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Macroalgae diversity and its relationship with environmental conditions in polluted waters of Seribu Islands, Jakarta Bay, Indonesia

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Abstract. *Handayani S, Widhiono I, Widyartini DS. 2023. Macroalgae diversity and its relationship with environmental conditions in polluted waters of Seribu Islands, Jakarta Bay, Indonesia. Biodiversitas 24: 6279-6286.* Macroalgae are one of the important marine primary producers because they support the life of other organisms at a higher trophic level in aquatic ecosystems. This study aimed to determine the species diversity and composition of macroalgae and its relationship with local aquatic environmental conditions. This research was conducted in Seribu Islands, Jakarta Bay, and consisted of Pramuka Island, Semak Daun Island, Kotok Besar Island, Karang Bongkok Island, Kongsi Island, and Pari Island as sampling sites. This research used the transect method with quadratic sampling and the data was analyzed using the Shannon-Wiener Diversity Index, Dominance Index, and Evenness. Diversity parameter calculations were carried out using PAST4.0 software. The relationship between diversity and water quality was analyzed using PCA software. Across the six sampling sites, there were 41 species of macroalgae belonging to 3 divisions, namely Chlorophyta (19 species), Phaeophyta/Ochrophyta (10 species), and Rhodophyta (12 species). The species richness among islands showed that Karang Bongkok Island had the highest species with 28 species and the lowest was Semak Daun Island and Kongsi Island with only 15 species. The Diversity Index was the highest in Karang Bongkok Island with 2.679 and the lowest was in Kongsi Island with 1.907. The species with the largest number of individuals were *Halimeda macroloba* with 930 individuals, followed by *Sargassum binderi* with 648 individuals, and *Corallina officinalis*. with 257 individuals. The diversity of macroalgae species on the six islands is classified as moderate and can be used as an indicator of marine ecosystems. Physicochemical parameters that affect macroalgae diversity in the Seribu Islands waters are temperature, depth, currents, salinity, Total Dissolved Solids (TDS), pH, Dissolved Oxygen (DO), Cu, and Phosphate. The finding of this study implies that despite the high pollution in Seribu Islands waters, it is still good for the growth of macroalgae.

Keywords: Aquatic ecosystem, *Corallina officinalis*, *Halimeda macroloba*, indicator, *Sargassum binderi*

INTRODUCTION

Seribu Islands is a group of islands situated in the north of Jakarta Bay and is located 42 km from the Jakarta coastline. There are several environmental problems in Jakarta Bay one of which is the high pollution level. According to Kunzmann et al. (2018), Jakarta Bay is among the most polluted marine water bodies in Asia. The main sources of water pollution in Jakarta Bay are wastes produced by industrial and other anthropogenic activities (Kunzmann et al. 2018). Pollution of sea waters is closely related to anthropogenic activities on land (Baum et al. 2015; Breckwoldt et al. 2016; Kunzmann et al. 2018; Azizi et al. 2021). For example, most of the 71 organic contaminants identified in river water from the Jakarta area are chemicals used in households. Personal care product ingredients, pharmaceutical drugs, and flame retardants were found in exceptionally high concentrations, especially at the river mouths flowing to Jakarta Bay (Breckwoldt et al. 2016). A study by Azizi et al. (2021) found microplastic pollution in the sediments of Jakarta Bay.

The high level of pollution in Jakarta Bay affects the quality of water bodies. This condition can be identified from changes in the physical, chemical, and biological components of the surrounding waters. From the physical aspect, some changes include light intensity, temperature, salinity, and pH. On the other hand, changes in chemical aspects include nitrates and phosphates. Changes in physical and chemical components will cause a decrease in water quality which can affect the life of various marine biota. One group of marine organisms that are affected by pollution is macroalgae or seaweeds (Rugebregt et al. 2020).

