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Relationship between habitat characteristics and microalgae community on the coastal area of Malang Regency, Indonesia

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ABSTRACT

The purpose of this study was to analyse and to identify the types and abundance of microalgae across various sub-habitats (water column, sediment, rocky substrates, and mangrove roots) and to assess the environmental parameters affecting microalgae abundance in the coastal areas of Malang Regency, East Java. The research was conducted at six sites located in Malang Regency, specifically in the coastal areas of Tambakrejo, Gajahrejo, and Sitiarjo villages. A descriptive quantitative method was used. The results revealed that the microalgae identified belonged to Bacillariophyceae, Chlorophyceae, Cyanophyceae, Chrysophyceae, Dinophyceae, and Zygnematophyceae taxa. Bacillariophyceae dominated the microalgae community in the coastal area. The diversity and evenness indices indicated moderate levels, whereas the dominance index was low. Environmental variables were generally favourable for microalgae growth. NMDS statistical analysis showed significant variation in microalgae distribution across the study locations, highlighting distinct microalgae compositions at each site. Canonical correspondence analysis revealed that Bacillariophyceae were presented at all sites due to their high adaptability.

Keywords: adaptive capacity, benthic algae, diatoms, diversity index, dominance index, environmental parameter, marine, planktonic.

INTRODUCTION

Microalgae are microscopic organisms, single-celled or multicellular that thrive in aquatic ecosystems. They perform photosynthesis, serve as a primary energy source, and play a crucial role in the aquatic food web. As primary producers, they are vital for maintaining the balance of aquatic ecosystems (Nickelsen, 2017). This group of organisms exhibits remarkable diversity, with various cell structures, sizes, pigments, and shapes (Mercer and Armenta, 2011). Microalgae can live in various environment, including freshwater, brackish, and marine environment. Equipped with chlorophyll pigments, they efficiently carry out photosynthesis by converting carbon dioxide and water into carbohydrates and using sunlight as the energy source (Tan et al., 2020). The diversity, abundance, and dominance of microalgae in the aquatic ecosystem are influenced by various factors such as temperature, light intensity, salinity, pH, dissolved oxygen, and nutrient availability (Chowdury et al., 2020). Microalgae are highly sensitive organisms, reacting strongly to changes in aquatic environmental factors and the presence of contaminants (McKnight et al., 2023). This makes the presence and abundance of microalgae an effective indicator of the overall health of aquatic ecosystems.

Coastal ecosystems involve interactions between biotic and abiotic components. East Java's coastal region is abundant in natural resources, characterized by a variety of distinct physical features, including seagrass, coral reefs, and mangrove ecosystem, sandy shores, rocky coasts, and mudflat. Several research regarding microalgae were conducted previously in East Java coastal including Arsad et al. (2022), Mahmudi et al. (2023a), and Mahmudi et al. (2023b). The present study is the continuation of our extending research in different sites of East Java coast which covered the southern region of East Java, located in Malang Regency, includes the villages of Tambakrejo, Gajahrejo, and Sitiarjo. The beaches in Malang Regency selected for this study are Sendiki Beach, Tamban Beach, Sendang Biru Beach, Ungapan Beach, and Tanjung Penyu Beach. Additionally, the mangrove areas included in this research are the Bajulmati Estuary Mangrove Area and the Gunung Pithing Mangrove Conservation (GPMC).

This study aimed to analyse the types and abundance of microalgae based on habitat characteristics and to analyse the relationship between environmental parameters and microalgae abundance along the coastal area of Malang Regency, East Java.

MATERIAL AND METHODS

Sampling sites

The study was carried out from March to September 2024 along the coastal area of Malang Regency, East Java, covering Tambakrejo Village, Gajahrejo Village, and Sitiarjo Village with total of seven sampling points (Table 1). The research location map is presented in Figure 1.

