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Marine Microalgae Assemblages of the East Java Coast Based on Sub-Habitats Representatives and their Relationship to the Environmental Factors

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ABSTRACT

The East Java coast has biodiversity potential, including microalgae. Microalgae are primary producers for the aquatic ecosystem, whose distribution depends on water quality parameters and sub-habitat characteristics. The purpose of this study was to analyse and identify the microalgae, as well as environmental quality parameters based on sub-habitat characteristics in the northern part of the East Java coast, Indonesia. The research was conducted from March to June 2023. Sample sites were determined using purposive sampling techniques at nine sites located in Gresik, Lamongan, and Tuban coasts. Water samples were collected from various sub-habitats, including the water column, sediments, rocks, mangroves, artificial substrates, macroalgae, and water plants consisting of water hyacinth (*Eichhornia crassipes*) and Coontail (*Ceratophyllum demersum*). The obtained results depicted microalgae found were from Bacillariophyceae, Chlorophyceae, Chrysophyceae, Coscinodiscophyceae, Cyanophyceae, Dinophyceae, Trebouxiophyceae, and Zygnematophyceae. Bacillariophyceae dominated the community in all sites. The expected outcome of this study is to provide and complete the database of microalgae morphologically based on sub-habitat characteristics, particularly on the north coast of East Java, Indonesia.

Keywords: biodiversity; diatoms; non-metric multidimensional scaling; water quality.

INTRODUCTION

East Java, located in Indonesia, share a land border only with West Java in the western part. However, The Java Sea and the Indian Ocean border East Java's northern and southern coasts, respectively. In the eastern part, East Java is separated from Bali by the narrow Bali Strait. Nearly surrounded by the sea, the coastal area of East Java extends broadly from north to east and south. East Java boasts a coastline of 3,498 km, a sea area of 54,718 km^2, and is home to 427 islands, which contributes to its rich marine biodiversity, including microalgae (Kurniawan and

Efendy, 2020). Microalgae are aquatic photosynthetic microorganisms that consist of single cells or colonies and are cosmopolitan in their distribution (Winahyu et al., 2013). They can thrive in various salinity levels, ranging from freshwater and brackish water to marine environments. These organisms can exist as a planktonic, benthic, or epiphytic species (Arsad et al., 2021). The growth rate of microalgae is influenced by environmental factors such as temperature, salinity, nutrients, pH, light intensity, and other interconnected factors. These factors collectively support microalgae in maintaining the stability of aquatic ecosystems (Prasetyo et al., 2022). From an ecological perspective, microalgae play a significant role as primary producers in the marine food chain and are responsible for oxygen production. Furthermore, certain microalgae permanently inhabit benthic environments and exhibit sensitivity or tolerance to pollutants, making them valuable bioindicators for assessing the health of aquatic ecosystems (Ashour et al., 2019).

Numerous studies related to the distribution of microalgae in Indonesia have been conducted, including research on the East Java Coast. Previously, Nafisyah et al. (2018) previously conducted microalgae research in Probolinggo, North East Java; Zakiyah et al. (2020) studied microalgae in the South of East Java (Trenggalek and Sendang Biru), North East Java (Banyuwangi and Situbondo), and Madura (Pasongsongan & Pamekasan); Rahma et al. (2020) described microalgae at various depths in Sendang Biru, South East Java; Mahenda et al. (2021) in Kenjeran Surabaya, North East Java; Arsad et al. (2022) explored the biodiversity of microalgae in South East Java (Pacitan and Sempu Island) as well as Probolinggo and Situbondo (unpublished data); and recently Mahmudi et al. (2023) depicted the community of microalgae in North East Java (Pasuruan and Sidoarjo). In the present study, research on microalgae assemblages continues along the North coast of East Java including Gresik, Lamongan, and Tuban.

The northern coast of East Java exhibits characteristics of sandy, muddy, and gravel sediment. The Gresik area's coast features sandy sediment with an elongated beach shape, encompassing a substantial portion of the coastal land. Sandy beaches typically have a low resistance to wave and ocean current erosion. Due to the slow river flow on sandy beaches, high tides often lead to the merging of seawater with the river. Consequently, beaches in the Gresik region frequently undergo shoreline modifications or accretion because of sedimentation processes (Solihuddin et al., 2021). The Lamongan coast experiences tides and is primarily dominated by sand and sandy loam substrates. In the Tuban Regency, particularly in the Jenu District, there are abundant coastal resources, including mangroves, coral reefs, and seagrasses (Musrifah, 2020). Some coastal areas along the North Coast of East Java serve as docks and ports. Several beaches in the northern part of East Java are used for tourism and residential purposes. Lamongan boasts a lengthy coastline of 47 km, covering a sea area of 902.4 km², 12 miles from sea level. It is one of the regions with a coastal area along the northern coastline, offering immense potential, including biodiversity in its waters and natural beauty, attracting coastal tourism (Bhaskoro et al., 2020). The coastal area of Lamongan is bustling with tourism activities and marine cultivation. Tuban, with an area of 1,904.70 km² and a beach length of approximately 65 km, has district planning that divides the Tuban Regency into several strategic areas, one of which is the Minapolitan strategic area (Shabrina et al., 2020).