Water quality greatly affects the structure and composition of macroalgae which includes diversity, evenness, abundance, dominance, and biomass (Arfah and Patty 2016). In addition, macroalgae growth is directly affected by light intensity and nutrients, including phosphate and nitrate which are needed in the formation of proteins in photosynthesis. Research on the effect of seawater quality on the diversity of macroalgae has been widely carried out in the world. For example, as study by Mushlihah et al. (2021) in Makassar Bay showed that the highest level of macroalgae cover was found in areas with high nutrient content and turbidity levels. A study by Rugebregt et al. (2020) revealed that the diversity of macroalgae is positively correlated with water quality and vice versa. AbouGabal et al. (2022) found differences in alpha and beta diversity of macroalgae on the coast of Alexandria, Egypt, influenced by levels of heavy metal pollution and physicochemical parameters. The results of other study state that differences in the diversity of sublittoral macroalgae are caused by changes in seawater depth levels (Pinedo et al. 2013).

Macroalgae consists of three divisions, i.e. Chlorophyta, Phaeophyta, and Rhodophyta. Chlorophyta is mostly found in marine sediments, Phaeophyta is found on rocky substrates on the intertidal shore while Rhodophyta is found in warm waters in tropical areas such as Jakarta Bay (Asmida et al. 2017). Therefore the taxonomical diversity of macroalgae is largely determined by the type of substrate in water (Rugebregt et al. 2020). Apart from the type of substrate, the diversity of macroalgae is also greatly influenced by the quality of the water (Hamzah et al. 2020; Mushlihah et al. 2021; Sofiana et al. 2022; AbouGabal et al. 2022).

The widespread pollution in Jakarta Bay also impacts the waters of the Seribu Islands (Baum et al. 2015). Nonetheless, there is limited ecological study to determine the diversity and distribution of macroalgae and the main factors that influence it in this area. This is necessary and beneficial for the sustainability of macroalgae in Seribu Islands and their preservation. Therefore, this study aims to assess the diversity and composition of macroalgae in Seribu Islands, Jakarta, Indonesia and its relationship with environmental conditions. It is hoped that the results of this research can be used as a basis for better conservation and management design for the ecosystem in the future.

MATERIALS AND METHODS

Study area and period

The research was located in coastal water ecosystems on six islands of Seribu Islands, Jakarta Bay, Indonesia namely Karang Bongkok Island, Kotok Besar Island, Semak Daun Island, Pramuka Island, Kongsi Island and Pari Island (Figure 1). Data collection was conducted from February to September 2022. The study area was divided into six stations. Geographically, the coordinates of the stations are as follows: Semak Daun Island: 5°16'00"S 106°38'00"E; Pramuka Island 5°44'4.0"S 106°37'0.3"E; Kotok Besar Island 5°42'0.1"S 106°32'3.8"E; Karang Bongkok Island 5°41'0.6"S 106°33'4.6"E; Kongsi Island 5°51'18.8"S 106°36'03.4"E; Pari Island 5°51'14.9"S 106°37'55.7"E (Figure 1).

Each research station has different characteristics. Semak Daun Island (Station 1) is an uninhabited island with white sandy beaches, and a popular tourist destination for activities such as snorkeling, fishing, and camping. Pramuka Island (Station 2) is an inhabited island with sandy and dead coral beaches and has a dense population and is busy with human activities due to its role as the administrative center of the Seribu Islands Regency. Kotok Besar Island (Station 3) is an inhabited by island rangers only and has sandy beach with coral and shell fragments, making it as destination for snorkeling and diving, bondol eagel conservation. Karang Bongkok Island (Station 4) is an island inhabited only by island rangers and has sandy beach with broken coral pieces and functions as a research center for marine biota. Kongsi Island (Station 5) is inhabited by a small population with sandy beach and muddy sand, and has the office of Marine Fisheries Research Institute. Pari Island (Station 6) is an inhabited island with sandy beaches, coral fragments, and muddy sand, and is maritime tourist destination for activities such as snorkeling and diving.