Sampling procedure

Water quality and microalgae samples from the water column sub-habitat were collected during the high tide. Meanwhile samples from sediment, rocky substrates, and mangrove roots were taken during the low tide. For mangrove root sampling, roots with a diameter of 2 cm were selected and cut into 10 cm sections, representing the observed substrate area. The roots were then gently brushed to ensure even sampling and

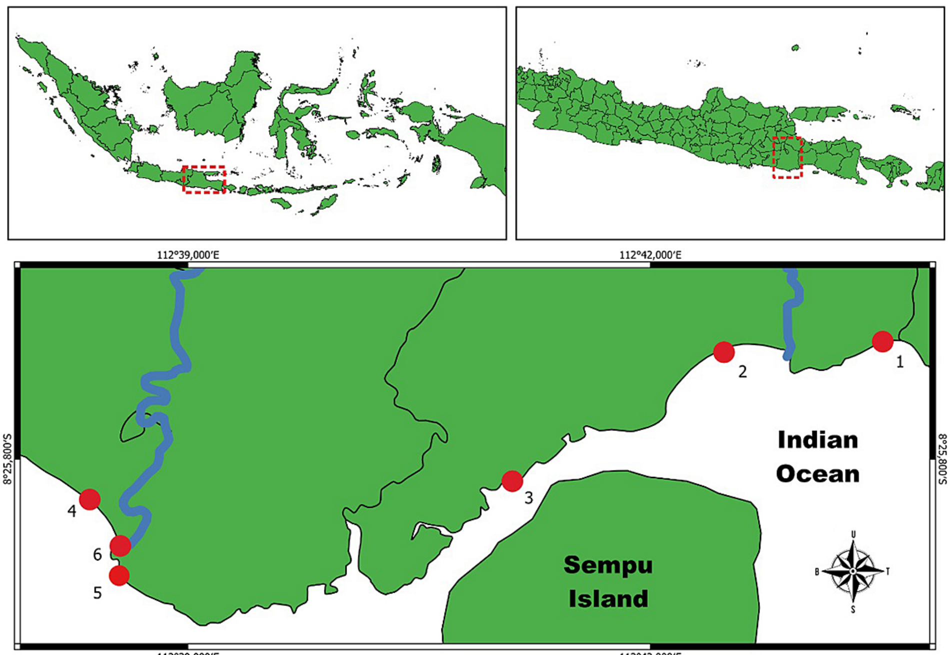

Figure 1. Map of research locations for microalgae distribution in the coastal area of Malang Regency, East Java

Table 1. Sampling points

Area	Sampling points	Ordinates	Site characteristic
Tambakrejo Village	Sendiki Beach	8°41'67.82" LS dan 112°72'59.35" BT	Bordering the Indian Ocean, Sendiki Beach features stretches of white sand. The eastern end is characterized by a small stream, scattered rocks, high waves, and minimal visitor activity. The central area, with its sandy substrate is popular among tourists.
	Tamban Beach	8°41'71.69" LS dan 112°71'21.63" BT	The eastern side borders the Indian Ocean. The central area is used by local fishermen to land small boats and is also a tourist spot. The western side is popular for fishing. Tamban Beach is surrounded by mangrove area that stretch from the beach to the area behind the shrimp ponds.
	Sendang Biru Beach	8°43'20.02" LS dan 112°68'41.91" BT	Sendang Biru Beach borders the Sempu Strait, attracts many tourists with its scenic views. The eastern side is used by local fishermen to dock their boats, while the central area is the main spot for tourism. The western side, near the fish auction place, is also used by fishermen for landing catches.
Gajahrejo Village	Ungapan Beach	8°26'06" LS dan 112°38'25" BT	Ungapan Beach is the area's main tourist spot, near an estuary with fine, light brown sand. Its central area, close to residential areas, is popular for canoeing and has farms and shrimp ponds. This area has sandy mud sediments with lower salinity. The far end sees little activity but includes mangrove planting, with muddy sand sediment.
Sitiarjo Village	Tanjung Penyu Beach	8°26'32" LS dan 112°38'34" BT	This location is close to the Bajulmati Estuary and faces Kletek Island, allowing water from the island to flow here. The sediment is coarse white sand.
	Bajulmati River Estuary	8°26'16" LS dan 112°38'43" BT	At this point, seawater mixes with freshwater, with high human and tourist activity, including boats for sightseeing. Salinity is relatively high, and the sediment is fine, light brown sand with a slightly muddy texture. There is a small mangrove area with fine brown sandy-mud sediment.

rinsed with distilled water before being placed into sample bottles (Steinke et al., 2003). On the other part, samples from sandy sediment and rocky substrate sub-habitats were conducted during the low tide by using the transect technique. Samples were taken from the substrate surface within a square transect frame measuring 5 × 5 cm (Siregar, 1995). During the high tide, water column samples were collected using a plankton net with a mesh size of 25 µm, filtering a total of 25 litres of water (Hutami et al., 2018). Samples then filtered and transferred into 30 ml sample bottles and preserved with 2–3 drops of 1% Lugol's solution. Samplings were conducted twice, with a two-week interval between the first and second sampling.

