BIODIVERSITAS
Volume 24, Number 8, August 2023
Pages: 4418-4426

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240823

Microalgae diversity in varying habitat characteristics in Pasuruan and Sidoarjo coastal areas, East Java, Indonesia

MOHAMMAD MAHMUDI[1,2,♥], SULASTRI ARSAD[3,♥♥], EVELLIN DEWI LUSIANA[1,2,4], MUHAMMAD MUSA[1,2,4], FIKA FITRIANESIA[1], SAFRIZAL FIKRI RAMADHAN[1], ABDUR RAHMAN ARIF[1], FRIZCA RANIA SAVITRI[1], ADELITA ASMO DEWINTA[1], ANINDYA DIVANATA ONGKOSONGO[1]

[1]Study Program of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia. Tel.: +62-341-553512, Fax.: +62-341-556837, ♥email: mudi@ub.ac.id
[2]AquaRES Research Group, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia
[3]Institute of Marine and Environmental Sciences, University of Szczecin. Mickiewicza 16a, 70-383 Szczecin, Poland.
♥♥email: sulastri.arsad@phd.usz.edu.pl
[4]MicroBASE Research Group, Post-graduate program, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia.

Manuscript received: 15 December 2022. Revision accepted: 23 August 2023.

Abstract. *Mahmudi M, Arsad S, Lusiana ED, Musa M, Fitrianesia F, Ramadhan SF, Arif AR, Savitri FR, Dewinta AA, Ongkosongo AD. 2023. Microalgae diversity in varying habitat characteristics in Pasuruan and Sidoarjo coastal areas, East Java, Indonesia. Biodiversitas 24: 4418-4426.* Microalgae are microscopic eukaryotic organisms which live in various types of habitats. The purpose of this study was to identify the types and the abundance of microalgae in several sub-habitats, including sediments, mangroves, water columns, and artificial substrates; and to analyze the environmental factors that affect the abundance of microalgae. The research was conducted in several sites in the coastal areas in Pasuruan and Sidoarjo, East Java, Indonesia. A quantitative descriptive method was applied with data collection used a purposive sampling method. Samples were collected using net for planktonic microalgae and using sampling plot for epiphytic and benthic microalgae. The microalgae were grouped using NMDS (non-metric multidimensional scaling) and the relationships between microalgae abundance and water quality parameters were analyzed using CCA (canonical correspondence analysis). The results show that Bacillariophyceae, Cyanophyceae, and Chlorophyceae classes were found in all study sites, but Trebouxiophyceae and Dinophyceae were only found in Pasuruan Beach. The highest abundance of microalgae was found in sediment habitat in Wughoyo Beach, Sidoarjo with 706,605 ind. cm^{-2}. The diversity, the evenness, and the dominance index in both coastal areas ranged from 1.43-2.61; 0.71-0.96; and 0.06-0.27, respectively. Similarity analysis using the NMDS showed that there was no similarity among the three sites, suggesting each site had high microalgal variation. The CCA analysis showed that Bacillariophyceae were found in all sites, indicating its high adaptability. The results of this analysis imply that particular habitat has a unique microalgae diversity, thus preserving diverse habitat types is important.

Keywords: Benthic, biodiversity, diatoms, phycology, planktonic, tropical waters

INTRODUCTION

Microalgae are eukaryotic microorganisms that can be found in various aquatic habitats with sufficient sunlight (Sari et al. 2019a; Liao et al. 2020). As cosmopolitan organism, microalgae can live in freshwater, brackish water, and marine water. They usually live on the water surface, water columns, and the bottom of the waters and various substrates, ranging from hard to smooth substrates, artificial substrates, and mangroves (Zakiyah et al. 2020; Arsad et al. 2022). Some microalgae are sedentary by attaching to the rocks and either sensitive or tolerance to water pollution (Tang 2022). Benthic microalgae which live in sediment including epipelic diatoms (Vernanda et al. 2022).

Microalgae play an important role in aquatic ecosystem as the primary producers and serve as the main link in the food chain (Sari et al. 2019b; Nava and Leoni 2021). The ability to do photosynthesis makes microalgae as the primary supplier of dissolved oxygen in the water. Furthermore, microalgae can be used as a bioindicator to assess the environmental health status (O'Neill 2022). This organism also contains pigments which can benefit human, such as being utilized for natural feed, bio-chemical industries, biofuel, and cosmetics (Rizwan et al. 2018). Also, some species of microalgae with a high content of protein, carbohydrates, and lipids have great potential to be developed for additional food supplement, owing to their high concentrations of nutrients and phytochemicals. Moreover, various studies showed that microalgae can also be developed for cosmetics purpose because of their bioactive components. The active compounds extracted from microalgae, including chlorophyll, canthaxanthin, cryptoxanthin, phycocyanin, lycopene and vitamin E, can be explored to improve the structure and appearance of facial skin in humans (Mourella et al. 2017).

The abundance and distribution of microalgae are highly affected by the environmental conditions including the biotic and abiotic components of the waters (Lauritano et al. 2020; Firmaningrum et al. 2021). The environmental status of water quality can be determined by calculating the diversity index, evenness index, and dominance index of microalgae (Arsad et al. 2019).

Indonesia is a tropical maritime country with abundant sunlight, making it have a great diversity of microalgae. Several studies on microalgae have been conducted in various marine areas in Indonesia. In East Java, several studies on microalgae have been carried out in Sempu Island and Siwil Beach Pacitan (Arsad et al. 2022), Probolinggo and Situbondo (unpublished data), Trenggalek and Sendangbiru (south coast), Banyuwangi and Situbondo (north coast of East Java), and Pasongsongan and Pamekasan Madura (north and south coast) (Zakiyah et al. 2020). In addition, Nafisyah et al. (2018) carried out research in mangrove sediments in Probolinggo and found Cryptic occurrence of *Chattonella marina* var. *marina*. Other studies on marine microalgae have 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; Tambaru 2022), Simeulue Island (Purbani et al. 2021), and Tambrauw sea West Papua (Purbani et al. 2019).

Various studies on microalgae in East Java Indonesia have been carried out. However, there is limited understanding on how environmental conditions and habitat characteristics affect the diversity of epiphytic, benthic, and planktonic microalgae in the coastal ecosystem. Therefore, this study aimed to identify the diversity and abundance of microalgae in the beaches in Pasuruan and Sidoarjo, East Java in varying habitats (i.e., sediment, mangroves, water columns, and artificial substrates), and to analyze environmental factors that affect the abundance of microalgae on these substrates. In doing so, we collect data on environmental factors and microalgae to measure their abundance, relative abundance, diversity index, evenness index, and dominance index. We expected that the results of this study might be useful to reveal the biodiversity and composition of microalgae based on their habitats, and to understand the relationship between microalgae and environmental conditions.

