Global J. Environ. Sci. Manage. 8(4): 561-574, Autumn 2022, Serial #32

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

Microalgae diversity in several different sub-habitats

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ARTICLE INFO

Article History:
Received 01 October 2021
Revised 11 January 2022
Accepted 21 February 2022

Keywords:
Benthic environment
epiphytic
macroalgae and microalgae
non-metric multidimensional scaling (nMDS)
planktonic

DOI: 10.22034/gjesm.2022.04.08

ABSTRACT

BACKGROUND AND OBJECTIVES: Biodiversity is the variety of life that exists on Earth, including all the organisms, species, and populations that come together in a complex manner to form communities and ecosystems. This study aimed to assess the diversity of microalgae in several different sub-habitats by identifying their types and abundance in sediments, mangroves, macroalgae, and water columns; additionally, this study analyses the environmental factors that affected the abundance of microalgae in several sub-habitats.

METHODS: This study used a quantitative descriptive method with data collection techniques, incorporating the purposive sampling method. Data were analysed using non-metric multidimensional scaling.

FINDINGS: The results showed that the composition of microalgae species found in the sub-habitats of sediments, mangroves, macroalgae, and water columns at Siwil Beach were the class of Bacillariophyceae (70%), Chlorophyceae (17%), and Cyanophyceae (13%) in all sub-habitats. In Sempu Island, microalgae were found only from Bacillariophyceae (100%) in the four sub-habitats. The highest abundance of microalgae on Siwil Beach was in the sub-habitat of mangroves, with a total of 5,423,073 cells/cm^2, while the highest abundance in Sempu Island was in the sub-habitat of macroalgae, with a value of 1,986,252 cells/cm^2. Moreover, based on non-metric multidimensional scaling analyses, there was no similarity of algae diversity between Siwil Beach and Sempu Island, with a high variation of microalgae.

CONCLUSION: The present study demonstrated that the class Bacillariophyceae dominated the communities of microalgae found both in Siwil Beach and Sempu Island. Moreover, factors that mainly affected the abundance of microalgae were environmental, which is already proven by the measurement of water quality in each sub-habitat at both locations. Siwil Beach and Sempu Island water quality was relatively still under the Indonesian national quality standard for seawater. This research is thought to be the first step in exploring the diversity of microalgae in several sub-habitats in East Java, Indonesia, and linking the type and availability of microalgae found in various sub-habitats with environmental water quality parameters and human activities around the waters. In addition, this paper provides the basic information of microalgae diversity based on sub-habitats, especially in the southern part of East Java Indonesia.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
48	5	1

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Note: Discussion period for this manuscript open until January 1, 2023 on GJESM website at the “Show Article”.

INTRODUCTION

Biodiversity is the variety of life that exists on earth, including all the organisms, species and populations that come together in a complex manner to form communities and ecosystems. Biodiversity describes the diversity both in number and frequency in nature. It is usually used in plants, animals, microorganisms and others that make up an ecosystem (Rawat and Agarwal, 2015). As a mega biodiversity nation, the diversity and abundance of microalgae in Indonesia are very high (Pikoli *et al.,* 2019). The characteristics of microalgae are that they are planktonic, epiphytic and benthic. Microalgae live in various sub-habitats (Hopes and Mock, 2015), such as benthic microalgae found in sedimentary habitats, epiphytic microalgae attached to substrates such as seaweed (Al-Harbi, 2017) and mangrove roots, and planktonic microalgae found in the water column. Microalgae are autotrophic organisms that use light to synthesize compounds such as carbohydrate, proteins and lipids (Musa *et al.,* 2021). Benthic microalgae, called microphytobenthos, are microscopic and capable of photosynthesis in sediments. This type of microalgae can grow at low light levels by utilizing a high concentration of nutrients in the sediment. These microalgae are widely distributed in nature, adapted to different environments and have high diversity in size, morphology, life cycle, pigment and metabolism (Baklouti *et al.,* 2018). This is in accordance with the statement of Risjani et *al.* (2021), suggesting that microalgae can live in various habitats with high levels of biodiversity. Habitats of microalgae in various areas have different environmental conditions. Environmental parameters such as physical, chemical and biological parameters significantly affect environmental conditions in microalgae habitats (Prazukin *et al.,* 2021). In every coastal ecosystem, there are biotic and abiotic components that interact. East Java has coastal areas with abundant microalgae. The study of distribution of marine microalgae has been carried out in several regions in Indonesia such as in Tanjung Benoa Bali (Suteja *et al*., 2021), West Coast South of Celebes (Tambaru *et al*., 2021), Simeulue Island (Purbani *et al*., 2021), Tambrauw sea West Papua (Purbani *et al.,* 2019), Negeri Waai Beach of Maluku Tengah Regency (Hulopi *et al.,* 2016) and East Java coast (Zakiyah et al., 2020). However, the study of microalgae in several sub-habitats in Siwil beach and Sempu Island is not done yet. The previous research on both places was focused on distribution of brown algae (Achmadi dan Arisandi, 2021) and mangrove, respectively (Suhardjono, 2013). Siwil Beach and Sempu Island are often used for touristic activities, aquaculture and domestic activities. Therefore, the availability and the abundance of microalgae are very influenced by the environmental factors (Astuti *et al.,* 2020). In addition, the analysis of the relationship between microalgae abundance and environmental factors is still limited to the influence of two variables, namely the relationship between microalgae in the water column and the environmental parameters (Golubkov *et al.,* 2019). In previous studies, there has not been an analysis of the relationship between microalgae in various sub-habitats with different locations nor has there been an analysis of the relationship between microalgae and environmental parameters. Based on this, this study will compare the relationship between microalgae, various sub-habitats in different locations and environmental factors. The aims of the current study are to assess the diversity of microalgae in several different sub-habitats, by identifying their types and abundance of microalgae in sediments, mangroves, macroalgae and water columns, and to analyse the environmental factors that affected the abundance of microalgae in these sub-habitats, to provide the database information of microalgae diversity based on sub-habitats. This study has been carried out in the South Coast of East Java of Indonesia in 2021.