Microalgae sample analysis

Identification and quantification of microalgae were analysed (Prescott, 1970), species diversity using the Shannon-Weiner index (Baliton et al., 2020), evenness index (Shannon and Weaver, 1949), and dominance index using Simpson's formula (Arazi et al., 2019). The abundance of microalgae in the water column sub-habitat was calculated based on APHA (1976) using the following formula:

$$N = n\frac{T}{L} \times \frac{Vt}{Va} \times \frac{1}{P} \times \frac{1}{W} \quad (1)$$

where: N is microalgae abundance (ind/L); n is number of individuals in each genus; T is cover glass area (22 × 22 mm^2); L is microscope field of view (1.306 mm^2); Vt is volume of filtered water sample (30 ml); Va is volume of water sample observed (0.05 ml); P is the number of fields of view (9); W is the volume of filtered water (25 L). The abundance of epiphytic, epipelic, and benthic microalgae is calculated using the formula from APHA (2012) as follows:

$$N = \frac{3Oi}{Op} \times \frac{Vr}{3Vo} \times \frac{1}{A} \times \frac{n}{3p} \quad (2)$$

where: N is the number of periphyton diatoms per unit area (individuals/cm^2); Oi is the area of the cover glass (22 × 22 mm^2);

Op is the area of the field of view under the Olympus CX 21 microscope at 100x magnification (1.306 mm^2); *Vr* is the volume of the water sample in the sample bottle (30 ml); *Vo* is the volume of one drop of the sample (0.06 ml); *A* is the scraped area (Roots: 34.6 cm^2; sediment and rocks: 25 cm^2); *N* is the number of counted epiphytic diatoms; and *P* is the number of fields of view (5).

Water quality measurement

The measurement of environmental parameters such as temperature (°C, DO meter model PDO-520), brightness (cm, Secchi disk), current velocity (m/s), pH (pH meter 5 in 1 EZ-9909A), salinity (ppt, Refractometer 2 in 1 Brix 0–32%, Salt 0–28%), and dissolved oxygen (mg/L, DO meter model PDO-520). All these parameters were conducted in situ. Nitrate (mg/L) and orthophosphate (mg/L) were analysed ex-situ in the Freshwater Fisheries Laboratory at Sumber Pasir by using a Genesys 10 UV-Vis spectrophotometer.

Data analysis

Data was analysed by using nMDS (non-metric Multidimensional Scaling) PAST software version 4.13 and Microsoft Excel 2016. The nMDS plot, based on the Bray-Curtis matrix equation, was used to represent group compositions in a two-dimensional format (Hasanah et al., 2014). The stress value in the nMDS method was employed to assess the accuracy of the plot in depicting the sample composition structure (Musa et al., 2022). The second statistical analysis method used to analyse microalgae statistics using the Canonical Correspondence Analysis (CCA) method. This method is direct gradient analysis and a particular type of multivariate regression, where species composition is immediately connected to observed environmental factors (Palmer, 1993) and can be used to determine the correlation between water quality and microalgae abundance.

RESULTS AND DISCUSSIONS

Microalgae composition

The highest composition of microalgae at Sendiki Beach was from the Bacillariophyceae class, with 88% in sediment habitats, 83% in the water column, and 66% on rocky substrates, while the lowest composition was from the Zygnematophyceae class on rocky substrates (6%). At Tamban Beach, Bacillariophyceae also dominated in mangrove roots (90%), water column (82%), sediment (81%), and rocky substrates (66%), with the lowest being Zygnematophyceae on rocky substrates (6%). At Sendang Biru Beach, Bacillariophyceae were predominant in the water column (81%) and sediment (75%), with the lowest being Dinophyceae in sediment (4%). At Ungapan Beach, the highest composition was Bacillariophyceae in sediment (90%) and water column (73%), while Cyanophyceae had the lowest in both water column and sediment (10%). At Tanjung Penyu Beach, Bacillariophyceae dominated the water column (80%) and sediment (77%), with the lowest being Chrysophyceae in the water column (3%). At the Bajulmati River Estuary, Bacillariophyceae were most abundant in sediment (77%) and the water column (67%), while Cyanophyceae had the lowest in the water column (13%) and sediment (10%).

