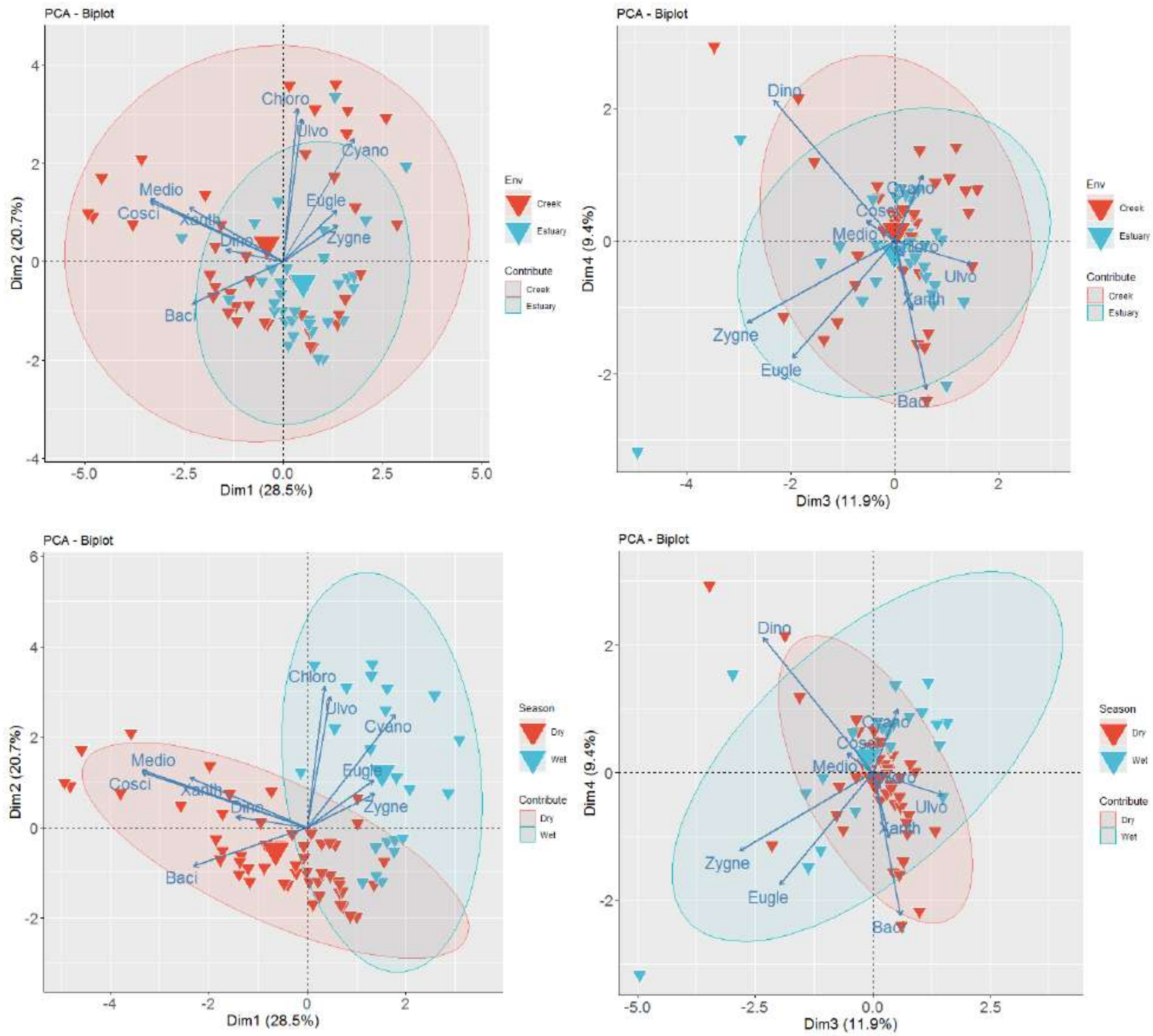

Figure 5. Biplot of the principal component analysis (PCA) of phytoplankton community distribution in the tidal mangrove creeks and the PRE (Baci: Bacillariophyceae, Cosci: Coscinodiscophyceae, Medio: Mediophyceae, Chloro: Chlorophyceae, Cyano: Cyanophyceae, Xanth: Xanthophyceae, Eugle: Euglenophyceae, Dino: Dinophyceae, Zygne: Zygnematophyceae and Ulvo: Ulvophyceae).