MATERIALS AND METHODS

Study area

This study was conducted in the South Coast of East Java in two locations (Fig. 1a and 1b), namely Siwil Beach, Pacitan Regency (8° 15' 53.5" S and 111° 16' 48.8" E) and Sempu Island, Malang Regency (8° 27' 24" - 8° 4' 54" S and 112° 40' 45" - 112° 42' 45" E). The selection of locations on Siwil Beach and Sempu Island was done because these locations represented the distribution of microalgae on Java Island, especially in the southern part; besides, Siwil Beach is used for various water use activities such as tourism, aquaculture and domestic activities, whereas Sempu Island is used for tourism and domestic activities. In addition, the current strength in the waters around Sempu Island range from 0.3–0.6 m/s (Luthfi *et al.,* 2018); from the observation station with its back to the Indian Ocean, the waves in the waters around Sempu Island are low, while the current velocity in Siwil Beach, according to

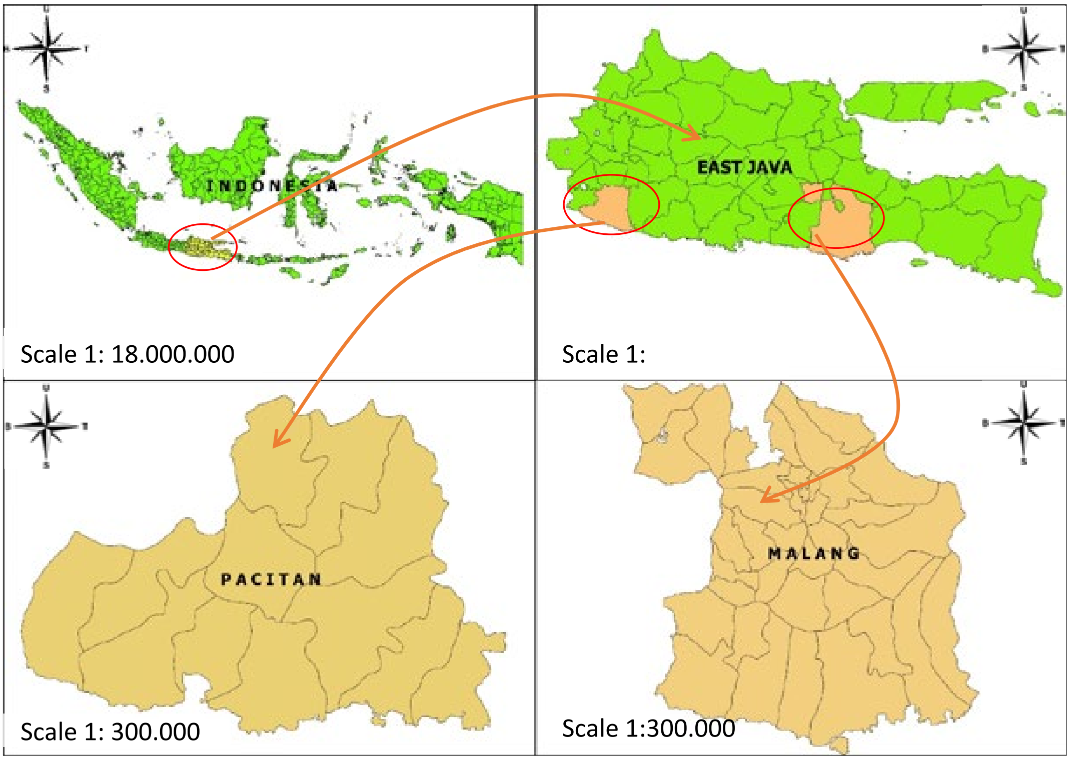

Fig. 1(a): Geographic location of the study area at the Siwil Beach and Sempu Island, in Indonesia