This study aimed to identify the types and abundance of microalgae based on sub-habitat characteristics on the North Coast of East Java. In addition, the assessment of correlation between microalgae abundance and water quality parameters is also examined. We anticipate that the results of this study will provide valuable insights into the composition and abundance of microalgae in relation to their sub-habitats. Furthermore, it will help explain the relationship between the presence of microalgae and environmental water quality parameters.

MATERIALS AND METHODS

Study area and period

The research was conducted in the northern part of East Java, encompassing Gresik, Lamongan, and Tuban (Fig. 1). Three beach sites were selected for each area (Fig. 2) using a purposive sampling method, aiming to represent the distribution of microalgae along the northern coast of East Java (Table 1). The study took place from March to June 2023, coinciding with the rainy season.

Sampling of water quality and microalgae in the water column sub-habitat occurred during high tide, while sampling of microalgae in sandy

Table 1. Description of sampling site

Site location	Sub-habitats/ substrates
Ayang-Ayang beach, Gresik (S1) (8˚58'37.55" S &112˚38'48.13" E)	water column, sandy sediments, rocks, mangrove root
Ngemboh beach, Gresik (S2) (6°54'13" S & 112°329'55" E)	water column, sandy sediments, rocks
Bangsalsari beach, Gresik (S2) (6°54'23" S &112°30'25" E)	
Dalegan beach, Gresik (S3) (6°53'30.5" S & 112°27'58.5" E)	water column, sandy sediments, rocks
Putri Klayar beach, Lamongan (S4) (6°52'25.9" S &112°26'22.9" E)	water column, sandy sediments, rocks, mangrove root, artificial substrate
Lorena beach, Lamongan (S5) (6°52'10.3" S & 112°21'03.4" E)	water column, sandy sediments, rocks, mangrove root
Ya'ang beach, Lamongan (S6) (6˚52'52" S & 112˚12'50" E)	water column, sandy sediments, rocks, mangrove root
Kutang beach, Lamongan (S6) (6˚53'09.7" S & 112˚11'47.5" E)	
Boom beach, Tuban (S7) (6°53'33" S & 112°03'45" E)	water column, sandy sediments, rocks, macroalgae
Cemara beach, Tuban (S8) (6º50'26"–6º51'24" S & 112º00'54"–112º01'32" E)	water column, sandy sediments, rocks, macroalgae
Pantai Remen, Tuban (S9) (6º45'56" S & 111º58'05" E)	water column, sandy sediments, rocks

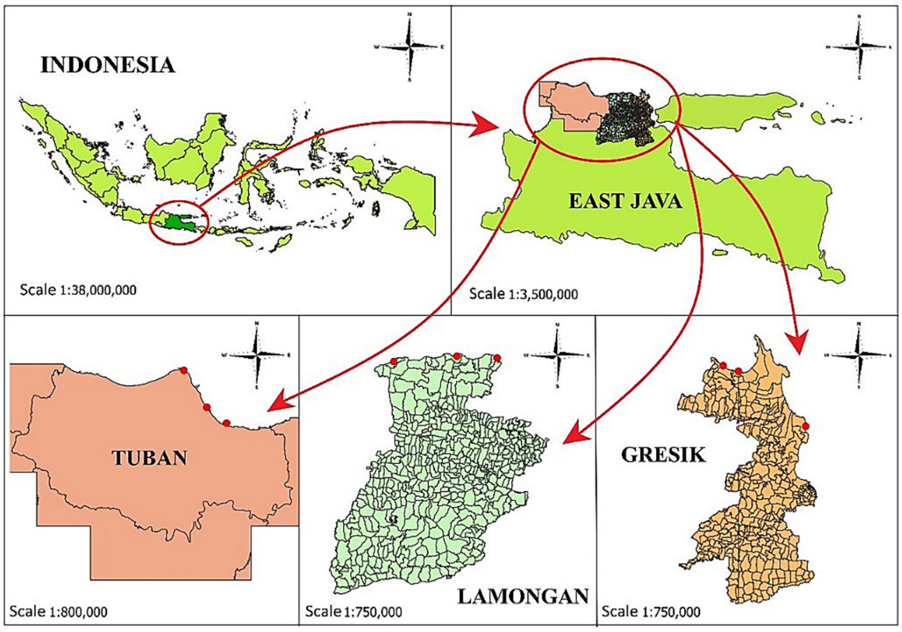

Figure 1. Research location of East Java, Indonesia (Gresik, Lamongan, and Tuban)

sediments, rocky substrates, mangrove roots, macroalgae, and artificial (concrete) substrates was carried out during low tide. Overall, these areas serve multiple purposes, including tourism, fishing activities, marine cultivation, and domestic activities.