MATERIALS AND METHODS

Study area and period

The research was carried out from May to June 2022. This research was conducted in two regencies, i.e. Pasuruan and Sidoarjo, located in East Java, Indonesia (Figure 1). The sampling sites were Penunggul Beach (7°42'10.8"S 113°05'24.9"E), Watuprapat Beach (7°40'13.51"S 113° 3'55.82"E), and Pasir Panjang Beach (7°39'9.34"S 113° 2'28.62"E) for the Pasuruan area; and Lusi Island (7°34'24.1"S 112°52'49.7"E), Ketingan Beach, (7°48’01.2”S 112°832’73.9”E) and Wughoyo Beach (7°24’40.8” S 112°49’26.6”E) for the Sidoarjo area. The three sampling sites in each regency were selected to represent varying aquatic environments. The characteristics of the research location in Pasuruan Regency, especially Penunggul Beach, are tourist areas that have mangrove forest and muddy sediment types. Watuprapat Beach is close to residential area and fishing port; it has only a small extent of mangroves; the water colour is cloudy green; and the type of bottom substrate is sandy sediment. Pasir Panjang Beach is adjacent to residential area, there is no mangroves, and it has rocky sediment types. On the other side, the study sites in Sidoarjo Regency also have its own characteristics. Lusi Island is an artificial island that is located at the mouth of a river, has a dense mangrove vegetation, and has a type of muddy sediment. Lusi Island is an artificial island formed by the mud sediments of Lapindo dredging and has an extensive mangrove forest with 94 ha (Rahmadani and Kuntjoro 2020). Ketingan Beach is also located at the end of a river mouth, has a large extent of mangrove area, and has a type of muddy sediment. Wughoyo Beach is a coastal area dominated by ponds, close to settlements, has dense mangrove forests, and has a type of muddy sediment.

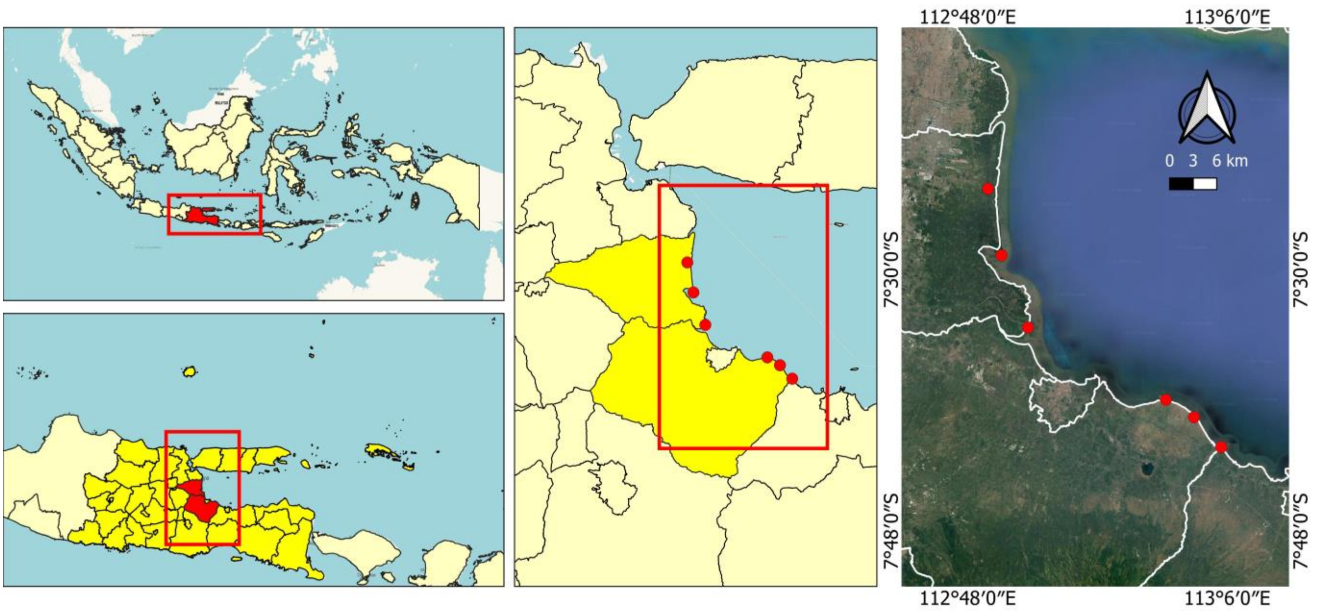

Figure 1. Research location map of microalgae diversity in Sidoarjo and Pasuruan, East Java, Indonesia

Sampling of microalgae in the water column and sediment was carried out at all locations. However, samples of microalgae in mangroves were only carried out on all sites in Sidoarjo and Penunggul Beach, Pasuruan. In addition, samples of microalgae on artificial substrates were also only carried out at Penunggul Beach. Samples from artificial substrates were taken from bridge foundations made of wood and concrete, which functions as a barrier between land and water. This location is the only area which has mangrove vegetation and artificial substrate in the Pasuruan coastal area.

Data collection procedure

Collection of samples

The research used a quantitative descriptive approach with data collection used a purposive sampling technique by collecting data directly at the research location. In terms of sampling, the strategy for selecting sampling sites should be integrated into the overall logic of any study (Campbell et al. 2020). Sampling epiphytic microalgae were conducted at low tide (6 am local time). At high tide, beginning at 7 am local time, water quality measurements and water column sampling were also done. Sampling was carried out twice, with three sampling points at each site. Samples of microalgae were taken from various habitats and analyzed *ex-situ*. However, the water quality parameters were measured both *in-situ* (temperature, transparency, current, depth, DO, pH, salinity) and *ex situ* (nitrate, orthophosphate, chlorophyll-a).

Sampling of microalgae in sediments was taken within a 5x5 cm^2 plot to a depth of 1 cm using a spoon and stored in a 100 mL bottle (Nindarwi et al. 2019). Sampling microalgae from mangrove roots was done within a 5x5 cm^2 plot using a sharp knife and stored in a 100 mL plastic bottle (Wahyudi et al. 2017). Sampling of microalgae in the water columns was carried out by filtering 25 liters of water using a plankton net with a mesh size of 150 microns at each sampling site (Triawan and Arisandi 2020). The samples were then put into a 100 mL bottle and preserved with Lugol's with a concentration of 1%, as much as 2 drops, or approximately 0.1 mL. Samples were then transported to the Hydrobiology Laboratory, Universitas Brawijaya, Malang for further analysis.

Identification and calculation of microalgae

Microalgae were observed using a light microscope (Olympus CX21) with a magnification of x100 and x400. The calculation of microalgae abundance in sediments, mangroves, and artificial substrates followed the formula from APHA (2005). Meanwhile, the calculation of the abundance of microalgae in the water column used the APHA (1989). The relative abundance of microalgae was calculated (Salahi et al. 2017) as well as diversity index (Sournia 1978), evenness index (Sournia 1978) and dominance index (Ludwig and Reynold 1988).

Measurement of water quality parameters

Water quality as supporting parameters was measured in the sampling locations. The observed variables were temperature (Thermometer Hg), current velocity (Current Meter Tatonas Tipe TH-02.), pH (pH meter Krisbow Type KW 06-744), transparency (Secchi disc, Fadliyah et al. 2021), salinity (Refractometer Atago Tipe PAL-06S), and dissolved oxygen (DO Meter Lutron DO-5509). In addition, the analysis of chlorophyll-a, nitrate, and ortho-phosphate used Spectrophotometer Genesys 10 UV-Vis.

Data analysis

The data obtained were processed using Microsoft Excel 2016 and analyzed using non-metric multidimensional scaling (NMDS) and Canonical Correspondence Analysis (CCA) to investigate the correlation between water quality parameters with microalgae abundance using PAST 4.10 software.