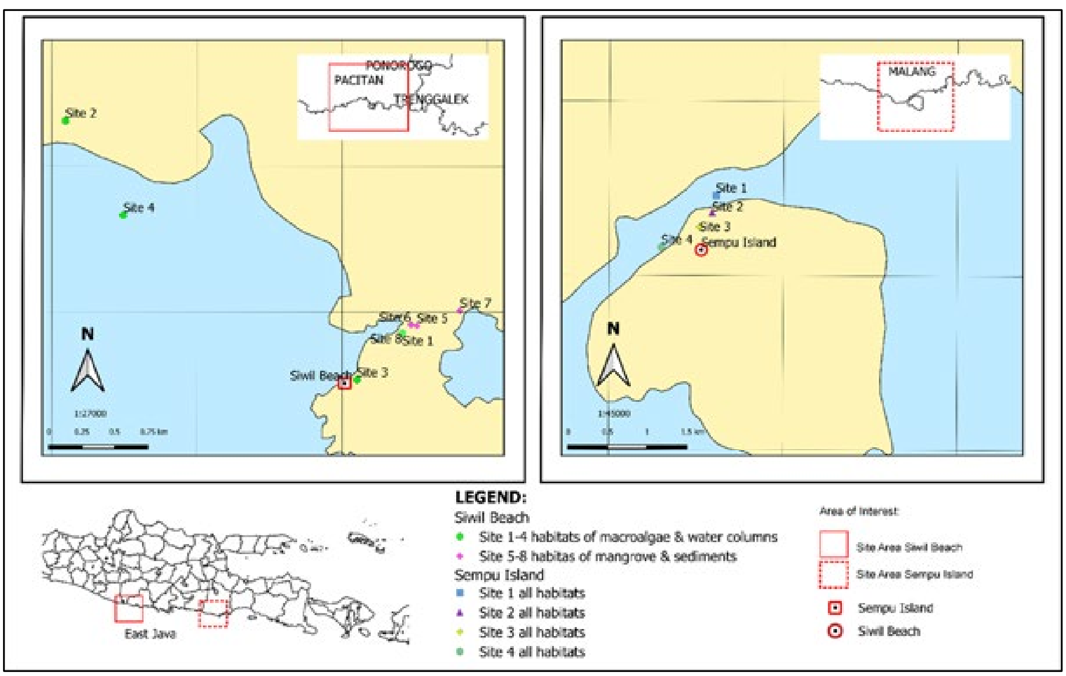

Fig. 1(b): The sampling sites details of Siwil Beach and Sempu Island, in Indonesia

Khotimah *et al*. (2018), can reach 17 m/s with a wave range of 4–5 m. Sampling on Siwil Beach was carried out at eight sites: four sites were located in the sub-habitats of mangroves and sediments and four sites in the sub-habitats of macroalgae and water columns. Meanwhile, sampling in Sempu Island was carried out at four sites, with each site containing the sub-habitats of sediments, mangrove roots, macroalgae and water columns. The determination of the sampling location was carried out to represent the population in Siwil Beach and Sempu Island. The present study was carried out in April–June 2021, during the dry season. Water quality and microalgae sampling in the water column sub-habitat was conducted at high tide. In contrast, sampling of microalgae in the sub-habitats of sediments, mangrove roots and macroalgae was carried out at low tide, as these conditions allow epiphytic microalgae to stick to the sediment surface, mangrove roots and macroalgae. As stated by Garcia *et al.* (2012), taking epiphytic microalgae at low tide can facilitate sampling because of the short immersion.

Research procedure

Sampling of microalgae

Microalgae sampling in the sub-habitats of sediments, mangrove roots and macroalgae was carried out at the lowest tide using the transect technique, by taking samples on the surface of the substrate on which a rectangular slate mold (5 x 5 cm^2) had been placed, following the protocol from Essien *et al.* (2008). On the other hand, microalgae sampling in the water column sub-habitat was carried out following Kadim and Arsad (2016). Briefly, samples were taken using a plankton net (mesh size 25 mm). The filtered sample was placed into a 30 mL sample bottle and was preserved using Lugol's 4%.

Sample Analysis of Microalgae

Identification and calculation of microalgae were carried out in the laboratory using an Olympus light microscope with a magnification of 4x10 morphologically, by using book of Prescott (1970) and the Lackey drop method modified from Clark (1981), respectively. It was then continued with the calculation of the abundance of microalgae in the water column habitat (APHA, 1989), relative abundance (Kusumaningsari *et al.,* 2015), the abundance of epiphytic and benthic microalgae (APHA, 1989), diversity and uniformity index (Shannon, 1948) and dominance index (Kadim and Arsad, 2016).

Water quality measurements

Water quality measurements were performed *in situ* that covers temperature (°C, PDO-520 DO meter), transparency (cm, Secchi disk), pH (mediatech digital pH meter 009), dissolved oxygen (DO) (mg/L, PDO-520 DO meter) and salinity (‰, refractometer). Furthermore, nitrate (mg/L, UV-VIS spectrophotometer), phosphate (mg/L, Genesys 10S UV-VIS spectrophotometer) and biological parameters including chlorophyll-a (mg/L, Genesys 10S UV-VIS spectrophotometer) were measured *ex-situ*. All the water parameters were taken once on each site during the study.

Data analysis

In this study, data were analysed using the non-metric multidimensional scaling (nMDS) method with the plot of the nMDS method referring to the Bray Curtis matrix equation, used to detect species composition (Borchhardt *et al.,* 2017). This nMDS analysis was carried out using PAST software version 403 for Windows Operating System.

RESULTS AND DISCUSSION

The composition of microalgae found

Based on the analysis of microalgae found at Siwil Beach and Sempu Island, it was found that the species and composition on Siwil Beach were in more significant number than those in Sempu Island, with a percentage ratio of species of 67% on Siwil Beach and only 33% in Sempu Island. The Bacillariophyceae, Chlorophyceae and Cyanophyceae dominated the microalgae found on Siwil Beach (Fig. 2a). In contrast, only Bacillariophyceae was detected on Sempu Island (Fig. 2b). This is due to the low nitrate and phosphate content in these waters; thus, only tolerant microalgae can live. Bacillariophyceae was the most commonly found in various waters, with high adaptability to various environmental conditions (Arsad et *al.,* 2021; Everest and Aslan, 2016). Moreover, diatoms can be found in various places where water is available; they can stick to all substrates such as gravels and plants, and can live in various places in the aquatic environment (Kwon *et al.,* 2021). The genera found in all sub-habitats at Siwil Beach and Sempu Island were genera from the class of Bacillariophyceae, namely *Amphora*, *Cyclotella*, *Diploneis*, *Grammatophora*, *Pleurosigma*, *Rhizosolenia*, *Synedra*, *Nitzschia* and