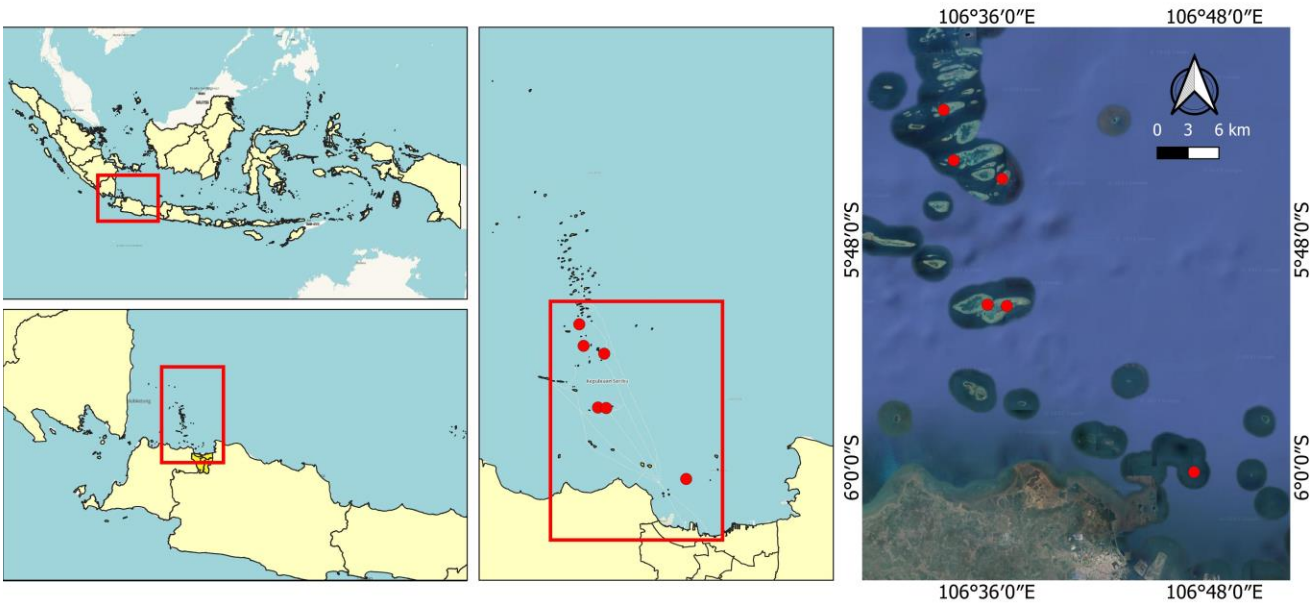

Figure 1. Map of the sampling sites in Seribu Islands, Jakarta Bay, Indonesia

Data collection procedure

Data on macroalgae were collected using quadratic transect method. We established six sampling sites (Figure 1) in which at each site, three line transects were made along 50 m perpendicular from the coast to the island edge with a distance between transects of 20 m. The first observation was made by placing a square transect measuring 1 m x 1 m at a distance of 5 m from the shoreline. Placement of the next square plot at a distance of 10 m from the first placement, and so on up to 50 m (Handayani et al. 2023).

We recorded macroalgae species, substrate type, and environmental parameters (including temperature, salinity, brightness, current, TDS, depth, substrate, pH, DO, Nitrate, Orthophosphate, Hg, Pb, and Cu). For identification, macroalgae samples of unknown species were taken and put into plastic samples. Furthermore, macroalgae samples that have been put in plastic were stored or preserved for identification purposes. Identification of the species of macroalgae was found using the identification books according to Brodie et al. (2013), Lima et al. (2017), Newton (2017), Ramesh et al. (2019). In addition to using the macroalgae identification book, the macroalgae nomenclature was matched with Guiry and Guiry (2021) to adapt to the current development of scientific nomenclature.

Data analysis

Data were analyzed to reveal the diversity and composition of macroalgae community, including the Shannon-Wiener Diversity index, Evenness index and Dominance index (Bakus 2007). The calculation of diversity parameters was carried out using PAST 4.0 software. The sampling data was then used to see the relationship between water quality and biodiversity and composition of macroalgae at the study sites. Effect of water quality on macroalgae diversity was analyzed using Principle Component Analysis (PCA) software.