RESULTS AND DISCUSSION

Types and abundance of microalgae in Sidoarjo and Pasuruan beaches

Composition and type of microalgae

The composition of microalgae from all habitats in Pasuruan consisted of five (5) classes of microalgae, namely Bacillariophyceae (20 genera), Cyanophyceae (2 genera), Chlorophyceae (8 genera), Dinophyceae (1 genus), and Trebouxiophyceae (2 genera). Microalgae composition in Penunggul Beach was higher in term of genera than that in Watuprapat and Pasir Panjang Beach. The composition of microalgae found in Penunggul Beach was Bacillariophyceae (18 genera), Cyanophyceae (2 genera), Chlorophyceae (8 genera), Dinophyceae (1 genus), and Trebouxiophyceae (2 genera), while in Watuprapat Beach was Bacillariophyceae (17 genera), Cyanophyceae (2 genera), and Chlorophyceae (5 genera), and in Pasir Panjang Beach was Bacillariophyceae (14 genera), Cyanophyceae (2 genera), Chlorophyceae (4 genera), and Dinophyceae (1 genus). In percentage, the composition of genera of microalgae in Penunggul Beach was 40%, Watuprapat Beach was 30%, and Pasir Panjang Beach was 30%.

On the other site, the composition of microalgae from all habitats in Sidoarjo consisted of three (3) classes of microalgae, including Bacillariophyceae (24 genera), Cyanophyceae (4 genera) and Chlorophyceae (4 genera). The number of genera found in Wughoyo Beach was higher than that in Lusi Island and Ketingan Beach. The overgrown mangrove trees and the environmental parameters including water quality allows the condition of the surrounding waters to be better maintained and have a high nutrient content.

The types of microalgae found both in Pasuruan and Sidoarjo indicated that Bacillariophyceae class is more common than other classes such as Cyanophyceae, Chlorophyceae, Dinophyceae, and Trebouxiophyceae. The Bacillariophyceae is a group of algae which are often found in all types of aquatic environments both as plankton and periphyton (Roshith 2018). These organisms easily adapt and tolerate to environmental changes (Marella et al. 2020) and make the best possible use of nutrients for their growth (Jin and Agusti 2018; Arsad et al. 2022). Diatoms have a strong cell wall structure in silica, making it survive in extreme conditions and have high reproductive capacity

(Kale and Karthick 2015). Additionally, diatoms can attach to the substrate in the form of a gelatinous stalk so that they can adapt to strong to slow currents (Li et al. 2018).

Microalgae found in Pasuruan and Sidoarjo coastal areas consisted of *Achanantes, Actinastrum, Amphipora, Amphora, Aulacoseira, Bacilaria, Bacullaria, Biddulphia, Chaetoceros, Chloroccoum, Cladophora, Clasteroiopsis, Cocconeis, Coelastrum, Cycotella, Diploneis, Eucampia, Fragilaria, Gleoocytis, Grammatophora, Gyrosigma, Hemialus, Hylotheca, Istmia, Lauderia, Leptocylindrus, Lyngbya, Melosira, Mougeotia, Navicula, Nitzchia, Oedogonium, Oscillatoria, Peridinium, Phormidium, Pinnularia, Pleurosigma, Rhizosolenia, Scenedesmus, Skeletonema, Spirulina, Synedra, Tetrahedron, Thalassionema, Triceratium,* and *Ulotrix*.

Microalgae abundance

The highest microalgae abundance was found in the sediment of both Penunggul Beach (Pasuruan) and Wughoyo Beach (Sidoarjo) with 69,590 ind. cm^{-2} and 706,605 ind. cm^{-2}, respectively (Table 1). Muddy substrate in the sediment has a finer particle size, making it has a higher organic matter since small particles have a higher ability to trap organic matter than large particles (Sitindoan et al. 2020). The abundance of benthic microalgae can be affected by the type of sediment and the quality of the water (Beni et al. 2020). The lowest abundance of microalgae in Pasuruan was found in Pasir Panjang in the habitat of water column with 4,701 ind. cm^{-2}. On the other hand, the lowest abundance in Sidoarjo coast was found in Lusi Island (8,441 ind. cm^{-2}).

The abundance of microalgae is influenced by the characteristics of each habitat. Microalgae that live in the water column are strongly influenced by factors such as currents, tides, and temperature. Furthermore, the substrate influences the types of microalgae that live on the bottom of the water (Sitindoan 2020). Meanwhile, microalgae found in mangrove roots can be influenced by soil texture, soil pH, and salinity (Kasang et al. 2016). The low abundance of microalgae can be caused by the season, when during the rainy season, nutrient contents are low, resulting in low abundance of microalgae (Gurning et al. 2020).

The most abundance genus found was *Istmia* with relative abundance of 9.6-16.5%, followed by *Nitzchia* (7.9-24.2%), *Rhizosolenia* (9.1-16.8%), and *Chaetoceros* (3.3-15.3%). *Isthmia* has a high level of resistance to organic matter making this genus can optimally utilize organic matter in the water under any conditions in its environment (Rasmiati et al. 2017). The domination of *Nitzschia* is because it has a high tolerance and adaptability to a broad range of conditions even in polluted environments (Siregar et al. 2014). *Rhizosolenia* genus can tolerate a broad range of environmental changes such as temperature, salinity, and pH to live in various environmental conditions (Lim et al. 2017). Furthermore, *Chaetoceros* can be found in almost all waters and serve as fish feed, and due to its fast growth, this genus is reported to be tolerant on the high temperatures around 33-35°C and a salinity range at above 20 ppt (Minggat et al. 2021).

Biological index

The analysis results showed that the diversity index of microalgae in Pasuruan and Sidoarjo beaches ranged from 1.43 to 2.61. The highest index was in the sediment habitat of Penunggul Beach Pasuruan (2.61), while the lowest was in Lusi Island Sidoarjo (1.43). The diversity index ranging from 1 to 3 indicates moderate diversity, suggesting the moderate distribution of individuals and community stability. Diversity index of higher than 3 indicates that the condition of an area experiences low ecological pressure, high species diversity, high individual distribution, and community stability (Singh and Saxena 2015).

The evenness index of microalgae in Pasuruan and Sidoarjo beaches ranged between 0.71 and 0.96. The highest value was in Penunggul Beach Pasuruan with 0.96, while the lowest was in Wughoyo Beach Sidoarjo with 0.71. The evenness index between 0.5 and 1 indicates a balance state, suggesting no competition for space, nutrients and other resources (Rösch et al. 2019; Sumiarsih et al. 2020). The evenness index closes to 1 show that the distribution of individuals across species is even (Ulfah et al. 2019). Conversely, the evenness index close to 0 implies an uneven distribution of individuals across species or a dominance of certain species groups, possibly due to environmental pressure (Arsad et al. 2021). Based on the results, the evenness index obtained in Sidoarjo and Pasuruan beaches presented a balanced evenness value.

The dominance index of microalgae in Pasuruan and Sidoarjo beaches ranged from 0.06 to 0.27. The highest dominance index was in Lusi Island Sidoarjo with of 0.27, while the lowest index was in Penunggul Beach Pasuruan with 0.06. The dominance index closes to 1 means a domination of particular species (Sanz et al. 2017), while the dominance index closes to 0 signifies there is no dominance species (Sandeep 2019). Thus, the results of this study indicate that there is no single dominant species both in Pasuruan and Sidoarjo coastal areas.