Sampling procedures

Microalgae samples were collected from sub-habitats of sandy sediment, rocks, mangrove roots, macroalgae, and artificial substrates during low tide using a 5 x 5 cm transect technique (Arsad et al., 2021). Additionally, samples from water column were obtained during high tide using plankton net 25 µm of mesh size for every 25 L of water (SNI 03-4717-1998, modified). The filtered samples were then transferred into 30 ml sample bottles and preserved with 2-3 drops of 1% Lugol solution. Sampling of microalgae and measurement of water quality parameters were conducted twice, with a two-week interval between each

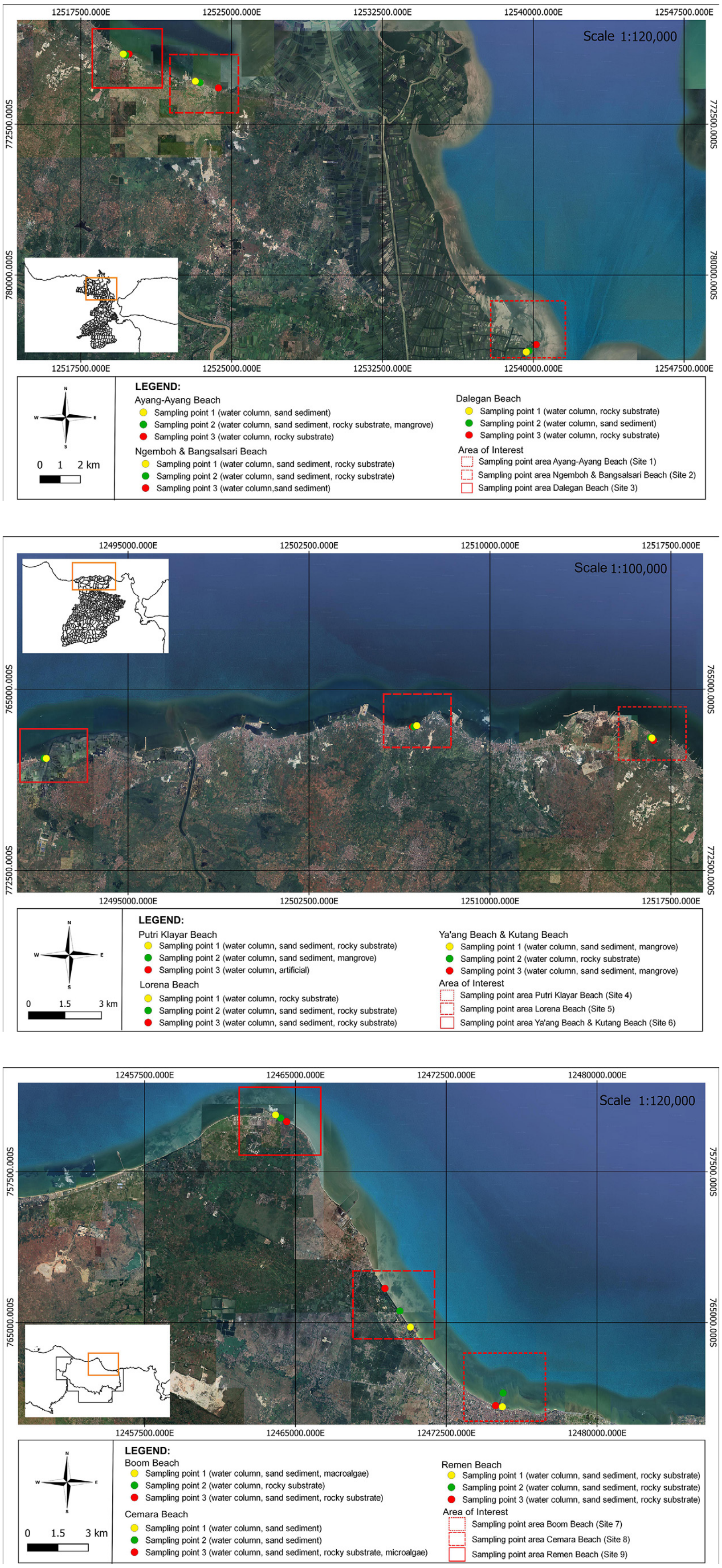

Figure 2. Sampling site: (a) Gresik (Ayang-Ayang Beach, Ngemboh and Bangsalsari Beaches, Dalegan Beach); (b) Lamongan (Klayar Putri Beach, Lorena Beach, Ya'ang Beach and Kutang); (c) Tuban (Boom Beach, Cemara Beach, Remen Beach)

session. Water quality parameters were measured both in-situ and ex-situ. In-situ measurements included temperature (°C, DO meter model PDO-520), transparency (cm, Secchi disk), current (m/s, manual current meter), pH (pH meter 5 in 1 EZ-9909A), salinity (ppt, Refractometer 2 in 1 Brix 0 – 32% Salt 0 – 28%), dissolved oxygen (mg/L, DO meter model PDO-520). Ex-situ measurements involved nitrate (mg/L, Spectrophotometer Genesys 10 UV-Vis) and orthophosphate (mg/L, Spectrophotometer Genesys 10 UV-Vis) at the Laboratory of Sumber Pasir, Universitas Brawijaya Malang.