RESULTS AND DISCUSSION

Macroalgae composition

There were 41 species of macroalgae across the sampling sites in the Seribu Islands waters recorded to the level of species belonging to 22 genera and 14 families (Table 1). The composition of macroalgae species was classified into three divisions, namely green macroalgae (Chlorophyta), red macroalgae (Rhodophyta), and brown macroalgae (Phaeophyta/Ochrophyta). Chlorophyta was the most diverse division of macroalgae with a total of 19 species (46.3%) compared to Rhodophyta with 12 species (29.3%) and Phaeophyta with 10 species (24.4%) (Figure 2).

Halimeda macroloba from Chlorophyta division had the highest abundance with 930 individuals or clumps. The high occurrence species from Chlorophyta may be due to the sand substrate and coral rubble along the intertidal zone of the six islands studied. Sand substrate is a suitable substrate for macroalgae growth from Chlorophyta (Johan et al. 2015). This is in line with Anggadiredja (2017) statement that macroalgae from Chlorophyta prefer to grow on sandy beaches and many species of macroalgae from Chlorophyta are tolerant of lower salinity. Some species do not tolerate higher salinity because these macroalgae grow well on sand substrates. Even though the sand substrate is a less stable medium, it is easy to crash when there is a big wave (Ferawati et al. 2014).

Rhodophyta is a division of macroalgae with the second largest number of species after Chlorophyta. Rhodophyta is a cosmopolitan macroalgae which can be found from the intertidal area to the deeper sea. The most commonly found macroalgae from the Rhodophyta division was *Corallina officinalis*. This species is usually found living in colonies and densely packed and found in fairly shallow waters. The substrate where it attaches is sand, mud or rock. Macroalgae from the Phaeophyta division were the fewest found in this study area, because most of the thallus of macroalgae from this division are in the form of sheets and are relatively thinner when compared to thallus from other divisions. Therefore, macroalgae from this division need areas that do not experience drought for too long. So that the main habitat is in the subtidal zone, while in the intertidal zone these macroalgae usually grow in basins which remain inundated during high tides, and the end areas of the intertidal zone are close to the subtidal zone, so they can still be submerged in seawater. The most common species of Phaeophyta macroalgae was *Sargassum binderi.*

This research found that *Halimeda macroloba, Sargassum binderi, Dictyota bartayresiana, Acanthophora spicifera* and *Caulerpa racemosa* were the dominant macroalgae species. The five macroalgae species represent the divisions Chlorophyta, Rhodophyta and Phaeophyta (Ochrophyta). The number of macroalgae species found in this study does not fully describe the diversity of macroalgae in the Seribu Islands because it does not reflect the entire macroalgae season. Draisma et al. (2018) recorded 67 macroalgae species from 27 islands in the Seribu Islands. Wulandar et al. (2020) noted that there were 20 species of macroalgae found on Semak Daun Island. Only two islands are the same in this study, namely Semak Daun Island and Kotok Besar Island.

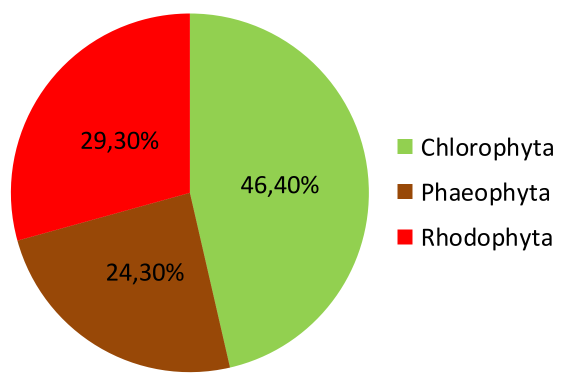

Figure 3. The composition of macroalgae species across the sampling sites in the Seribu Islands, Jakarta Bay, Indonesia

The presence of species and changes in the composition of macroalgae can be attributed to the dynamics of environmental factors (Kharismawati et al. 2019) or unexplained investigative variance such as seasonality (El Shoubaky 2013; Henriques et al. 2015), sampling depth (Kang et al. 2011) and competition (Kerswell 2006). In general, the number of species and the composition of all taxa differed between periods and researchers.