Overall, Bacillariophyceae (diatoms) were the most frequently encountered class. Diatoms are unicellular algae found worldwide in nearly all aquatic environments. They exhibit widespread distribution, diverse morphology, rapid response to environmental changes, and varying tolerance ranges across species. Diatoms are well-known bioindicators and have been used in water quality assessments for decades (Pinto et al., 2021). The classes and genera found in the three regions are detailed in Table 2.

Microalgae abundance

The highest microalgae abundance at Sendiki Beach was found on rocky substrates (1,263,737 ind/cm^2), while the lowest was in the water column habitat (96,753 ind/L). At Tamban Beach, the highest abundance was in the mangrove root habitat (6,644,785 ind/cm^2), and the lowest was in the water column (119,954 ind/L). At Sendang Biru Beach, sediment habitats recorded the highest abundance (1,260,031 ind/cm^2), with the lowest in the water column (138,219 ind/L). At Ungapan Beach, the highest abundance was in sediment habitats (1,255,736 ind/cm^2), while the water column had the lowest (455,745 ind/L). At Tanjung Penyu Beach, sediment habitats also showed the highest abundance (1,119,208 ind/cm^2), with the water column having the lowest (130,321 ind/L).

Table 2. Class and Genus Composition Identified

Bacillariophyceae		
Achnanthes	*Dictyoneis*	*Meuniera*
Actinocyclus	*Diploneis*	*Navicula*
Amphiprora	*Encyonema*	*Nitzschia*
Amphora	*Entomoneis*	*Paralia*
Asterionella	*Eucampia*	*Pinnularia*
Aulacosiera	*Eunotia*	*Pinnunavis*
Bacillaria	*Fragillaria*	*Pleurosigma*
Biddulphia	*Frustulia*	*Skeletonema*
Caloneis	*Gomphonema*	*Striatella*
Centronella	*Grammatophora*	*Surirella*
Chaetoceros	*Gyrosigma*	*Synedra*
Cocconeis	*Hantzschia*	*Tabellaria*
Coscinodiscus	*Hemialus*	*Thalassionema*
Cyclotella	*Isthmia*	*Trachyneis*
Cylindrotheca	*Leptocylindrus*	*Triceratium*
Cymatopleura	*Licmophora*	*Ulnaria*
Cymbella	*Luticola*	
Dactyliosolen	*Melosira*	
Chlorophyceae		
Chlorella	*Mesotaenium*	*Scenedesmus*
Chlorococcum	*Microspora*	*Staurastrum*
Closterium	*Oedegonium*	*Tetraedron*
Cylindrocystis	*Oocystis*	*Ulothrix*
Hydrodicton	*Radiofilum*	*Zygnema*
Lagerheimia		
Cyanophyceae		
Anabaena	*Lyngbya*	*Oscillatoria*
Chroococcus	*Merismopedia*	*Spirulina*
Geitlerinema		
Zygenematophyceae		
Netrium		
Spirotaenia		
Dinophyceae		
Peridinium		
Chrysophyceae		
Dinobryon		

In the Bajulmati River Estuary, the highest abundance was found in sediment habitats (1,404,567 ind/cm^2), while the water column recorded the lowest (109,094 ind/L). The highest abundances were observed in rocky substrates, sediment, and mangrove roots. This is attributed to activities around these areas that introduce organic matter into the water, providing nutrients that enhance aquatic productivity and subsequently increase microalgae abundance (Khoa et al., 2020).