Observation and data analysis

Samples of microalgae were morphologically observed using a light microscope, the Olympus CX21 at a magnification of x400. The identification and calculation (abundance and relative abundance) of microalgae were used Prescott (1970), diversity index was using formula from Shannon-Weaver (Baliton et al., 2020), evenness index (Shannon & Weaver, 1949), and dominance index by using Simpson (Arazi et al. 2019). Moreover, microalgae abundance in the water column was determined using APHA (1998) formula as following:

$$N = \frac{T}{L} \times \frac{P}{p} \times \frac{V}{v} \times \frac{1}{w} \quad (1)$$

where: N – microalgae abundance (cell/ L); T – cover glass area (24×24 mm); L is wide field of view of the microscope (0.785 mm^2); P – the number of individuals per site (cell); p – number of fields of view (9); V – volume of microalgae concentrate in sample bottle (30 ml); v – the volume of concentrate under the cover glass (0.06 ml); w – the volume of filtered water sample (25 L). Epiphytic and benthic microalgae abundance based on APHA (2012):

$$K = \frac{n}{Ac} \times \frac{At}{Vs} \times \frac{Vt}{As} \quad (2)$$

where: K – the abundance of rocky substrate microalgae per unit area (cell/ cm^2); n – the number of microalgae found in each site (cell); As – the observed substrate area (5×5 cm); Ac – the field of view (0.785 mm^2); At – the area of the cover glass (24×24 mm); Vt – the volume of the sample (30 ml); Vs – the sample volume under the cover glass (0.06 ml).

Statistical analysis

The data were analysed using *non-metric Multidimensional Scaling* (nMDS), which was conducted using software PAST 4.13 and Ms. Excel 2016. The nMDS plot was generated based on the Bray-Curtis matrix equation, which is employed to represent group composition in a two-dimensional format (Hasanah et al. 2014). The stress value in the nMDS method is used to assess the accuracy of the value of a plot that describes the compositional structure of the samples (Musa et al., 2022).

RESULTS AND DISCUSSION

Composition, abundance, and relative abundance of microalgae

The highest microalgae composition in the Gresik area was found to be Bacillariophyceae at site1 (94.6%), whereas the lowest composition was Chlorophyceae at site 3 (0.1%). Similarly, Bacillariophyceae also experienced as the highest composition of microalgae were found at site 4 (95.3%), while the lowest was Chlorophyceae at site 5 (0.3%). In the Gresik and Lamongan areas, Bacillariophyceae also constituted the highest microalgae composition at site 7 (97.4%), while the lowest composition was Zygnematophyceae at site 8 (0.2%). Bacillariophyceae are commonly found in various aquatic environments due to their cosmopolitan nature, rapid reproduction, wide distribution, and tolerance to environmental changes (Hadi et al. 2022). Besides, diatoms are known to thrive wherever there is water, attaching themselves to various substrates such as gravel, plants, and various aquatic environments (Kwon et al., 2021). The types of microalgae found are detailed in Table 2.

In the Gresik area, the highest abundance of microalgae was found on the rocky substrate at site 3 of first sampling point (8,276,790 cell/cm^2), whereas the lowest abundance of microalgae was found in the water column at site 2 of third sampling point (12,741 cell/L). In Lamongan, the highest abundance was found on artificial substrate (concrete) at site 4 of third sampling point (125,942 cell/cm^2), and the lowest was found in the water column at site 4 of second and third sampling point (2,940 cell/L). Similarly, in the Gresik area, the highest abundance of microalgae was found on the rocky substrate at site 7 of

Table 2. The type of microalgae found in this study

Bacillariophyceae		
Achnantes	*Epithemia*	*Pleurosigma*
Amphipora	*Fragilaria*	*Prorocentrum*
Amphora	*Frustulia*	*Rhizosolenia*
Asterionella	*Gomphonema*	*Rhoicosphenia*
Bacillaria	*Grammatophora*	*Rhopalodia*
Bacteriastrum	*Guinardia*	*Scoliopleura*
Biddulphia	*Gyrosigma*	*Seminavis*
Campylodiscus	*Halamphora*	*Skeletonema*
Chaetoceros	*Isthmia*	*Stauronella*
Climacosphenia	*Licmophora*	*Surirella*
Cocconeis	*Melosira*	*Synedra*
Cyclotella	*Navicula*	*Tabellaria*
Cylindrotheca	*Neidium*	*Thalasionema*
Cymbella	*Nitzchia*	*Trachyneis*
Diploneis	*Odontella*	*Triceratales*
Denticula	*Paralia*	*Thalassiosira*
Diatoma	*Pinnularia*	*Triceratium*
Entomoneis	*Plagiotropis*	
Chlorophyceae		
Carteria	*Radiofilum*	
Dynobrion	*Ulothrix*	
Cyanophyceae		
Anabaena	*Microcystis*	*Spirulina*
Aphanocapsa	*Oscillatoria*	*Synechocystis*
Chroococcus	*Spirrulina*	*Synura*
Lyngbya	*Raphidiopsis*	*Tolypothrix*
Merismopedia	*Phormidium*	
Zygnematophyceae		
Closterium	*Desmidium*	*Hyalotheca*
Cosmarium	*Mougeotia*	
Dinophyceae		
Dinophysis	*Peridinium*	*Ornithocercus*
Chrysophyceae		
Mallomonas	*Uroglenopsis*	*Ochromonas*
Cryptophyceae		
Cryptomonas		
Coscinodiscophyceae		
Coscinodiscus		
Trebouxiophyceae		
Oocystis	*Lagerheimia*	

third sampling point (926,187 cell/cm^2), while the lowest abundance was found in the water column at site 9 of second sampling point (7,841 cell/L). The highest abundance values of the three regions were observed in rocky substrate habitats. Natural rock has a porous texture that allows nutrients to settle in these cavities due to tidal activity. The rough texture of natural rock also makes it easier for epilithic diatoms to attach to the substrate (Rahim et al., 2017).