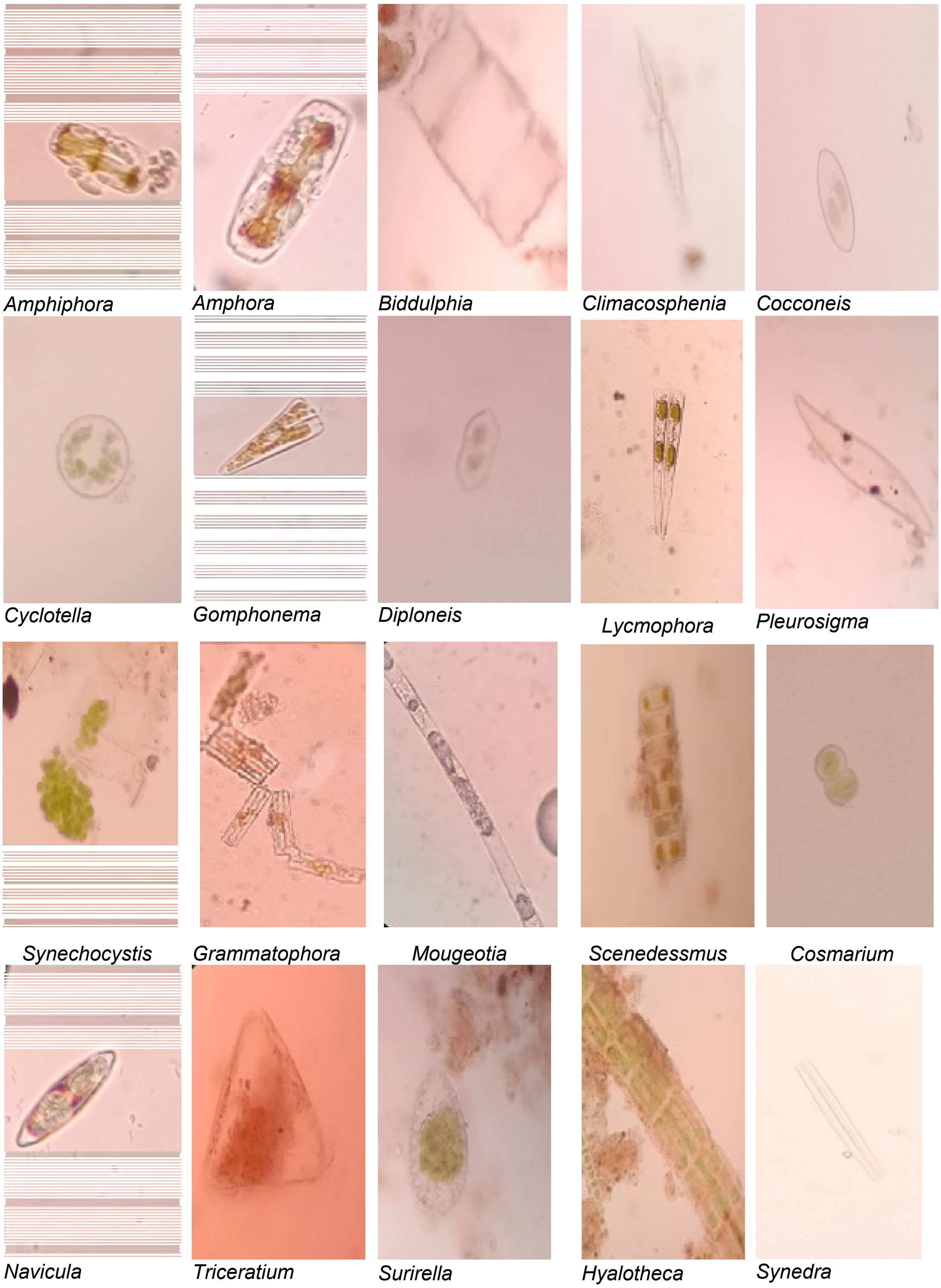

Fig. 2a: Several microalgae found in Siwil Beach (magnification 4x10)

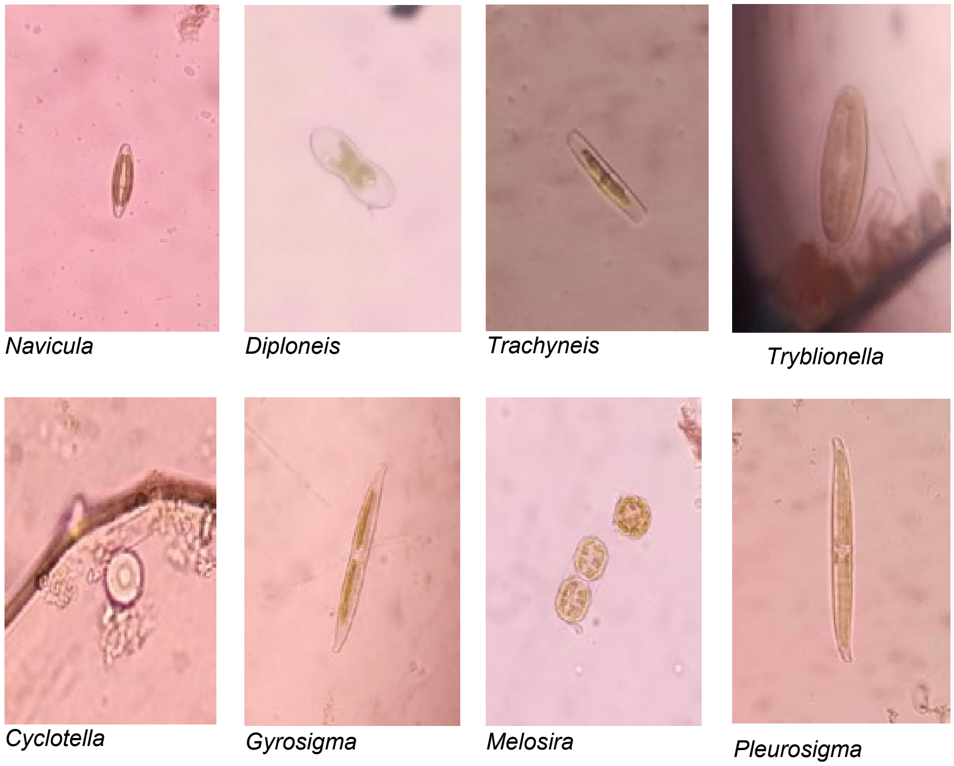

Fig. 2b: Several microalgae found in Sempu Island (magnification 4x10)