Biological index

In this study, rocky substrates exhibited the highest diversity index with H’ > 3, indicating a stable and balanced habitat structure. In contrast, sediment, water column, and mangrove root habitats showed moderate diversity with values of $1 \leq H' < 3$. A diversity index of H’ > 3 signifies habitat stability, while $1 \leq H' < 3$ indicates moderate pollution, and H’ < 1.0 reflects heavy pollution (Miranda and Krishnakumar, 2015). The evenness index values, approaching 1, suggest a uniform distribution of individuals among species. Low evenness indicates the dominance of a few species with high density due to environmental pressures, whereas higher evenness reflects similar abundance across species with no dominance (Nashaat et al., 2019). A dominance index closes to 0 suggests no single organism dominates the ecosystem, indicating a more even distribution of species. Conversely, a dominance index nearing 1 indicates that a single species dominates the ecosystem (Sihombing et al., 2017). The presence of dominant species is influenced by factors such as ammonia, phosphate, nitrate, nitrite, pH, and dissolved oxygen (Kostryukova et al., 2018). Overall, the dominance index values across all stations were categorized as low to moderate, indicating no single microalgae species dominated the ecosystems studied. The biological indices are presented in the following Table 3.

Environmental parameters

Water quality measurements across various habitat characteristics indicated that the water conditions were generally favourable, as most parameters remained within the standard thresholds suitable for microalgae growth (Table 4). However, there were instances where transparency and salinity values deviated from the standard limits. These variations in transparency and salinity are likely influenced by factors such as turbidity levels, watercolour, sediment substrate type, weather conditions, and the location and timing of sample collection. The water temperature at the research sites ranged from 29 to 31.2 °C, which is within the normal range for microalgae growth. Microalgae typically thrive at temperatures between 25 and 35 °C, with a maximum tolerance of 35 °C (Ras and Bernard, 2013). Brightness at the sites was recorded between 38.5 and 66.9 cm. Brightness below 0.45 cm can hinder microalgae growth due to limited dissolved oxygen (Herawati et al., 2021).

Table 3. Biological index of microalgae

Sites	Diversity index	Evenness index	Dominance index
Sendiki Beach	2.17	0.67	0.06
Tamban Beach	2.84	0.86	0.08
Sendang Biru Beach	1.35	0.42	0.05
Ungapan Beach	1.65	0.53	0.15
Tanjung Penyu Beach	1.46	0.44	0.04
Bajulmati River Estuary	1.46	0.44	0.04

Table 4. Environmental parameters value

Parameter	Site (beach)						Literature
	Sendiki	Tamban	Sendang biru	Ungapan	Tanjung Penyu	Muara Sungai	
Temperature	31.20	29.80	30.00	30.40	31.00	29.00	25–35 °C (Ras and Bernard, 2013).
Brightness	64.00	38.50	54.00	55.60	59.80	66.90	> 45 cm (Herawati et al., 2021)
Currents	0.143	0.14	0.072	0.564	0.052	0.094	Weak currents < 0.1 m/s to moderate currents 0.1–1 m/s (Padang et al., 2020)
Salinity	31.50	21.00	31.20	21.60	31.00	29.00	15–32 ppt (Nurjijar et al., 2022)
Dissolved oxygen	9.68	8.37	8.95	9.05	9.70	10.10	> 5 mg/L (Arofah et al., 2021)
pH	8.20	7.85	8.10	8.10	8.30	8.10	6–9 (Xu et al., 2020)
Orthophosphate	0.018	0.10	0.023	0.26	0.056	0.042	Oligotrophic < 0.015 to mesotrophic 0.015–0.13 mg/L (Nurjijar et al., 2022)
Nitrate	0.025	0.12	0.026	1.36	0.042	0.094	Oligotrophic 0–1 mg/L (Adriani et al., 2019)

Current speeds ranged from 0.052 m/s to 0.564 m/s, categorized as weak to moderate currents. Strong currents can carry microalgae away, preventing them from settling and thriving. Conversely, slower currents allow microalgae to utilize nutrients more effectively and optimize photosynthesis. Additionally, the recorded pH levels ranged from 7.85 to 8.3, which is favourable for microalgae survival. The optimal pH for microalgae growth is neutral to slightly alkaline, from 7 to 9 (Xu et al., 2020). Salinity in the northern coastal waters of East Java ranged from 21 to 31.2 ppt, while dissolved oxygen (DO) levels were between 8.3 and 10.1 mg/L. High salinity can cause osmotic stress and alter ion exchange, impacting the metabolism of photosynthetic organisms (Nurjijar et al., 2022). Nitrate and phosphate levels in these waters ranged from 0.02 to 1.36 mg/L and 0.01 to 0.1 mg/L, respectively. Elevated nitrate levels can lead to water pollution and eutrophication, whereas low nitrate levels may limit the nutrients necessary for phytoplankton growth (Nasution et al., 2019). Similarly, low orthophosphate levels can hinder phytoplankton growth, reducing their abundance in the water. Therefore, nitrate and orthophosphate concentrations act as limiting factors for microalgae growth, significantly influencing their abundance in aquatic ecosystems.