In the Gresik coast, *Skeletonema* exhibited the highest relative abundance in both sub-habitat characteristics: the water column (72%) and sandy sediment (65%). Furthermore, *Nitzchia* accounted for 51% of the rocky substrate, followed by *Pinnularia* at 26% in the mangrove. *Skeletonema* is a species with the ability to thrive in various aquatic environmental conditions and reproduce rapidly (Jamaludin et al., 2021). On the other hand, *Nitzschia* is commonly found on rocks and possesses a gelatinous stalk that aids in movement and attachment to substrates amidst changing water conditions. *Pinnularia* can survive in waters with low nutrient availability and is often found in macroalgae and/or substrates mixed with clumps of moss (Tarigas et al., 2020). In the Lamongan coast, the highest abundance was *Scoliopleura* (100%) in the mangrove, *Synedra* and *Nitzchia* (40%) in sandy sediments, *Melosira* (38%) on rocks, *Navicula* (34%) on artificial (concrete), and *Amphora*, *Isthmia, Synedra* (33%) in the water column. *Scoliopleura* belongs to the class Bacillariophyceae, which uses mucus to attach to substrates, including mangroves. Similarly, *Synedra* has an elongated shape, can move freely as a planktonic microalga, and uses mucus to attach to substrates (Harmoko & Krisnawati 2018). Meanwhile, *Nitzschia* belongs to the benthic microalgae that inhabit the bottom of water bodies and possess the property of adhering to substrates (Arsad et al., 2021). *Melosira* thrives as epipelic organisms in sandy mud and muddy sand (Aini et al., 2022). *Navicula* employs a strong attachment mechanism via a slimy stalk, allowing them to thrive in flowing waters (Lestari et al., 2021). Furthermore, *Amphora*, *Isthmia*, and *Synedra* are belong to Bacillariophyceae, capable of prolific reproduction and abundant presence in waters (Benni et al., 2020). In Tuban area, the highest relative abundance was *Chaetoceros* (54% and 34%) from water column and macroalgae, respectively; *Navicula* (46%) on rocks; and *Synedra* and *Navicula* (44%) in sediment. *Chaetoceros* is commonly found in both the water column and seaweed due to its cell structure forming chains or groups, resulting in a low sinking rate and reduced predation by herbivorous predators preferring microalgae with higher sinking rates (Supriyantini et al., 2020). Meanwhile, *Navicula* is frequently found on rocks and in sediments due to its adhesive nature, with a gelatinous-like substance that aids substrate adhesion (Kurnia et al., 2020). *Synedra* exhibits strong adaptability to extreme environmental condition changes and can be found in various habitat types (Herlina et al., 2018).

Ecological indices

The diversity index (H’) values in the three regions vary significantly, ranging from 1.05 to 2.65 in Gresik, 0.9 to 2.26 in Lamongan, and 1.49 to 2.43 in Tuban, respectively. According to Shannon-Weaver criteria, when the value of H’<1.0 means it indicates low diversity. However, if the H’ value is between 1 ≤ H’ ≥ 3, it signifies intermediate diversity. Supplementally, if the value of H’>3, it illustrates a high diversity index. a low diversity value among microalgae may suggest the presence of high ecological pressure, unstable ecosystems, and low water productivity. In cases where the aquatic ecosystem is in an unstable condition, there is a potential for an explosion in the population of certain species, leading to ‘blooms’ (Sidomukti & Wardhana, 2021).

The evenness index (E) in the Gresik, Lamongan, and Tuban coastal areas ranged from 0.48 to 0.95, 0.39 to 1.0, and 0.65 to 1.0, serially. An E value > 0,5 exhibits high uniformity and an even distribution of microalgae. Otherwise, an E value <0,5 signifies low uniformity and an uneven distribution of microalgae (Shabrina et al., 2021). As for the dominance index (D), Gresik, Lamongan, and Tuban show diverse values which were 0.10 to 0.54 (Gresik); 0.11 to 1.0 (Lamongan); and 0.12 to 0.45 (Tuban). Across these coastlines, the dominance value is low because it is less than 1.0. A dominance index value between 0 and 1 indicates low dominance with no dominated species. On the contrary, a D value exceeding 1 indicates high dominance with the presence of dominant species (Marsela et al., 2021).