Table 1. Microalgae abundance in various habitats of several beaches in Pasuruan and Sidoarjo, East Java, Indonesia

Habitat	Pasuruan Beach			Sidoarjo Beach		
	Penunggul Beach	Watuprapat Beach	Pasir Panjang Beach	Lusi Island	Ketingan Beach	Wughoyo Beach
Water column (mg. L^{-1})	6,726	5,010	4,701	8,441	25,118	58,226
Sediment (ind. cm^{-2})	69,590	65,472	48,589	370,597	511,424	706,605
Mangrove roots (ind. cm^{-2})	36,236	-	-	224,829	321,184	649,781
Artificial substrate (ind. cm^{-2})	32,633	-	-	-	-	-

Water quality analysis

Tides affect the distribution of microalgae communities due to changes in salinity, habitat conditions, and the distribution of nutrients (Lee et al. 2020). Temperature plays in important role in the life of microalgae because it can affect the composition, abundance, and the distribution of microalgae (Lauritano et al. 2020). The optimal temperature range for the growth and reproduction of microalgae is 20-30°C (Selviana et al. 2021). The results of this study indicates that most of the studied sites in Pasuruan show optimal temperature, while sites in Sidoarjo have temperature exceeding the optimum limit (Table 2).

Depth is one aspect that can affect the transparency of the waters, eventually affecting the intensity of sunlight penetrating the waters. The greater the depth, the smaller the amount of light intensity that penetrates the water's column, which might cause the number of microalgae lower (Siregar et al. 2014). Transparency has an important role for the growth and the development of microalgae because sunlight is used by microalgae to carry out photosynthesis (Xie et al. 2022). The optimum depth for phytoplankton to carry out photosynthesis in the water ranges from 5-20 m (Renny et al. 2016). Transparency value of >45 cm is considered good for the survival of aquatic organisms such as microalgae (Gurning et al. 2020).

According to Zhang et al. (2015), mangroves can reduce current strength and wave energy due to their root system and stems. Large currents can cause microalgae to be carried away (Bhushan et al. 2020). Slow currents are a suitable habitat for microalgae (Dayana et al. 2022). Currents that are too strong above 0.5 m. s^{-1} can disrupt the ecological balance of the waters that have been formed (Ravindran 2016). This is because currents contribute to benthic microalgae's spread and horizontal migration (Rizadha 2018).

The optimal salinity range for microalgae is 25-34 ppt (Aulia et al. 2021). The level of salinity can be affected by the layers of waters (Sohrabi et al. 2017). Also, the density of seawater, which has high salinity is heavier than that of freshwater (Arora et al. 2017). Thus, the deeper the waters, the higher the salinity of the waters. Salinity has a role in the ability of microalgae to maintain osmotic pressure between the protoplasm of cells and water in the surrounding waters (Mohrholz et al. 2015).

Dissolved oxygen (DO) is influenced by organic matter. The higher the organic matter, the lower the dissolved oxygen content in the waters (Dayana et al. 2022). DO concentration in waters is also affected by the presence of waste such as plastic, leaves, and branches (Paris et al. 2022). The optimal DO value for the growth of microalgae in waters according to Patty (2013) is ≥5 ppm.

The pH value can affect the presence of microalgae. Absorption of free CO2 and bicarbonate by microalgae causes a decrease in dissolved CO2 concentration and increases pH. The optimal pH range for biota life in the waters, especially microalgae is around 6-8 (Zhu 2015).

Phosphorus compounds bound in sediments can undergo decomposition by bacteria or through abiotic processes to form dissolved phosphate, which diffuse back to the water column (Patty et al. 2015). Orthophosphate is used for the formation of microalgae cells. According to Schilling et al. (2018), orthophosphate concentration is higher in the deep zone or water close to land. According to Hawrot-Paw et al. (2019), orthophosphate becomes a limiting factor for microalgae and can affect the level of productivity in water. Optimum orthophosphate for microalgae, according to Sidabutar et al. (2016), ranges from 0.09-1.08 mg. L^{-1}.

Nitrate as a nutrient has an important role in the growth of organisms, including in microalgae, to be processed in photosynthesis and is needed in the metabolic processes for their survival (Mahmudi et al. 2020). According to Rizqina et al. (2017), normal nitrate levels in seawater range from 0.01-50 μg. L^{-1} or equivalent to 0.00014-0.7 mg. L^{-1}. Chlorophyll-a has an important role in the process of photosynthesis of microalgae and can be used as an indicator to determine the level of primary productivity in waters (Hughes et al. 2018). The low concentration of chlorophyll-a on the coast results in a lack of supply of N and P nutrients (Suryoputro et al. 2023). Related to chlorophyll content in water, according to Gunawan et al. (2019), water is categorized as high supply of N and P nutrients waters if it has a chlorophyll-a value of >30 mg. m^{-3}.

Table 2. Water quality parameters in several beaches in Pasuruan and Sidoarjo, East Java, Indonesia

Parameter	Pasuruan			Sidoarjo			References
	Penunggul Beach	**Watuprapat Beach**	**Pasir Panjang Beach**	**Lusi Island**	**Ketingan Beach**	**Wughoyo Beach**	
Temp. (°C)	30.5-32	30-32.4	28.5-33.8	26.4-30.4	32.1-34.6	34.9-41.6	20-30 °C (Selviana et al. 2021)
Depth (cm)	94-130	90-120	104-118	51-95	49-73	65-95	-
Transparency (cm)	27.5-38	27-38	24-35	23-34.5	24.5-42.5	17.5-45	>45 cm (Gurning et al. 2020
Current (m. s^{-1})	0.03-0.05	0.06-0.07	0.06-0.7	0.01-0.03	0.02-0.05	0.05-0.08	>0.5 m s^{-1} [strong] (Rizadha 2018)
Salinity (ppt)	29-31	27-32	31-33	0-1	16-17	16-30	25-34 ppt (Aulia et al. 2021)
DO (ppm)	6.6-8.3	7.1-8.2	7.9-8.7	7.6-10.8	7-8.3	7.6-8.9	>5 ppm (Patty 2013).
pH	6.6-7.2	7-7.5	7-7.7	8-8.2	7-7.8	7.8-9	6-8 (Zhu 2015)
Orthophosphate (mg. L^{-1})	0.04-0.07	0.03-0.05	0.02-0.04	0.12-0.21	0.10-0.18	0.03-0.10	0.015 mg. L^{-1} (Rizqina et al. 2017)
Nitrate (mg. L^{-1})	0.32-0.77	0.20-0.50	0.21-0.40	0.61-0.97	0.33-0.67	0.24-0.54	0.00014-0.7 mg. L^{-1} (Rizqina et al. 2017)
Chlorophyll-a (mg. m^{-3})	10.3 - 20.3	5.1-13.7	1.6-8.9	1.6-6.4	6.1-27.7	25.6-66.9	> 15 mg. m^{-3} (Gunawan et al. 2019)

Microalgae grouping and its relationships with environment

Non-metric multidimensional scaling (NMDS)

NMDS was applied to find similarity among microalgae classes and to group them. The classes analyzes included Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dinophyceae, and Trebouxiophyceae found at each study site. Based on the NMDS results as presented in Figure 2, the Bacillariophyceae and Cyanophyceae classes are in the middle, indicating that these classes are evenly distributed in each study sites, especially in Watuprapat Beach and Penunggul Beach Pasuruan. The Dinophyceae class was only found in Penunggul and Pasir Panjang beach sediment. Trebouxiophyceae class was only found in Penunggul Beach in the mangroves and artificial substrates. Meanwhile, the Chlorophyceae class was found in Penunggul Beach in the water column and Lusi Island in the sediment.