NMDS ANALYSES

NMDS analysis was used to examine the similarity in microalgae abundance across the six stations in Malang Regency. The NMDS plot illustrates differences between samples at each location, where closer proximity between two samples indicates greater similarity in species composition. The NMDS analysis revealed significant spatial variation in microalgae community composition (Putro et al., 2023). The NMDS plot from this study is presented in Figure 2.

The NMDS analysis of microalgae abundance data revealed varying distribution patterns. Sendiki Beach site, located in the lower right quadrant of the NMDS plot, exhibited high abundance of Bacillariophyceae and Chlorophyceae, indicating environmental conditions favorable for the growth of these microalgae groups. Meanwhile, Tamban Beach site, positioned at the far left of the NMDS plot, showed the highest Bacillariophyceae abundance among all sites, accompanied by a significant presence of Cyanophyceae, suggesting nutrient conditions that support the dominance of these groups. Sendang Biru Beach site stood out with the presence of Dinophyceae, the only site to record this group. Its location in the upper right quadrant of the NMDS plot may reflect unique environmental conditions compared to the other sites. On the other hand, Ungapan Beach site, located at the bottom of the NMDS plot, stood out with the highest abundance of Chlorophyceae, suggesting the presence of environmental factors specifically supporting the growth of this microalgae group. Tanjung Penyu Beach, situated in the upper right quadrant of the NMDS plot, was unique for the presence of Chrysophyceae, a group not found at other sites. This could be attributed to specific environmental conditions favoring the presence of Chrysophyceae in this location. The Bajulmati River Estuary site, positioned in the