Environmental quality indicators

The measurements of water quality in all sub-habitats perform that water quality on the north coast of East Java (as shown in Table 3, 4, 5) is generally in good condition as it is still falls within the quality standards for microalgae growth. However, certain parameters, such as transparency and salinity, occasionally have values that either fall below or exceed the established quality standards. The influence of turbidity, water colour, sediment substrate, weather conditions, sampling location, and sampling time can all contribute to these fluctuations in values, causing them to occasionally deviate from the established limits. The water temperature was approximately 30–34.4°C, which is normal for microalgae’

Table 3. Water quality value in Gresik coast

Parameter	Gresik									Literature
	S1			S2			S3			
	T1	T2	T3	T1	T2	T3	T1	T2	T3	
Temperature (°C)	34	33	33.7	32.2	33.3	33.3	34.2	34.1	32.7	25–35°C (Maulana et al. 2017)
Transparency (cm)	49	55,5	63	82,5	82	76	84.8	66.5	91.8	>45 cm (Herawati et al. 2021)
Current (m/s)	0.06	0.07	0.08	0.05	0.06	0.07	0.04	0.09	0.04	Slow current< 0.1 m/s medium current 0,1–1 m/s (Padang et al. 2020)
pH	7	6.9	7.2	7.7	7.4	7.1	7.2	7.1	7.2	6–9 (Kumar & Saramma 2018)
Salinity (ppt)	29.5	30.8	31.5	26	25.5	29	32.5	31.5	30	15–32 ppt (Nurjijar et al. 2022)
DO (mg/L)	6.9	6.6	7.2	6.5	7.2	6.9	6.5	6.7	6.9	>5 mg/ L (Arofah et al. 2021)
Nitrate (mg/L)	0.03	0.02	0.01	0.02	0.025	0.023	0.017	0.035	0.035	Oligotrophic 0–1 mg/L (Adriani et al. 2019)
Orthophosphate (mg/L)	0.07	0.08	0.06	0.02	0.03	0.02	0.019	0.009	0.012	Oligotrophic <0.015 to mesotrophic 0.015-0.13 mg/L (Nurjijar et al. 2022)

Table 4. Water quality value in Lamongan coast

Parameter	Lamongan									Literature
	S4			S5			S6			
	T1	T2	T3	T1	T2	T3	T1	T2	T3	
Temperature (°C)	33.6	31.3	32.5	30.8	32.1	34.4	31.2	31.5	32.8	25–35°C (Maulana et al. 2017)
Transparency (cm)	39.5	35.3	35	63.8	60.8	61.5	31.5	27	43.8	>45 cm (Herawati et al. 2021)
Current (m/s)	0.11	0.05	0.08	0.05	0.07	0.06	0.11	0.11	0.11	Slow current< 0.1 m/s medium current 0,1–1 m/s (Padang et al. 2020)
pH	8	7.8	8.1	7.8	8.1	8.7	7.7	7.8	7.8	6–9 (Kumar & Saramma 2018)
Salinity (ppt)	28.5	30.5	33.5	32.5	34.5	34	33.5	34	34	15–32 ppt (Nurjijar et al. 2022)
DO (mg/L)	9.3	10	10.6	8.2	9	9	10.9	16.5	17.1	>5 mg/ L (Arofah et al. 2021)
Nitrate (mg/L)	0.027	0.015	0.032	0.06	0.075	0.079	0.1	0.04	0.11	Oligotrophic 0–1 mg/L (Adriani et al. 2019)
Orthophosphate (mg/L)	0.018	0.032	0.022	0.056	0.08	0.059	0.07	0.04	0.11	Oligotrophic <0.015 to mesotrophic 0.015-0.13 mg/L (Nurjijar et al. 2022)

growth. Microalgae can tolerate water temperatures up to 35°C (Zainuri et al., 2023). Furthermore, transparency values ranged from around 27 to 92.5 cm. Transparency values below 0.30 cm can inhibit sunlight penetration into the water, limiting microalgae growth (Maresi et al., 2015). The current velocity ranged from roughly 0.04 to 0.29 m/s, falling within the category of slow to intermediate currents. High current velocities can physically disrupt and displace microalgae, hindering their ability to settle and grow effectively. Nevertheless, slow currents enable microalgae to efficiently utilize available nutrients and optimize the photosynthesis process (Adrizal et al., 2022).

Table 5. Water quality value in Tuban coast

Parameter	Tuban									Literature
	S7			S8			S9			
	T1	T2	T3	T1	T2	T3	T1	T2	T3	
Temperature (°C)	30	31.9	31.2	31.2	31.9	31.3	32.2	32.7	33.3	25–35°C (Maulana et al. 2017)
Transparency (cm)	31.5	92.5	51	38	40.5	42	49.5	53.5	52.5	>45 cm (Herawati et al. 2021)
Current (m/s)	0.14	0.29	0.19	0.15	0.16	0.11	0.15	0.2	0.2	Slow current< 0.1 m/s medium current 0,1–1 m/s (Padang et al. 2020)
pH	7.2	7	7.4	6.6	7.4	6.7	7.2	7.2	7.6	6–9 (Kumar & Saramma 2018)
Salinity (ppt)	17	33	16	14	32	30	33.5	33.5	33.5	15–32 ppt (Nurjijar et al. 2022)
DO (mg/L)	5.7	6.1	7.7	6.4	6	6.1	6.8	6.9	7.2	>5 mg/ L (Arofah et al. 2021)
Nitrate (mg/L)	0.024	0.024	0.037	0.056	0.038	0.028	0.021	0.026	0.017	Oligotrophic 0–1 mg/L (Adriani et al. 2019)
Orthophosphate (mg/L)	0.025	0.013	0.04	0.033	0.022	0.016	0.007	0.01	0.023	Oligotrophic <0.015 to mesotrophic 0.015-0.13 mg/L (Nurjijar et al. 2022)

The pH levels ranged from 6.6 to 8.7, which is conducive to supporting microalgae life. pH values between 6 and 9 promote microalgae growth (Kumar & Saramma, 2018).