The presence of microalgae in the waters is influenced by environmental factors suitable to the needs of microalgae to support their life. According to Righetti et al. (2020), the Bacillariophyceae class predominates aquatic ecosystems and is found in various habitats but tends to be found more in oceans and coastal areas. According to Rizqina et al. (2017), the Dinophyceae class is the least frequently found microalgae because it has a slower reproduction than other classes.

The relationship between environmental factors and microalgae

The Canonical Correspondence Analysis (CCA) method was used to see the relationship between environmental factors (i.e., water quality parameters) and the variations of microalgae grouped by class as analyzed above, which included Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dinophyceae, and Trebouxiophyceae groups. Based on the CCA triplot analysis results as presented in Figure 3, Bacillariophyceae and Cyanophyceae classes have a good association with all parameters. This is likely because microalgae from these two classes are known to have very good adaptability to a broad range of environmental conditions.

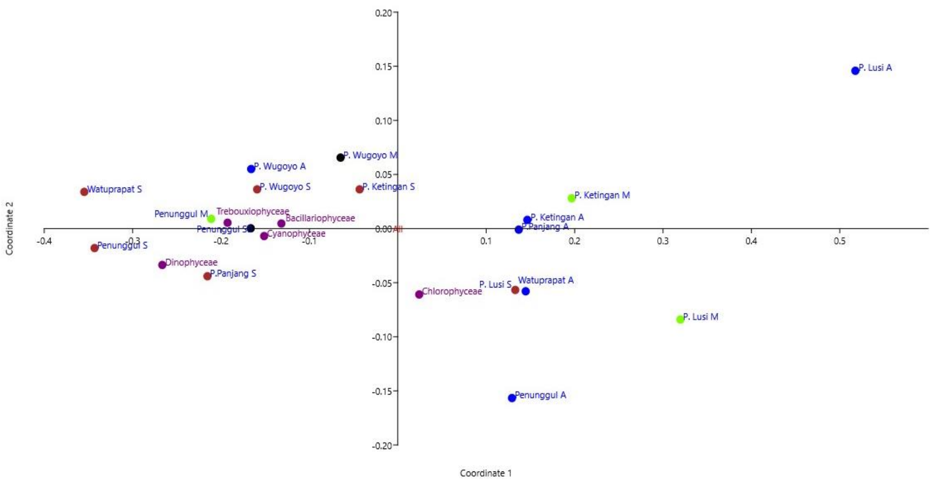

Figure 2. Results of NMDS analysis to group microalgae based on class. Notes: P = beach/island; A = water column; S = sediments; M = mangrove; SB = artificial substrate

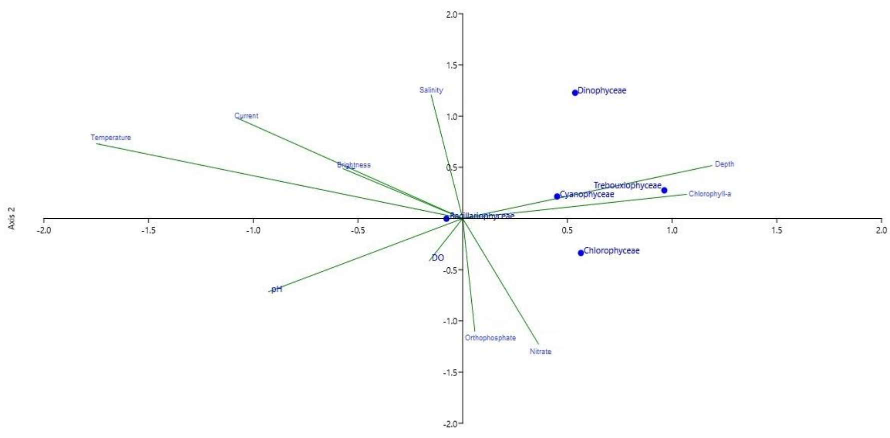

Figure 3. Results of Canonical Correspondence Analysis (CCA) to investigate the relationship between water quality parameters and microalgae group

According to Ameilda et al. (2016), Bacillariophyceae can tolerate changes in the environment; therefore, the types and numbers of this class dominate the waters. Cyanophyceae is found in waters with high concentrations of nitrate, chlorophyll-a, and orthophosphate (Nasution et al. 2019). Cyanophyceae can grow on rocks and warm waters rich in organic matter. The dominance of phytoplankton from Cyanophyceae is caused by the influence of eutrophic water conditions with high nutrient concentrations. This is in line with the principal component analysis results, which show that Cyanophyceae is affected by orthophosphate and nitrate concentrations (Rahman et al. 2016). Furthermore, Chlorophyta such as Trebouxiophyceae and Chlorophyceae tend to have a positive correlation with nitrate concentration and depth. This is in accordance with a study by Simmonds et al. (2015), which found that phytoplankton in Chlorophyceae, which receives sunlight radiation will passively migrate vertically based on the time of day from morning to evening and night. At noon, the concentration of phytoplankton is higher in areas slightly below the water surface because there is turbulence which can lead to higher levels of nutrients.

In conclusion, the current study depicted that Bacillaripophycae class dominated the microalgae found in all areas in both Pasuruan and Sidoarjo. Furthermore, the highest microalgae abundance was found in the sediment of both Penunggul Beach Pasuruan and Wughoyo Beach Sidoarjo. However, the lowest abundance of microalgae found in the water column in Pasir Panjang Pasuruan and Lusi Island Sidoarjo. Moreover, NMDS and CCA analysis shows that Bacillariophyceae and Cyanophyceae classes are evenly distributed in each study site and have a good association with all parameters consecutively. In general, this study provided the database of microalgae from several habitats in Pasuruan and Sidoarjo as well as linking their relationship to environmental condition. Future research recommends isolating the microalgae and conducting biomolecular studies, especially for the diatoms that could be potentially new to science.

ACKNOWLEDGEMENTS

The researchers would like to thank the Faculty of Fisheries and Marine Sciences, Universitas Brawijaya for the funding through the Associate Professor Grant (HLK) of the Faculty of Fisheries and Marine Sciences through Community Funds DPA (Budget Execution Document) PTNBH (State University with Legal Entity) Universitas Brawijaya Number: 2345/UN10.F06 /PP/2022.

REFERENCES

Ameilda CH, Dewiyanti I, Octavina C. 2016. Community structure in macroalgae *Ulva lactuca* perifiton in Coastal Waters Ulee Lheue. Banda Aceh. J Ilmiah Mahasiswa Kelautan dan Perikanan Unsyiah 1 (3): 337-347. [Indonesian]

American Public Health Association (APHA). 1989. Standard methods for the examination of water and wastewater. American Public Control Federation. 20th edition, Washington DC. American Public Health Association.

American Public Health Association (APHA). 2005. Standard Method for The Examination of Water and Wastewater. 16th Edition, Washington DC. 1202 p.