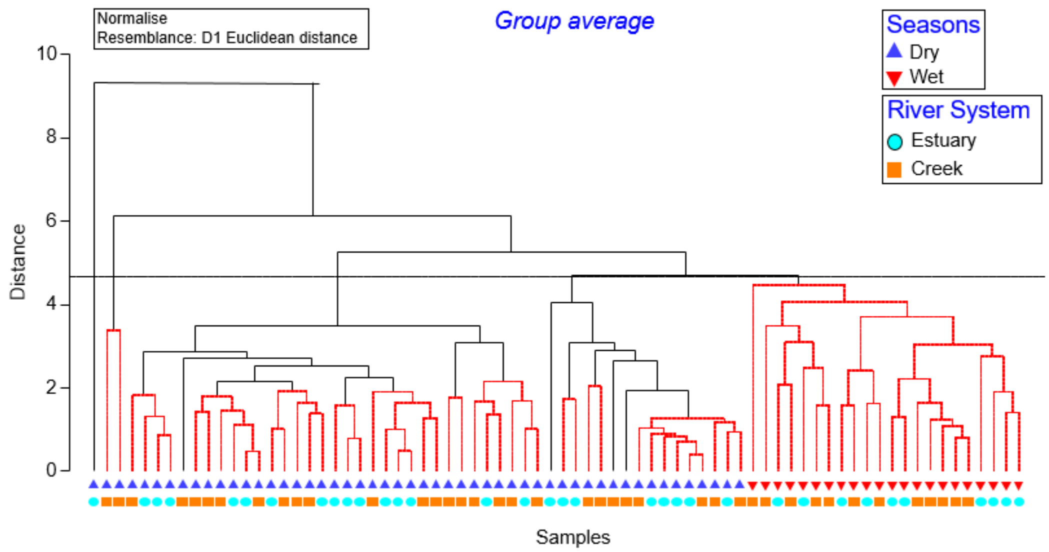

Figure 6. Hierarchical clustering of dendrogram showing dominant parameter in various clusters associated with seasons (Dry vs Wet) and ecosystem (Creek vs Estuary).

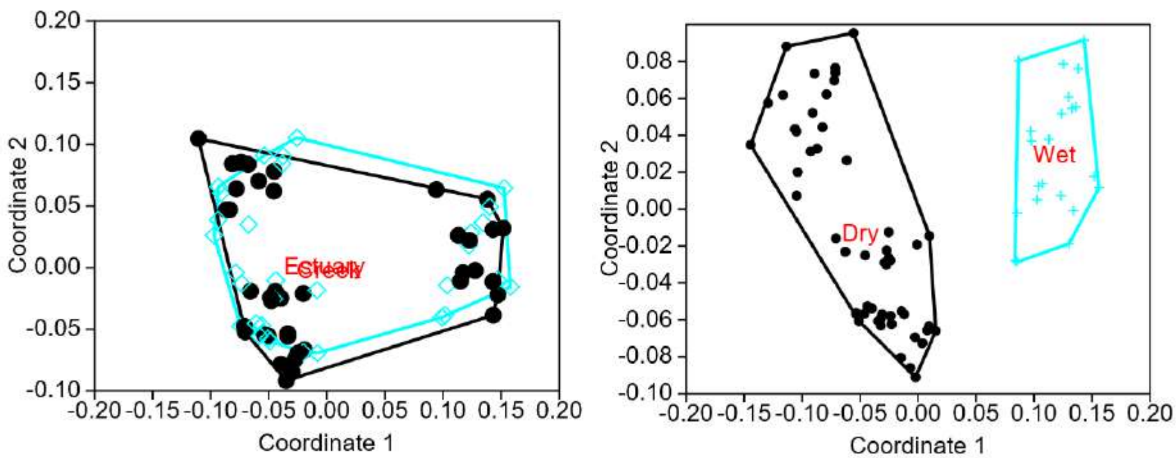

Figure 7. Non-metric multidimensional scaling (NMDS) test between sampling sites and seasons.

Discussion

The salinity of an estuary is a key measure of its overall health. In the PRE, salt content increased consistently over the dry winter months before plummeting sharply in the wetter spring and summer months. Diatom growth is highly sensitive to changes in salinity. In addition, salinity shifts have an impact on the species composition and community structure of phytoplankton in the mangrove estuary (Hilaluddin et al., 2020). Diatoms, which prefer high salinity, are more frequent in estuarine regions, while green algae, which prefer lower salinity, dominate upstream regions. Salinity levels were found to be greater than normal during the dry season because of the lack of precipitation, higher air temperature, and lower fresh water flow (Abowei, 2010). However, during the wet season, salinity is low because of the massive freshwater discharge (Gadhia et al., 2012; McLusky, 1989). Water temperature affects both the diversity of aquatic life and the rate of photosynthesis (Plinski and Jozwiak, 1999; Huang et al., 2019). With an increase of 37℃, photosynthesis rates appear to decrease (Abowei, 2010). When it comes to the physical environment, temperature plays the most important role in ensuring the proper growth, reproduction, survival, and dispersal of all living things. Because the ambient temperature affects the estuary water temperature (Fatema et al., 2015). When measuring water quality, DO is crucial (Huang et al., 2019). DO levels were found to be high in the PRE and tidal mangrove creeks during the dry season, but low during the rainy season. Oxygen solubility decreases with increasing water temperature (Badran, 2001). During the rainy season, DO levels drop because more oxygen-depleting pollutants are carried into the estuary by runoff from nearby industrial and agricultural districts (Pearce, 2003).