Salinity levels ranged from 14 to 34.5 ppt, while dissolved oxygen (DO) levels ranged from 5.7–17.1 mg/L. Very high salinity content can lead to osmotic pressure and ion exchange, affecting the metabolism of photosynthetic organisms (Mahardhika et al., 2023). On the other hand, microalgae can thrive optimally at DO concentrations greater than 5 mg/L. Conversely, it can be a limiting factor for microalgae growth if the value is lower than 5 mg/ L (Setyaningrum et al., 2020). Nitrate and phosphate levels were found to be between 0.01–0.11 mg/L and 0.007–0.11 mg/L, respectively. High nitrate levels in water bodies can lead to pollution and eutrophication, while low nitrate levels can result in a deficiency of nutrients for the growth of phytoplankton (Nasution et al., 2019). Meanwhile, very low orthophosphate levels can inhibit phytoplankton growth, leading to reduced microalgae abundance (Rizqina et al., 2018). Nitrate and orthophosphate levels obtained are limiting factors for microalgae growth, and they have a significant impact on microalgae abundance in aquatic ecosystems.

Similarity of microalgae in different sub-habitats and relationship between water quality parameters and microalgae distribution

Data analysis using nMDS was employed to assess the proximity of the number of microalgae found in each sub-habitat in Gresik, Lamongan, and Tuban. The nine study sites were grouped based on the average results of microalgae classes from the first and second iterations. nMDS analysis was also applied to investigate the relationship between microalgae classes and the average results of water quality parameters during the first and second iterations. The analysis plot depicts the distribution of points, each representing a specific site within all sub-habitats. The results of the nMDS analysis for the three regions are presented in Figure 3.

The nMDS plot (Fig. 3) illustrates the similarity of microalgae in the Gresik area of Ayang-Ayang Beach for water column (AA WC), sandy sediment (AA SS), rocky substrate (AA RS), and mangrove (AA MG); Ngemboh and Bangsalsari beaches for water column sub-habitat (NB WC), sandy sediment (NB SS), rocky substrate (NG RS); Dalegan Beach for water column sub-habitat (DL WC), sandy sediment (DL SS), rocky