Arora N, Patel A, Sharma M, Mehtani J, Pruthi PA, Pruthi V, Poluri KM. 2017. Insights into the enhanced lipid production characteristics of a freshwater microalga under high salinity conditions. Indones Eng Chem Res 56 (25): 7413-7421. DOI: 10.1021/acs.iecr.7b00841.

Arsad S, Mulasari YW, Sari NY, Lusiana ED, Risjani Y, Musa M, Sari LA, Prasetiya FS. 2022. Microalgae diversity in several different sub-habitats. Glob J Environ Sci Manag 8 (4): 561-574. DOI: 0.22034/GJESM.2022.04.08.

Arsad S, Putra KT, Latifah N, Kadim MK, Musa M. 2021. Epiphytic microalgae community as aquatic bioindicator in Brantas River. East Java. Indonesia. Biodiversitas 22 (7): 2961-2971. DOI: 10.13057/biodiv/d220749.

Arsad S, Zsalzsabil NAN, Prasetiya FS, Safitri I, Saputra DK, Musa M. 2019. Microalga periphyton community on different substrates and its role as aquatic environmental bioindicator. Saintek Perikanan: Indones J Fish Sci Technol 15 (1): 73-79. DOI: 10.14710/ijfst.15.1.73-79.

Aulia AE, Maimunah Y, Suprastyani H. 2021. Penggunaan ekstrak daun lamtoro (*Leucaena Leucocephala*) sebagai pupuk dengan salinitas yang berbeda terhadap laju pertumbuhan biomassa dan klorofil-a pada mikroalga *Chlorella vulgaris*. J Fish Mar Res 5 (1): 47-55. DOI: 10.21776/ub.jfmr.2021.005.01.8. [Indonesian]

Bhushan S, Kalra A, Simsek H, Kumar G, Prajapati SK. 2020. Current trends and prospects in microalgae-based bioenergy production. J Environ Chem Eng 8 (5): 104025. DOI: 10.1016/j.jece.2020.104025.

Campbell S, Greenwood M, Prior S, Shearer T, Walkem K, Young S, Bywaters D, Walker K. 2020. Purposive sampling: complex or simple? Research case examples. J Res Nursing 25 (8): 652-661. DOI: 10.1177/1744987120927206.

Dayana ME, Singkam AR, Jumiarno D. 2022. Keanekaragaman mikroalga sebagai bioindikator di perairan sungai. J Pendidik Biol Sains 5 (1): 77-84. DOI: 10.31539/bioedusains.v5i1.3531. [Indonesian]

Fadliyah S, Sari LA, Pursetyo KT, Zein A, Idris MH, Cahyoko Y. 2021. The variability in population structure of gastropods in Sedati Waters, Sidoarjo Regency, East Java. IOP Conf Ser: Earth Environ Sci 679 (1): 012074. DOI: 10.1088/1755-1315/679/1/012074.

Firmaningrum NF, Sari LA, Pursetyo KT, Zein A, Idris MH, Cahyoko Y. 2021. Biodiversity studies of echinoderms in Sedati waters, Sidoarjo District, East Java Province. IOP Conf Ser: Earth Environ Sci 718 (1): 012089. DOI: 10.1088/1755-1315/718/1/012089.

Gunawan EAA, Agussalim, Surbakti H. 2019. Pemetaan sebaran klorofil-a menggunakan citra satelit landsat multitemporal di Teluk Lampung Provinsi Lampung. Maspari J: Mar Sci Res 11 (2): 49-58. DOI: 10.56064/maspari.v11i2.9467. [Indonesian]

Gurning LFP, Nuraini RAT, Suryono S. 2020. Kelimpahan fitoplankton penyebab harmful algal bloom di Perairan Desa Bedono, Demak. J Mar Res 9 (3): 251-260. DOI: 10.14710/jmr.v9i3.27483. [Indonesian]

Hawrot-Paw M, Koniuszy A, Gałczyńska M, Zając G, Szyszlak-Bargłowicz J. 2019. Production of microalgal biomass using aquaculture wastewater as growth medium. Water 12 (1): 106. DOI: 10.3390/w12010106.

Hughes DJ, Campbell DA, Doblin MA, Kromkamp JC, Lawrenz E, Moore CM, Suggett DJ. 2018. Roadmaps and detours: active chlorophyll-a assessments of primary productivity across marine and freshwater systems. Environ Sci Technol 52 (21): 12039-12054. DOI: 10.1021/acs.est.8b03488.

Jin P, Agustí S. 2018. Fast adaptation of tropical diatoms to increased warming with trade-offs. Sci Rep 8 (1): 1-10. DOI: 10.1038/ncomms12518.

Kale A, Karthick B. 2015. The diatoms. Resonance 20 (10): 919-930. DOI: 10.1007/s12045-015-0256-6.

Kasang AM, Toknok B, Korja IN. 2016. Karakteristik hutan mangrove di Desa Bolobungkang Kecamatan Lobu Kabupaten Banggai. J Ilmiah Kehutanan 4 (1): 9-15. [Indonesian]

Lauritano C, Rizzo C, Lo Giudice A, Saggiomo M. 2020. Physiological and molecular responses to main environmental stressors of microalgae and bacteria in polar marine environments. Microorganisms 8 (12): 1957. DOI: 10.3390/microorganisms8121957.

Lee M, Won NI, Baek SH. 2020. Comparison of HPLC pigment analysis and microscopy in phytoplankton assessment in the Seomjin River

Estuary, Korea. Sustainability 12 (4): 1675. DOI: 10.3390/su12041675.

Li A, Zhao X, Anderson S, Zhang X. 2018. Silica nanowire growth on *Coscinodiscus* species diatom frustules via vapor–liquid–solid process. Small 14 (47): 1801822. DOI: 10.1002/smll.201801822.

Liao Y, Jiang X, Xiao Y, Li M. 2020. Exposure of microalgae *Euglena gracilis* to polystyrene microbeads and cadmium: Perspective from the physiological and transcriptional responses. Aquat Toxicol 228: 105650. DOI: 10.1016/j.aquatox.2020.105650.

Lim YK, Phang SM, Abdul Rahman N, Sturges WT, Malin G. 2017. Halocarbon emissions from marine phytoplankton and climate change. Intl J Environ Sci Technol 14 (6): 1355-1370. DOI: 10.1007/s13762-016-1219-5.

Ludwig JA, Reynolds JF. 1988. Statistical Ecology A Primer on Methods and Computing. A Wiley Interscience Publication, Canada.

Mahmudi M, Lusiana ED, Herawati EY, Serihollo LG. 2020. Environmental factors and seasonal effect on the potential harmful algae presence at Ambon Bay. Indonesia. Biodiversitas 21 (7): 3101-3107. DOI: 10.13057/biodiv/d210730.

Marella TK, López-Pacheco IY, Parra-Saldívar R, Dixit S, Tiwari A. 2020. Wealth from waste: Diatoms as tools for phycoremediation of wastewater and for obtaining value from the biomass. Sci Total Environ 724: 137960. DOI: 10.1016/j.scitotenv.2020.137960.

Minggat E, Roseli W, Tanaka Y. 2021. Nutrient absorption and biomass production by the marine diatom *Chaetoceros Muelleri*: Effects of temperature, salinity, photoperiod, and light intensity. J Ecol Eng 22 (1): 231-240. DOI: 10.12911/22998993/129253.