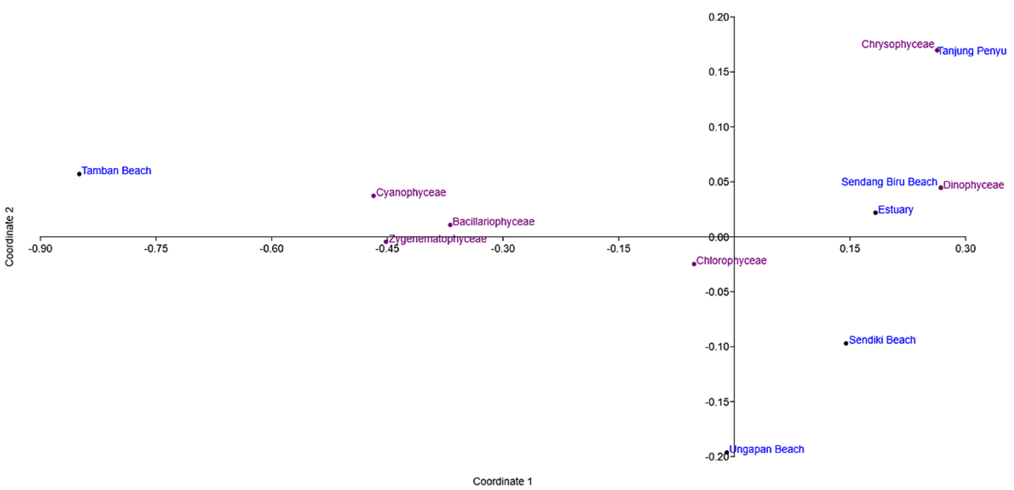

Figure 2. NMDS data analysis plot

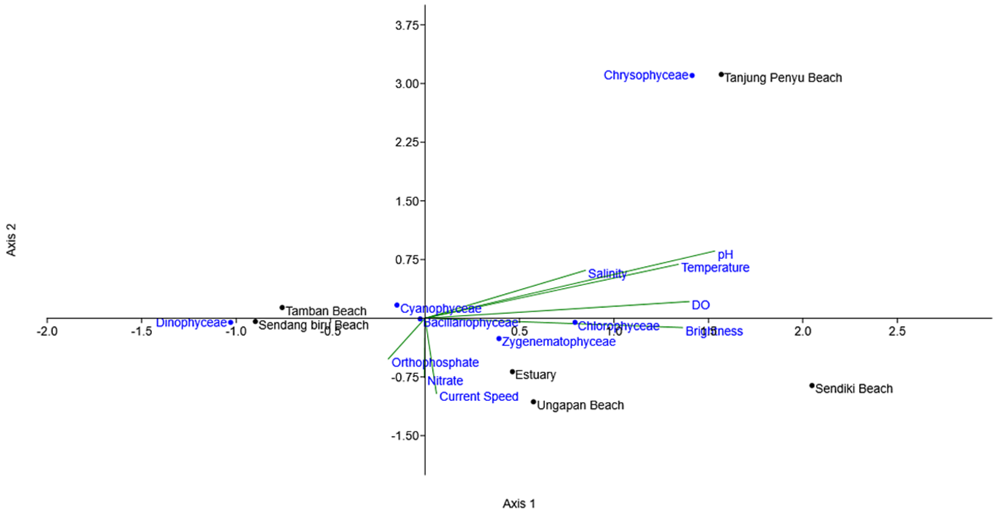

Figure 3. CCA data analysis plot

mid-right section of the NMDS plot, displayed a more balanced distribution of Bacillariophyceae, Cyanophyceae, and Chlorophyceae, possibly reflecting transitional or mixed conditions typical of estuarine environments.

CCA analyses

The CCA analysis results (Fig. 3) indicate that Bacillariophyceae and Cyanophyceae tend to cluster near the centre of the plot, suggesting that these classes can be found in various aquatic conditions due to their high adaptability. Bacillariophyceae are particularly adaptable to diverse environmental conditions, such as temperature, pH, light, and salinity, and exhibit a higher growth rate compared to other classes (Yi et al., 2017). Cyanophyceae, on the other hand, are capable of thriving in a wide range of environments, from freshwater and marine systems to terrestrial ecosystems. They can tolerate extreme habitats, surviving in dry conditions and at high water temperatures (Allaf and Peerhossaini, 2022). The abundance of this class is also influenced by the concentration of inorganic nutrients, commonly thriving in waters with high orthophosphate levels (Jiang et al., 2014).

Phylum Chlorophyta, including Chlorophyceae and Zygnematophyceae, is associated with parameters such as light intensity and dissolved oxygen. Chlorophyceae are often abundant due to their adaptability and rapid reproduction. These taxa typically thrive in waters with adequate light intensity (Bellinger and Sigee, 2015). In contrast, Chrysophyceae and Dinophyceae were less prevalent in this study, as reflected by their distant positions in the analysis. Chrysophyceae tend to inhabit slightly acidic waters with low alkalinity, conductivity, and productivity (Bock et al., 2022). Dinophyceae, known for their slower growth rates compared to other classes, are more likely to proliferate in nutrient-rich waters (Yang et al., 2021).

CONCLUSIONS

This study indicates that the microalgae identified belong to the classes Bacillariophyceae, Chlorophyceae, Cyanophyceae, Chrysophyceae, Dinophyceae, and Zygnematophyceae. Bacillariophyceae was the most prevalent class across all habitat types. Chrysophyceae and Dinophyceae were only found in sediment habitats, while Zygnematophyceae was exclusive to rocky habitats. Microalgae abundance varied across habitats, with the highest abundance observed in the mangrove root habitat at Tamban site, and the lowest in the water column at Sendiki site. The water quality parameters revealed a significant impact on microalgae abundance. Bacillariophyceae were adaptable to varying water quality conditions due to their strong cell walls. Chlorophyceae were influenced by high light intensity and dissolved oxygen, facilitated by their high chlorophyll content for photosynthesis. Cyanophyceae were affected by inorganic nutrients like orthophosphate and could thrive at relatively higher temperatures. Conversely, Dinophyceae, Chrysophyceae, and

Zygnematophyceae were found in lower abundance in this study. Additionally, the study noted similarities and differences in microalgae composition across the six sites, reflecting high microalgae diversity. These variations are likely due to differing environmental characteristics and conditions along the coastal areas of Malang Regency, East Java.

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