Nitrates, nitrites, and ammonia, which make up DIN, often come from watersheds upstream and enter the estuary via neighbouring rivers and surface runoff (Valiela and Bowen, 2002). The primary sources of DIN in this analysis are PRE and its tributaries. DIN levels in tidal mangrove creeks were higher than in PRE on average during the dry season. It has been hypothesized that inundation and tidal mixing push these nutrients out of the mangrove area, while nitrate in water is typically linked to the release of anoxic interstitial waters of the surficial mangrove sediments. Most of the DIN in the PRE came from human habitation, building sites, and agricultural runoff and shrimp farms, all of which are considered point sources of pollution. Riverine loadings, the breakdown of organic matter in the sediments, and the intrusion of neighbouring coastal water into the estuary during flood tide (Krishnan et al., 2020) all play a role in determining the bioavailability of phosphorus (DIP), especially during the rainy season. Phytoplankton rely heavily on dissolved orthophosphate as a source of nutrients due to its rapid uptake by phosphorus-deficient cells from bodies of water with lower concentrations (Boney, 1986). Algae and other photosynthetic aquatic life, especially primary producers, benefit from the presence of phosphate compounds in water (Howarth et al., 2011; Caraco et al., 1989). Similar results were observed in the estuaries of the Quatipuru River and the Matang Mangrove in Malaysia (Pamplona et al., 2013; Tanaka and Choo, 2000). In order for diatoms to flourish, dissolved silica (DSi) must be present (Krishnan et al., 2020). Silica has a crucial role in controlling the diversity of phytoplankton (Sospedra et al., 2018). Due to the tidal flooding and mixing with the surficial mangrove sediments, dissolved silica concentrations were higher in the mangrove creeks during the dry season. However, during the wet season, water turbidity and transparency rose due to significant rainfall and increased surface runoff, leading to a drop in light intensity and diatom density (Hilaluddin et al., 2020).

High phytoplankton productivity is common in mangrove estuaries because of the easy availability of nutrients from nearby mangrove litter (Tanaka and Choo, 2000). Blue-green algae (Cyanophyceae) replaced diatoms (Bacillariophyceae and Coscinodiscophyceae) in the wet season (Hilaluddin et al., 2020; Krishnan et al., 2020). Cyanophyceae are the phytoplankton species that thrive in settings of high turbidity and inadequate light availability (Robarts and Zohary, 1987), and temperatures above 25°C give favourable conditions for their growth rates. Rapid growth of blue-green algae was observed in high-phosphorus environments that were also warm during the wet season (Suthers et al., 2019). Algal abundance in fresh water systems can also be affected by salinity (Winder and Cheng, 1995). Blue-green algae can withstand up to 5–6 psu of salt before dying (Suthers et al., 2019). However, numerous species of Chlorophyceae and dinoflagellates benefit from high turbidity due to their exceptional shade tolerance (Hilaluddin et al., 2020). Multiple dinoflagellate species have been shown to adapt to varying light levels (Matsubara et al., 2007).

Diatom proliferation in silicified organisms is dependent on silicate content (Krishnan et al., 2020; Srinivas et al., 2018). Diatom (Bacillariophyceae and Coscinodiscophyceae) growth increased in response to higher silica inputs, leading to lower silica concentrations in the water column. In contrast, diatoms (Bacillariophyceae and Coscinodiscophyceae) flourish during the dry season, reducing silica concentration in the water (Gamier et al., 1995). Since diatoms need silica to form their frustules, there was a significant inverse relationship between silica content and diatom concentration during the wet season. Due to its use in cell wall production, silica is toxic to diatoms (Krishnan et al., 2020). Reduced river flow and tidal mixing during the dry season enrich the water in the PRE and mangrove creeks with DIN and DIP, altering the algal population (Kumar et al., 2014). During the wet season, phytoplankton abundance was low because heavy rainfall created low salinity, high turbidity from run-off, and intense flushing activity, considerably stratifying the water column (Iqbal et al., 2017).

Conclusion

The study reveals seasonal environmental shifts significantly impact tropical phytoplankton in the tidal mangrove creeks. Multivariate analysis showed distinct dry and wet season water quality differences. A greater diversity and uniformity of phytoplankton is supported by water exchange, which transports nutrients and phytoplankton into related ecosystems. Due to seasonal variations, phytoplankton succession from diatoms to Chlorophyceae is linked to physicochemical and nutritional changes. This pattern is noticeable in the PRE and the tidal mangrove creeks. These findings provide valuable insights for future researchers involved in mariculture initiatives, highlighting the importance of seasonal variations in phytoplankton dynamics for sustainable management practices.

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