Navicula. However, of the genera found in all sub-habitats, some genera dominated in all sub-habitats at Siwil Beach and Sempu Island, namely *Nitzschia* and *Navicula*. This is in line with what was stated by Mucko *et al.* (2021) that the genera *Nitzschia* and *Navicula* were found in various habitats; historically, they have been camouflaged within a category of small pennate diatoms with single-celled cells that can reach very high relative abundance, accounting for 60% or even 90% of the total number of the class Bacillariophyceae. The genera *Nitzschia* and *Navicula* can live in waters with both high and low salinity; therefore, the genera *Nitzschia* and *Navicula* are also found on Siwil Beach, which has high salinity (Akcalan, 2020).

Microalgae abundance

The highest abundance of microalgae was found on Siwil Beach in the sub-habitat of mangrove roots with a value of 5,423,073 cells/cm^2, whereas the lowest was detected in the sub-habitat of water columns with a value of 890,457 cells/L. Most of the microalgae associated with mangroves could be found in the mangrove roots and the surrounding water columns. The microalgae abundance in the mangrove area is influenced by the mangrove canopy cover and the level of turbidity of the waters (Essien *et al.,* 2008). On the other hand, the highest abundance found in Sempu Island was in the macroalgae sub-habitat, with a value of 1,986,252 cells/cm^2, and the lowest was found in the sub-habitat of water columns, with a value of 371,362 cells/L. Waters with a high density of macroalgae will create many substrates for the attachment of microalgae. The process of fouling in macroalgae takes a long time; thus, the epiphytic microalgae will be abundant in a stable macroalgae habitat. Macroalgae can also affect the structure, type and community of microalgae (Zadorozhna *et al.,* 2017). The category of abundance of phytoplankton in the waters is 0–2,000 cell/L (oligotrophic), 2,000–15,000 cell/L (mesotrophic) and more than 15,000 cell/L (eutrophic) (Linus *et al.,* 2016). Therefore, it can be said that Siwil Beach and Sempu Island are included in eutrophic waters with an abundance value of > 15,000 cells/L. The abundance of microalgae is presented in Fig. 3.

Relative abundance

In Siwil Beach, the highest relative abundance was detected from the genus *Nitzschia* (35.8%), *Synechocystis* (36.1%), *Navicula* (35.2%) and *Gramatophora* (23%) from the sub-habitat of sediments, mangrove roots, macroalgae and water columns, respectively. As stated by Garcia *et al.* (2012), *Nitzschia* can tolerate a less favourable environment and an environment with hyper eutrophication. Meanwhile, *Synechocystis* is often found in mangrove areas because it is an epiphytic microalga that favours habitats with high nitrogen levels (Alvarenga *et al.,* 2015). On the other hand, *Navicula* microalgae can adapt to their habitat and have a wide distribution, both vertically and horizontally in the waters (Buczko *et al.,* 2015). In contrast, *Grammatophora* sp. has colonizing cells and is a planktonic and epiphytic microalga with a cosmopolitan distribution, so it is commonly found in the sub-habitat of water columns (Klein, 2017). As for Sempu Island, the highest relative abundance was observed from the genus *Pinnularia* (53.85%) in the sub-habitats of sediments and macroalgae, while *Cyclotella* (71.43%) and *Navicula* (53.85%) were detected in mangrove roots and water column sub-habitats, respectively. *Pinnularia* can live in waters with low or high nutrients, usually found in sediments or substrates containing moss, and cluster in distribution. This is reinforced by the study from Silva *et al.* (2016), who demonstrated that *Pinnularia* can live in oligotrophic waters, has low salinity and has low pH. On the other hand, the distribution of *Cyclotella* is influenced by the mixing in the waters, and these microalgae can usually be found in shallow waters. *Cyclotella* lives in both solitary and colonies, in fresh and coastal waters (Houk *et al.,* 2015). Meanwhile, *Navicula* is a microalga of the Bacillariophyceae class that can multiply rapidly, thus increasing its abundance. According to Vijver *et al.* (2011), the number of *Navicula* will be abundant and dominate as benthic diatom microalgae, particularly in areas with temperate and tropical climates.

Biological index

The calculation of the microalgae diversity index at Siwil Beach and Sempu Island resulted in various values. According to Farhadian *et al.* (2015), this diversity index is correlated with aquatic environmental conditions, in which when the diversity index is low, some species may be dominant in these waters. Based on the diversity index calculation results in both locations, it appeared that Siwil Beach had moderate microalgae community stability, and Sempu Island had moderate community stability except in the sub-habitats of sediments and mangrove roots. The diversity index, which has a value of less than three and more than one, could be interpreted to have a moderate level of stability in the biota community. Additionally, it could show that the quality of the waters is still relatively good for the growth of aquatic biota (Winahyu *et al.,* 2013). The results of the uniformity index values