Mohrholz V, Naumann M, Nausch G, Krüger S, Gräwe U. 2015. Fresh oxygen for the Baltic Sea—An exceptional saline inflow after a decade of stagnation. J Mar Syst 148: 152-166. DOI: 10.1016/j.jmarsys.2015.03.005.

Mourella ML, Gomez CP, Legido JL. 2017. The Potential Use of Marine Microalgae and Cyanobacteria in Cosmetics and Thalassotherapy. Cosmetics 4 (46): 1-14. DOI: 10.3390/cosmetics4040046.

Nasution A, Widyorini N, Purwanti F. 2019. Relationship analysis of phytoplankton abundance to nitrate and phosphate in the Morosari Waters Demak. Manag Aquat Res J 8 (2): 78-86. DOI: 10.14710/marj.v8i2.24230.

Nava V, Leoni B. 2021. A critical review of interactions between microplastics. microalgae and aquatic ecosystem function. Water Res 188: 116476. DOI: 10.1016/j.watres.2020.116476.

Nafisyah AL, Masithah ED, Matsuoka K, Lamid M, Alamsjah MA, O-hara S, Koike K. 2018. Cryptic occurrence of *Chattonella marina var*. marina in mangrove sediments in Probolinggo, East Java Province, Indonesia. Fish Sci 84 (12): 1-11. DOI: 10.1007/s12562-018-1219-0.

Nindarwi DD. 2019. Study of calcium hydroxide ($Ca(OH)_2$) and sodium bicarbonate (NaHCO3) treatment through the dynamics of pH, COD, N/P ratio value and plankton abundance. J Aquac Fish Health 8 (2): 72-79. DOI: 10.20473/jafh.v8i2.12428.

O'Neill EA, Rowan NJ. 2022. Microalgae as a natural ecological bioindicator for the simple real-time monitoring of aquaculture wastewater quality including provision for assessing impact of extremes in climate variance–A comparative case study from the Republic of Ireland. Sci Total Environ 802: 149800. DOI: 10.1016/j.scitotenv.2021.149800.

Paris A, Kwaoga A, Hewavitharane C. 2022. An assessment of floating marine debris within the breakwaters of the University of the South Pacific. Marine Studies Campus at Laucala Bay. Mar Pollut Bull 174: 113290. DOI: 10.1016/j.marpolbul.2021.113290.

Patty SI. 2013. Distribution temperature. salinity and dissolved oxygen in Waters Kema North Sulawesi. J Ilmiah Platax 1 (3): 148-157. DOI: 10.35800/jip.1.3.2013.2580. [Indonesian]

Patty SI, Arfah H, Abdul MS. 2015. Nutrients (phosphate. nitrate), dissolved oxygen and pH relation to productivity of Jikumerasa Waters Buru Island. J Pesisir Laut Tropis 3 (1): 43-50. DOI: 10.35800/jplt.3.1.2015.9578. [Indonesian]

Purbani DC, Ambarwati W, Kusuma AB, Herliany NE. 2019. Identification of marine microalgae from Tambrauw, West Papua. J Ilmu Teknol Kelaut Tropis 11 (3): 777-791. DOI: 10.29244/jitkt.v11i3.25862.

Purbani DC, Yuliani Y, Sumerta IN. 2021. Spatial diversity of microalgae in Simeulue Island, Indonesia. IOP Conf Ser: Earth Environ Sci 762 (1): 012004. DOI: 10.1088/1755-1315/762/1/012004.

Rahmadani D, Kuntjoro S. 2020. Keanekaragaman plankton yang toleran di perairan kawasan Pulau Lusi Kabupaten Sidoarjo. LenteraBio: Berkala Ilmiah Biologi 9 (3): 258-266. DOI: 10.26740/lenterabio.v9n3.p258-266. [Indonesian]

Rahman A, Pratiwi NTM, Hariyadi S. 2016. The structure of phytoplankton communities in Lake Toba, North Sumatera. J Ilmu Pertanian Indonesia 21 (2): 120-127. DOI: 10.18343/jipi.21.2.120. [Indonesian]

Rasmiati E, Nedi S, Amin B. 2017. Analysis of total organic matter and phytoplankton abundance in the Dumai River Estuary Waters of Riau Province. [Doctoral Dissertation]. Riau University, Riau. [Indonesia]

Ravindran B, Gupta SK, Cho WM, Kim JK, Lee SR, Jeong KH, Choi HC. 2016. Microalgae potential and multiple roles—current progress and future prospects—an overview. Sustainability 8 (12): 1215. DOI: 10.3390/su8121215.

Renny DP, Djuwito, Irwani. 2016. Pengaruh kandungan nitrat dan fosfat terhadap kelimpahan di Muara Sungai Wulan. Demak. Diponegoro J Maquares 5 (4): 224-232. DOI: 10.14710/marj.v5i4.14411. [Indonesian]

Righetti D, Vogt M, Zimmermann NE, Guiry MD, Gruber N. 2020. PhytoBase: a global synthesis of open-ocean phytoplankton occurrences. Earth Syst Sci Data 12 (2): 907-933. DOI: 10.5194/essd-12-907-2020.

Rizadha MH, Putri FES, Fakhraini MS, Fauzan M, Widiarti R. 2018. Analisa kelimpahan mikroalga epifitik (Diatom dan Dinoflagellata) pada makroalga berdasarkan perbedaan faktor lingkungan di Pulau Bintan, Kepulauan Riau. Pertemuan Ilmiah Nasional Tahunan XV ISOI. 267-274. [Indonesian]

Rizqina C, Sulardiono B, Djunaedi A. 2017. Hubungan antara kandungan nitrat dan fosfat dengan kelimpahan fitoplankton di Perairan Pulau Pari Kepulauan Seribu. Manag Aquat Res J 6 (1): 43-50. DOI: 10.14710/marj.v6i1.19809. [Indonesian]

Rizwan M, Mujtaba G, Memon SA, Lee K, Rashin N. 2018. Exploring the potential of microalgae for new biotechnology applications and beyond: A review. Renewable Sustain Energy Rev 92: 394-404. DOI: 10.1016/j.rser.2018.04.034.

Rösch C, Roßmann M, Weickert S. 2019. Microalgae for integrated food and fuel production. Gcb Bioenergy 11 (1): 326-334. DOI: 10.1111/gcbb.12579.

Roshith CM, Meena DK, Manna RK, Sahoo AK, Swain HS, Raman RK, Das BK. 2018. Phytoplankton community structure of the Gangetic (Hooghly-Matla) estuary: Status and ecological implications in relation to eco-climatic variability. Flora 240: 133-143. DOI: 10.1016/j.flora.2018.01.001.

Salahi T, Pourbabaei H, Salahi M, Karamzadeh S. 2017. An investigation on plant species composition and diversity in the coniferous and broadleaved plantations: Case study of Bibi Yanlu Forest Park. Astara. Iran Biodiv 18 (3): 958-963. DOI: 10.13057/biodiv/d180313.

Sandeep KP, KumaraguruVasangam KP, Kumararaja P, Syama Dayal J, Sreekanth GB, Ambasankar K, Vijayan KK. 2019. Microalgal diversity of a tropical estuary in south India with special reference to isolation of potential species for aquaculture. J Coast Conserv 23 (1): 253-267. DOI: 10.1016/j.chemosphere.2016.10.109.