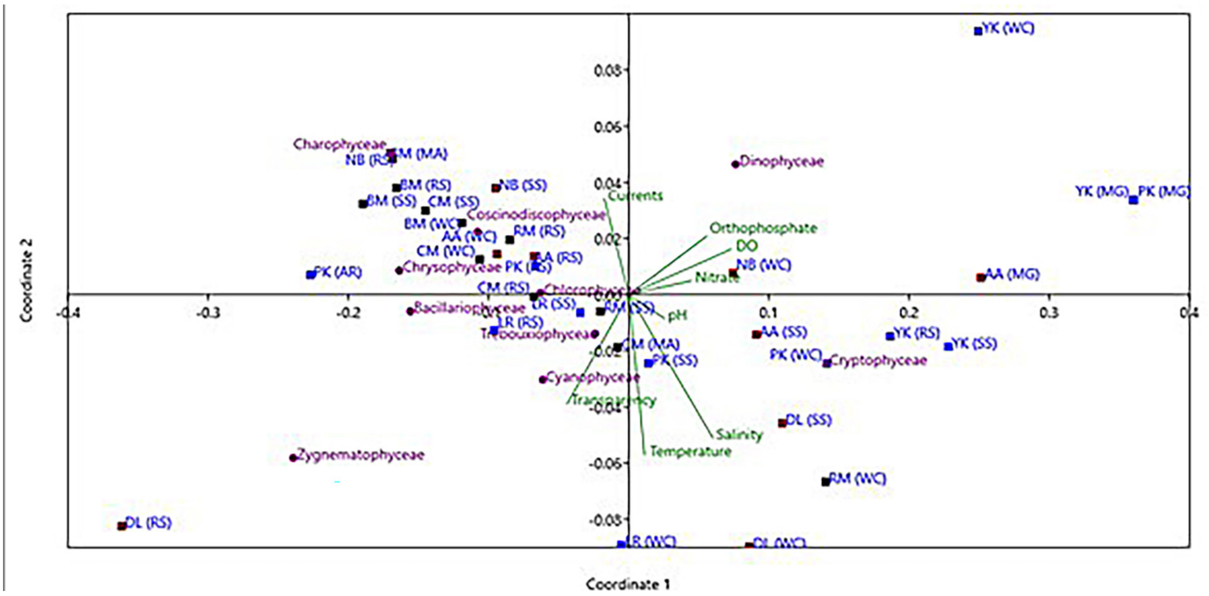

Figure 3. nMDS analysis plots

substrate (DL RS); Putri Klayar Beach for water column sub-habitat (PK WC), sandy sediment (PK SS), rocky substrate (PK RS), mangrove (PK MG), artificial (PK AR); Lorena Beach for water column sub-habitat (LR WC), sandy sediment (LR SS), rocky substrate (LR RS); Ya'ang Beach and Kutang Beach are sub-habitats of the water column (YK WC), sandy sediments (YK SS), rocky substrate (KT RS), and mangroves (YK MG); Boom Beach for water column sub-habitat (BM WC), sandy sediment (BM SS), rocky substrate (BM RS), macroalgae (BM MA); Cemara Beach for water column sub-habitat (CM WC), sandy sediment (CM SS), rocky substrate (CM RS), macroalgae (CM MA); and Remen Beach for water column sub-habitat (RM WC), sandy sediment (RM SS), rocky substrate (RM RS).

From the results of the nMDS plot, a stress value of 0.03862 was obtained, indicating a perfect plot with no possibility of error in its interpretation (Rahman et al., 2020). The stress value in the nMDS method serves to assess the accuracy of a plot that describes the compositional structure of the samples (Musa et al., 2022). Observing the plot, it becomes evident that the points within each sub-habitat at various research sites exhibit varying degrees of proximity, with some being close to each other and others more distant. The results reveal both similarities and differences in the microalgae composition across the nine sites distributed across Gresik, Lamongan, and Tuban, reflecting a high level of microalgae variation. This diversity likely arises from the distinct characteristics and environmental conditions present in these coastal areas, as evidenced by the water quality measurements taken at these sites. These variations in water quality results directly impact the microalgae composition found at each research site. For instance, the Ya'ang-Kutang beach point is notably distinct from others (Fig. 3) due to elevated dissolved oxygen and nitrate concentrations compared to the rest. Similarly, the Dalegan beach point stands out due to its lower nitrate levels in comparison to other beaches. Nitrate levels in the water significantly influence the abundance of planktonic microalgae, as they are essential for photosynthesis, metabolism, growth, and protein synthesis in microalgae (Dayana et al., 2022). Furthermore, DO levels are related to salinity, with higher salinity values resulting in lower dissolved oxygen content in the waters (Daroini & Arisandi, 2020).

The nMDS analysis of water quality parameters show a strong positive correlation between DO, nitrate, and orthophosphate parameters, as evidenced by the angles formed between vector lines adjacent to each other. This correlation suggests that high DO levels correspond to elevated concentration of nitrate and orthophosphate. The availability of dissolved oxygen is closely linked to nitrate because it facilitates the decomposition of organic matter (Arsad et al., 2022). Similar patterns emerge for other parameters, including temperature, transparency, salinity, and pH, as these parameters also exhibit angles between adjacent vector lines. These observations indicate that when temperature increases, transparency, salinity, and pH values also tend to increase in tandem. The presence of Cryptophyceae in the water column sub-habitat of Putri Klayar Beach suggests that Cryptophyceae are exclusively found in the water column of Putri Klayar Beach. Similarly, Charophyceae are exclusively found in the macroalgae sub-habitat of Boom beach. In contrast, Bacillariophyceae were found at all sites within each sub-habitat. This observation is supported by the position of Bacillariophyceae points on the plot, which are adjacent to all site points. Bacillariophyceae exhibit adaptability to various environmental conditions due to their silica-based cell wall, known for its strength and durability. Some types also have a gelatinous stalk that facilitates movement and attachment to substrates (Tarigas et al., 2020). The abundance of Bacillariophyceae holds potential significance for marine life, particularly pelagic fish (Andriani et al., 2017).

CONCLUSION

In conclusion, this study identifies Bacillariophyceae as the most prevalent microalgae across all habitat characteristics along the north coast of East Java. Briefly, microalgae in the water column habitat encompassed a variety of classes, including Bacillariophyceae, Chlorophyceae, Chrysophyceae, Coscinodiscophyceae, Cyanophyceae, Dinophyceae, Trebouxiophyceae, and Zygnematophyceae. In sandy sediments, the classes Bacillariophyceae, Chlorophyceae, Coscinodiscophyceae, Cyanophyceae, Chrysophyceae, Dinophyceae, and Zygnematophyceae were observed. From rocky substrates, microalgae included Bacillariophyceae, Chlorophyceae, Chrysophyceae, Coscinodiscophyceae, Cyanophyceae, and Zygnematophyceae. The macroalgae sub-habitat contained Bacillariophyceae, Coscinodiscophyceae, Chrysophyceae, and Cyanophyceae, while the mangrove roots sub-habitat featured Bacillariophyceae and Cyanophyceae. The nMDS analysis highlights the influence of water quality on microalgae, particularly planktonic microalgae. Water quality parameters are closely linked to various microalgae classes, indicating preferences based on factors such as temperature, light intensity, currents, salinity, pH, nitrate, dissolved oxygen, and orthophosphate. Additionally, the study reveals both similarities and differences in microalgae composition across nine sites in Gresik, Lamongan, and Tuban, reflecting a high degree of microalgae variation. The expected outcome from this study is to contribute to and enhance the database of morphologically classified microalgae, particularly within sub-habitat characteristics along the north coast of East Java, Indonesia.

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