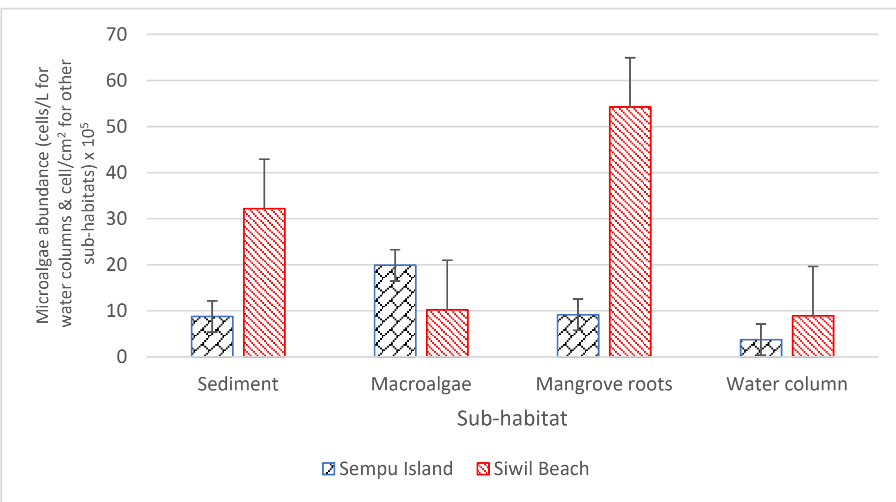

Fig. 3: Microalgae abundance at Siwil Beach and Sempu Island. Mean ± SE

found at Siwil Beach and Sempu Island showed values close to 1 and >0.5, indicating that the uniformity in these waters was in a balanced state, and there was no competition for food or living space (Fan *et al.,* 2021). In this study, Siwil Beach had a low dominance index, meaning no dominant species in the waters. A similar condition was also found in Sempu Island, with a dominance index value of <1. Hence, there was no dominance in the waters. According to Marsela *et al.* (2021), the dominance index ranges from 0 to 1, where a smaller value of the dominance index shows that no species dominates, while a higher value of the dominance index indicates the presence of a dominating species.

Water quality parameters

The water quality measurements (Table 1) in all sub-habitats revealed that the water quality at both Siwil Beach and Sempu Island were classified in good condition because it is still below the quality standard based on the Indonesian Government Regulation (Peraturan Pemerintah, 2021), and in these water conditions, microalgae can grow. This is indicated by the temperature that ranged from 20 to 30°C. Arsad *et al.* (2019) demonstrated that water temperature with more than 35°C could potentially kill microalgae. Moreover, the pH in this study ranged from 7 to 9, which is considered to be favourable (Nurhayati *et al.,* 2014). In addition, DO from the sampling sites were of >5 mg/L, which is still a good condition (Patty *et al.,* 2015). The lowest salinity level was detected around 35 ppm, whereas the normal and the highest values were 40 and 45 ppm, respectively (Altaee *et al.,* 2018). As for nitrate and phosphate, they ranged from 0.10 to 0.50 mg/L and from 0.002 to 0.050 mg/L, respectively (Patty *et al.,* 2015). In this study, the chlorophyll-a

Table 1: Water quality measurement results

Parameter	Siwil Beach (Sub-habitats of sediments and mangroves)				
	Site 1	Site 2	Site 3	Site 4	Peraturan Pemerintah, (2021)
Temperature (°C)	29.9	30.3	30.6	31.8	28-32
Transparency (cm)	23.35	32.85	25.55	32.05	> 5 m
pH	8	8.2	8.3	8.3	7-8.5
DO (mg/L)	8.5	8.8	7.5	7.5	>5
Nitrate (mg/L)	0.268	0.27	0.346	0.189	0.06
Phosphate (mg/L)	0.04	0.023	0.026	0.027	0.015
Salinity (‰)	35	40	40	41	34
Chlorophyll-a (mg/L)	2.035	2.921	2.889	5.317	-
Parameter	Siwil Beach (Sub-habitats of water columns and macroalgae)				
	Site 1	Site 2	Site 3	Site 4	Peraturan Pemerintah, (2021)
Temperature (°C)	30.2	29.6	31.6	30	28-32
Transparency (cm)	54.3	35.6	100	100	> 5 m
pH	8.2	8.2	8.4	8.4	7-8.5
DO (mg/L)	8	8.2	5.6	6	>5
Nitrate (mg/L)	0.288	0.323	0.238	0.174	0.06
Phosphate (mg/L)	0.038	0.019	0.04	0.02	0.015
Salinity (‰)	40	43	45	42	34
Chlorophyll-a (mg/L)	4.434	5.516	1.836	1.807	-
Parameter	Sempu Island (Sub-habitats of sediments, macroalgae, mangroves, and water columns)				
	Site 1	Site 2	Site 3	Site 4	Peraturan Pemerintah, (2021)
Temperature (°C)	29.2	29.2	32.5	32.6	28-32
Transparency (cm)	100	60	45	85	> 5 m
pH	8.2	8.1	8.1	8.2	7-8.5
DO (mg/L)	10.7	6.6	6.7	6.1	>5
Nitrate (mg/L)	0.203	0.325	0.214	0.203	0.06
Phosphate (mg/L)	0.036	0.037	0.032	0.024	0.015
Salinity (‰)	45	40	40	40	34
Chlorophyll-a (mg/L)	1.807	1.807	1.574	2.431	-

also correlated with the abundance of microalgae. A study conducted by Ratomski and Paw (2021) showed that there was a correlation between microalgae and chlorophyll-a, as this parameter could be determined by the biomass of microalgae in the water column. This result is also supported by Diana *et al.* (2021), suggesting that the availability of nutrients in the water column is positively related to the abundance of phytoplankton, which eventually will affect the level of chlorophyll-a in these waters.