Sanz JL, Rojas P, Morato A, Mendez L, Ballesteros M, González-Fernández C. 2017. Microbial communities of biomethanization digesters fed with raw and heat pre-treated microalgae biomasses. Chemosphere 168: 1013-1021. DOI: 10.1016/j.chemosphere.2016.10.109.

Sari LA, Pursetyo KT, Arsad S, Masithah ED, Setiawan E, Affandi M. 2019a. The effect of nutrient abundance on distribution of cyanobacteria and chlorophyll-a in sedati water, Sidoarjo. Pollut Res 38 (August): S38-S43.

Sari LA, Sari PDW, Nindarwi DD, Arsad S, Affandi M. 2019b. Harmful algae identification in Bomo water environment, Banyuwangi, East Java, Indonesia. Ecol Environ Conserv 25: S26-S31.

Schilling KE, Streeter MT, Isenhart TM, Beck WJ, Tomer MD, Cole KJ, Kovar JL. 2018. Distribution and mass of groundwater orthophosphorus in an agricultural watershed. Sci Total Environ 625: 1330-1340. DOI: 10.1016/j.scitotenv.2018.01.035.

Selviana D, Harmoko, Arisandi DA. 2021. Keanekaragaman mikroalga di Bendungan Barata Desa Wonokerto Kabupaten Musi Rawas. J Biologi dan Pembelajarannya 8 (2): 112-120. DOI: 10.25273/florea.v8i2.9746. [Indonesian]

Sidabutar HB, Hasbi M, Budijono. 2016. The effectiveness of tofu liquid waste for growing *Chlorella* sp. [Doctoral Dissertation]. Riau University, Riau. [Indonesian]

Simmonds B, Wood SA, Özkundakci D, Hamilton DP. 2015. Phytoplankton succession and the formation of a deep chlorophyll

maximum in a hypertrophic volcanic lake. Hydrobiologia 745 (1): 297-312. DOI: 10.1007/s10750-014-2114-z.
Singh J, Saxena RC. 2015. An introduction to microalgae: diversity and significance. In Handbook of marine microalgae. Academic Press. DOI: 10.1016/B978-0-12-800776-1.00002-9.
Siregar LL, Hutabarat S, Muskananfola MR. 2014. Distribusi fitoplankton berdasarkan waktu dan kedalaman yang berbeda di Perairan Pulau Menjangan Kecil Karimunjawa. Manag Aquat Resour J 3 (4): 9-14. DOI: 10.14710/marj.v3i4.7026. [Indonesian]
Sitindoan BMK, Siregar SH, Nurrachmi I. 2020. Effect of particle sizes and content of organic matter sediment on epipelic diatom abundance in Bayur Bay Waters of West Sumatera. Asian J Aquat Sci 3 (1): 49-59. DOI: 10.31258/ajoas.3.1.49-59.
Sohrabi M, Mahzari P, Farzaneh SA, Mills JR, Tsolis P, Ireland S. 2017. Novel insights into mechanisms of oil recovery by use of low-salinity-water injection. Spe J 22 (02): 407-416. DOI: 10.2118/172778-PA.
Sournia, A. 1978. Phytoplankton Manual. United Nations Educational, Scientific and Cultural Organization, Paris.
Sumiarsih E, Aryani N, Warningsih T, Mulyani I, Hasibuan IF. 2020. Plankton community structure in PLTA Koto Panjang Reservoir, Kampar District, Riau Province. IOP Conf Ser: Earth Environ Sci 430 (1): 012036. DOI: 10.1088/1755-1315/430/1/012036.
Suryoputro AA, Pramesti RA, Zainuri M, Maslukah L. 2023. Distribution patterns of chlorophyll-a and its relationship with phosphate, nitrate in Banjir Kanal Barat and Banjir Kanal Timur, Semarang, Indonesia. Ecol Eng Environ Technol 24 (2): 186-193. DOI: 10.12912/27197050/157038.
Suteja Y, Dirgayusa IGNP, Afdal A, Cordova MR, Rachman A, Rintaka WE, Takarina ND, Putri WAE, Isnaini, Purwiyanto AIS. 2021. Identification of potentially harmful microalgal species and eutrophication status update in Benoa Bay, Bali, Indonesia. Ocean Coast Manag 210 (4): 105698. DOI: 10.1016/j.ocecoaman.2021.105698.
Tambaru R, Burhanuddin AI, Massinai A, Amran MA. 2021. Detection of marine microalgae (phytoplankton) quality to support seafood health: A case study on the west coast of South Sulawesi, Indonesia. Biodiversitas 22 (11): 5179-5186. DOI: 10.13057/biodiv/d221156.
Tambaru R. 2022. Potentially harmful phytoplankton species in the southern part of West Coastal Waters of South Sulawesi. J Agrikan (Agribisnis Perikanan) 15 (2): 453-459. DOI: 10.52046/agrikan.v15i2.1258.
Tang J, Liang Q, Li C, Huang X, Xian X, Li J, Zhang R. 2022. Application of marine algae in water pollution control. IOP Conf Ser: Earth Environ Sci 966 (1): 012001. DOI: 10.1088/1755-1315/966/1/012001.
Triawan AC, Arisandi A. 2020. Struktur komunitas fitoplankton di perairan muara dan laut Desa Kramat Kecamatan Bangkalan Kabupaten Bangkalan. Juvenil 1 (1): 97-110. DOI: 10.21107/juvenil.v1i1.6867. [Indonesian]
Ulfah M, Fajri SN, Nasir M, Hamsah K, Purnawan S. 2019. Diversity. evenness and dominance index reef fish in Krueng Raya Water Aceh Besar. IOP Conf Ser: Earth Environ Sci 348: 012074. DOI: 10.1088/1755-1315/348/1/012074.
Vernanda O, Sari LA, Cahyoko Y, Arsad S, Pursetyo KT, Dewi NN, Mustafa S. 2022. Correlation of environmental factors with population of horseshoe crab (*Tachypleus gigas*) in Sedati Waters, Sidoarjo District. Intl J Adv Sci Eng Inf Technol 12 (2): 826-833. DOI: 10.18517/ijaseit.12.2.14958.
Wahyudi AJ, Hernawan UE, Fitriyah N. 2017. Ekspedisi widya nusantara. http://oseanografi.lipi.go.id/laporan/Laporan akhir Kegiatan EWIN 2017.pdf. [Indonesian]
Xie Y, Khoo KS, Chew KW, Devadas VV, Phang SJ, Lim HR, Show PL. 2022. Advancement of renewable energy technologies via artificial and microalgae photosynthesis. Bioresour Technol 363: 127830. DOI: 10.1016/j.biortech.2022.127830.
Zakiyah U, Mulyanto, Suwanti LT, Koerniawan MD, Suyono EA, Budiman A, Siregar UJ. 2020. Diversity and distribution of microalgae in coastal areas of East Java, Indonesia. Biodiversitas 21 (3): 1149-1159. DOI: 10.13057/biodiv/d210340.
Zhang X, Chua VP, Cheong HF. 2015. Hydrodynamics in mangrove prop roots and their physical properties. J Hydro-environ Res 9 (2): 281-294. DOI: 10.1016/j.jher.2014.07.010.
Zhu L. 2015. Microalgal culture strategies for biofuel production: a review. Biofuels, Bioproducts Biorefining: Innov Sustain Econ 9 (6): 801-814. DOI: 10.1002/bbb.157.