Diversity Index (H`), Evenness Index (E) and Dominance Index (D)

The results of the diversity index (H`), evenness index, and dominance index at each research site can be seen in the Table 2.

Table 1. List macroalgae species recorded across the sampling sites in the Seribu Islands waters, Jakarta Bay, Indonesia

Division	Class	Family	Species
Chlorophyta	Chlorophyceae	Halimedaceae	*Halimeda laccunalis* W.R. Taylor
		Halimedaceae	*Halimeda macroloba* Decainsne
		Halimedaceae	*Halimeda oppuntia* (L.) J.V.Lamouroux
		Halimedaceae	*Halimeda macrophysa* Askenasy
		Halimedaceae	*Halimeda gracilis* Harvey ex J. Agardh
		Halimedaceae	*Halimeda micronesica* Yamada
Chlorophyta	Chloropyceae	Caulerpaceae	*Caulerpa lentillifera* J. Agardh
		Caulerpaceae	*Caulerpa taxifolia* (M. Vahl) C. Agardh
		Caulerpaceae	*Caulerpa sertularoides* (S.G. Gmelin) M. Hawe
		Caulerpaceae	*Caulerpa racemosa* (Forsskal) J. Agardh
		Caulerpaceae	*Caulerpa racemosa* var *uvifera* (C. Agardh) J. Agardh
		Caulerpaceae	*Caulerpa serrulata* (Forsskal) J. Agardh
		Caulerpaceae	*Caulerpa antanina*. J.V. Lamouroux
Chlorophyta	Chlorophyceae	Siphonocladaceae	*Chaetomorpha crassa* (C. Agardh) Kutzing
		Siphonocladaceae	*Dictyosphaeria covernosa* (Borgensen) Forsskal
		Siphonocladaceae	*Boergensenia forbesii* (Harvey) Feldmann
Chlorophyta	Chlorophyceae	Dasycladaceae	*Neomeris annulata* Dickie
	Chlorophyecae	Ulvaceae	*Enteromorpha intestinalis* (L.) Nees
	Ulvophyceae	Boodleaceae	*Boodlea composita* (Harvey ex J.E. Gray) Egerod
Phaeophyta	Phaeophyceae	Dictyotaceae	*Padina tetrasomastica* Hauck
		Dictyotaceae	*Padina australis* Hauck
		Dictyotaceae	*Dictyota bartayresiana* J.V. Lamouroux
Phaeophyta	Phaeophyceae	Sargassaceae	*Sargassum binderi* Sonder ex J. Agardh
		Sargassaceae	*Sargassum polycystum* C. Agardh
		Sargassaceae	*Sargassum duplicatum* Bory
		Sargassaceae	*Cystoceria osmundacea* (Turner) Tevisan
Phaeophyta	Phaeophyceae	Sargassaceae	*Tubinaria ornata* (Turner) J. Agardh
		Sargassaceae	*Turbinaria conoides* (J. Agardh) Kutzing
		Sargassaceae	*Turbinaria decurrens* Bory de Saint-Vincent
Rhodophyta	Rhodopyceae	Hypneaceae	*Hypnea asperi* Kutzing.
		Hypneaceae	*Laurencia nidifica* J. Agardh.
Rhodopyta	Rhodophyceae	Corallinaceae	*Corallina officinalis* L.
		Corallinaceae	*Amphiroa fragilissima* (L.) J.V. Limouroux.
		Soliericeae	*Eucheuma edule* (Kutzing) Weber Bosse.
		Soliericeae	*Eucheuma alvarezii* Doty
		Soliericeae	*Eucheuma denticulatum* (N.L. Burman) Collins & Harvey
Rhodophyta	Florideophyceae	Rhodomelaceae	*Acathophora spicifera* (M. Vahl) Borgesen
		Rhodomelaceae	*Acanthophora muscoides* (L.) Bory
Rhodophyta	Rhodopyceae	Gracilariaceae	*Gracilaria salicornia* (C. Agardh) Dawson
		Galaxauraceae	*Galaxaura rugosa* (J. Ellis & Solander) J.V. Lamouroux