The similarity of microalgae in different locations and sub-habitats

The nMDS method was used to analyse the proximity of the number of microalgae found in each sub-habitat in two locations, namely Sempu Island and Siwil Beach, which were grouped by class, namely Bacillariophyceae, Chlorophyceae and Cyanophyceae, and the results of measurements of environmental parameters, namely temperature, transparency, pH, DO, nitrate, phosphate, salinity and chlorophyll-a. The result of the nMDS analysis is presented in Fig. 4. From Fig. 4, the nMDS plot shows similarities between associated microalgal on Siwil Beach for sediment, mangrove, macroalgae and water column sub-habitat (SWL SD, SWL MG, SWL MK and SWL WC, respectively). Associated microalgal in Sempu Island for sediment, mangrove, macroalgae and water column sub-habitat was indicated by SMP SD, SMP MG, SMP MK and SMP WC, respectively. It appeared that the points in each sub-habitat at Siwil Beach and Sempu Island were far from each other and did not show the closeness between the points of Siwil Beach and Sempu Island. This result indicates that there was no similarity in the composition of microalgae found between Siwil Beach and Sempu Island, with a high variation of microalgae in both locations. This is presumably due to different characteristics and environmental conditions between Siwil Beach and Sempu Island, which can be proven by the measurements of water quality both sites; for example, Siwil Beach had a higher chlorophyll-a level than Sempu Island, resulting in the high abundance of microalgae. Additionally, vegetation density and current conditions at Siwil Beach were also higher than those in Sempu Island, so they have the potential to carry more nutrients to help microalgae growth. As demonstrated by Kramer (2015), nutrient concentrations in the waters will control the growth of microalgae. In contrast, low nitrate content may cause death to the microalgae. Moreover, according to Safi (2003), currents and waves could also affect the composition of microalgae that are more varied. The non-parametric analyses produced on the environmental parameters in nMDS revealed a positive close correlation between the DO, nitrate and phosphate parameters, where graphically, these three parameters produced an angle between vector lines that were close to each other. This result can be interpreted such that if DO value is high, then the value of nitrate and phosphate in the waters is also high. This is further supported by Yolanda *et al.* (2016), who demonstrated that there was a positive relationship between DO and nitrate, where the oxygen content could help the decomposition process of organic

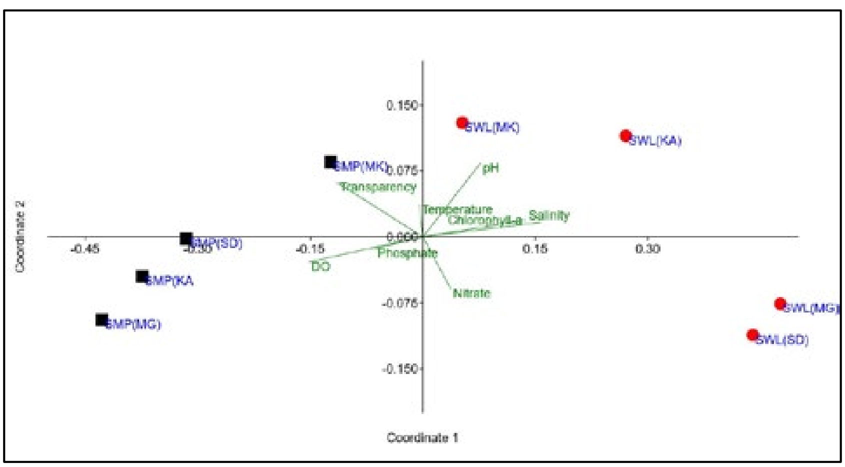

Fig. 4: nMDS analysis performance

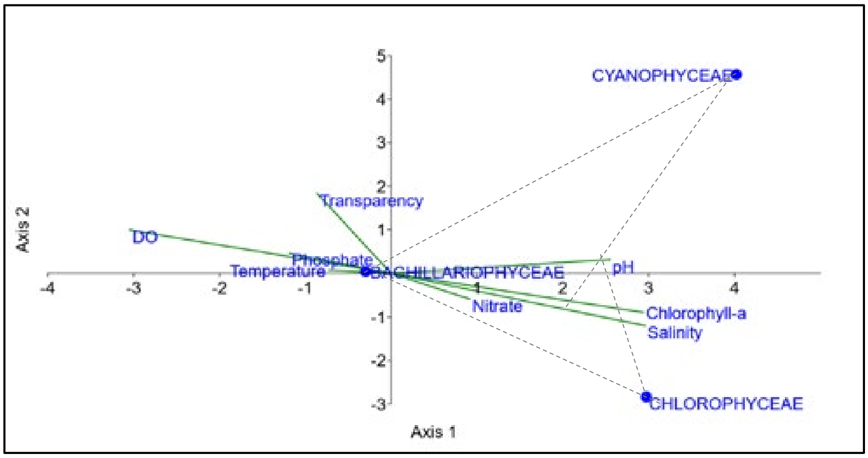

Fig. 5: CCA plot showing the relationship between the microalgal composition and environmental parameters

matter in the waters. The similar condition occurred for salinity, temperature, pH, chlorophyll-a, and transparency, where these environmental parameters formed an angle between vector lines that were close together. This means that if the salinity value is high, the pH, temperature and transparency values are also high.

Relationship of environmental parameters with microalgae distribution

In this study, the canonical correspondence analysis (CCA) was performed to determine the relationship between environmental parameters and the distribution of microalgae abundance (Fig. 5). The CCA analysis showed that the growth of Chlorophyceae and Cyanophyceae were positively correlated with the parameters of nitrate, pH, salinity and chlorophyll-a. This result is indicated by the projections of Chlorophyceae and Cyanophyceae, which were closer to the thick line on the nitrate parameter, pH, salinity and chlorophyll-a. Therefore, it can be assumed that the appearance of classes Chlorophyceae and Cyanophyceae is associated with high concentrations of nitrate, pH and salinity, and chlorophyll-a. This result is in accordance with Gardner *et al.* (2011), who demonstrated that an increase in nitrate will trigger an increase in pH as well as an increase in the photosynthesis process in Chlorophyceae and Cyanophyceae; hence, high abundance of Chlorophyceae and Cyanophyceae may increase chlorophyll-a (Kadim *et al.,* 2019). Additionally, Sari *et al.* (2019) also confirmed that nitrate plays an important role for the growth of plankton, especially in the class Cyanophyceae. The class Bacillariophyceae, on the other hand, is different from the classes Chlorophyceae and Cyanophyceae in terms of projection, where the class Bacillariophyceae was in the middle of the line. This indicates that the appearance of the class Bacillariophyceae is associated with all environmental parameters with moderate concentrations. The class Bacillariophyceae had a high abundance at Siwil Beach and Sempu Island, and this correlated with the measurement results of environmental parameters at Siwil Beach and Sempu Island, which were still classified as good waters for microalgae growth.

CONCLUSION

The present study demonstrated that the class Bacillariophyceae dominated the microalgae found in Siwil Beach and Sempu Island. At Siwil Beach, Cyanophyceae were found in sub-habitats of mangrove roots, macroalgae and the water column. Furthermore, microalgae from the class of Bacillariophyceae and Chlorophyceae were found in all sub-habitats; however, the numbers of Bacillariophyceae were greater than Chlorophyceae. Moreover, the microalgae found on Sempu Island in all sub-habitats were only from the Bacillariophyceae class, with the highest genus found in the sediment sub-habitat and the lowest genus found in the mangrove sub-habitat. Microalgae composition could be useful to determine ecosystem stability and water quality in these waters. In addition, by knowing the distribution of microalgae in an area, it can be used as a source of germplasm. Based on the results of the nMDS analysis, there is no similarity in the composition of microalgae species on Siwil Beach and Sempu Island: both had a high variation of microalgae. Different uses also cause differences in the distribution of microalgae. Siwil Beach is used as a shrimp pond and Sempu Island is used for tourism and fishing activities such as painting boats and cleaning fishing nets. Factors that mainly affected the abundance of microalgae were the environmental factors in each sub-habitat at both locations. Siwil Beach and Sempu Island water quality was relatively still under the Indonesian national quality standard for seawater. Nevertheless, microalgae found on both sites were dominated from the class of Bacillariophyceae; thus, the water quality at Siwil Beach and Sempu Island has the potential to be poor. This research is thought to be the first step in exploring the diversity of microalgae in several sub-habitats in East Java, Indonesia, and linking the type and availability of microalgae found in various sub-habitats with environmental water quality parameters and human activities around the waters. In addition, this study provides the database information about the diversity of microalgae in Siwil Beach and Sempu Island in several sub-habitats including sediment, macroalgae, mangrove roots and water column in the southern part of East Java Indonesia. Next, phylogeny analysis needs to be carried out using molecular biology for microalgae found in several sub-habitats in Indonesia.

AUTHOR CONTRIBUTIONS

S. Arsad initiated the study design, prepared and edited the manuscript preparation, and provided the literature research. Y.W. Mulasari worked on data collection, statistical analyses, literature research and manuscript preparation. N.Y. Sari focused on data collection, statistical analyses, literature research and manuscript preparation. E.D. Lusiana prepared the statistical analyses. Y. Risjani interpretated the data. M. Musa participated on data interpretation. M. Mahmudi prepared the statistical analyses. F.S. Prasetiya performed the English grammatical correction. L.A. Sari performed the critical review of the manuscript.

ACKNOWLEDGEMENT

This study was financially supported by the Faculty of Fisheries and Marine Sciences through the Non-Tax State Revenue Fund (PNBP) Universitas Brawijaya Number: [DIPA-023.17.2.677512/2021], with the contract number: [54/UN10.F06.06/2021].

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

ABBREVIATIONS

%	Per cent
°C	Degree Celsius
‰	Per Mille
mm	Micro meter
CCA	Canonical correspondence analysis
cell/L	Cell per litre
cell/cm²	Cell per square centimetre
cm	Centimetre

cm^2	Square centimetre
DO	Dissolved oxygen
E	East longitude
et al.,	And others
Fig.	Figure
L	Litre
m	Meter
mg/L	Milligram per Litre
ml	Millilitre
nMDS	non-metric multidimensional scaling
PAST	Paleontological Statistics
pH	Power of hydrogen
PP	Peraturan Pemerintah (Government regulation)
ppm	Part per Million
S	South latitude
SD	Standard deviation
SE	Standard error
SMP SD	Sempu sediment
SMP MG	Sempu mangrove
SMP MK	Sempu macroalgae
SMP WC	Sempu water column
SWL SD	Siwil sediment
SWL MG	Siwil mangrove
SWL MK	Siwil macroalgae
SWL WC	Siwil water column

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HOW TO CITE THIS ARTICLE

Arsad, S.; Mulasari, Y.W.; Sari, N.Y.; Lusiana, E.D.; Risjani, Y.; Musa, M.; Mahmudi, M.; Prasetiya, F.S.; Sari, L.A. (2022). Microalgae diversity in several different sub-habitats. Global J. Environ. Sci. Manage., 8(4): 561-574.

DOI: 10.22034/gjesm.2022.04.08

url: https://www.gjesm.net/article_249637.html