Table 2. Value of diversity index, evenness index, and dominance index at each research site in Seribu Islands waters, Jakarta Bay, Indonesia

Parameter	Semak Daun	Pramuka	Kotok Besar	Karang Bongkok	Kongsi	Pari
Shannon-Wiener (H`)	1.921	2.549	2.261	2.679	1.907	2.313
Evenness (E)	0.402	0.512	0.436	0.561	0.481	0.594
Simpson (D)	0.801	0.849	0.849	0.912	0.789	0.879

The lowest diversity index was found in Kongsi Island (1.907), and the highest was on Karang Bongkok Island (2.679). The diversity index at the study site ranged from 1.907 to 2.679. This means that the diversity of macroalgae species at the study site in the six islands is still relatively high or moderate. The moderate diversity index is caused by relatively stable environmental conditions and the number of species found. This follows the statement of Hamzah et al. (2020), which states that the value of 1<H'<3 means that species diversity is moderate and the environmental carrying capacity of the community is quite good. The high and low diversity of species in a water is strongly influenced by the number of species itself, the higher the number of species, the higher the diversity. The inter-island species richness showed that Karang Bongkok Island had the most species with 28 followed by Pramuka Island with 26 species, Kotok Besar Island with 23 species, Pari Island with 18 species and the lowest was Semak Daun Island and Kongsi Island which only 15 species were found. This is in accordance with (Farito et al. 2018), which stated that the difference in the value of the macroalgae diversity index is influenced by the number of individuals of each species and the total number of all macroalgae species. This is also in line with the statement of Magurran and McCarthy (2004) which species diversity is related to species richness and distribution within a community. The low diversity value illustrates the small number of macroalgae in these waters and indicates the presence of dominant species. According to Ferawati et al. (2014), the low level of diversity is mostly caused by the complexity of the habitat due to substrate damage or high waves. Another factor that causes low diversity is an excessive anthropogenic activity because macroalgae are organisms susceptible to environmental changes. According to Baleta and Nalleb (2016) the diversity of macroalgae species is influenced by the substrate and the way the algae attaches itself to the substrate, while Herlinawati et al. (2017) stated that various types of substrates can affect a more diverse diversity of macroalgae.

Species with the largest number of individuals were *Halimeda macroloba* (Chlorophyta) with 872 individuals, followed by *Sargassum binderi* (Phaeophyta) with 648 individuals and *Corallina officinalis* (Rhodophyta) with 257 individuals. In the intertidal zone at the research site, the substrate is sand, sand with coral rubble, and sand with dead coral; these substrates are suitable for *Chlorophyta* and *Phaeophyta*. Sandy substrate in seagrass ecosystems is a suitable habitat for macroalgae, especially from the *Chlorophyceae* and *Phaeophyceae* classes (Ferawati et al. 2014; Jamilatun et al. 2020).

Condition of Seribu Islands waters

The existence and diversity of macroalgae are influenced by water and environmental conditions such as temperature, current, brightness, pH, and salinity. In addition to the condition of the waters and their environment, the substrate is an important component that affects the presence of macroalgae. Water quality and substrate are very important for macroalgae life in shallow marine waters. The water quality in Seribu Islands can be seen in Table 3.

The results of temperature measurements in the waters of Seribu Islands ranged 27-30.4°C. The temperature at the study site was still within the normal range that macroalgae could tolerate. According to Melsasail et al. (2018), macroalgae found in tropical climates can grow well at a temperature of 20-30°C. A lower temperature will cause the biochemical activity in the thallus to stop and the membrane proteins and fats can suffer damages as a result of the formation of crystals in cells. Conversely, too high temperature would cause the destruction of biochemical mechanisms in the thallus. Seawater salinity affects the distribution, abundance, and growth of macroalgae in coastal waters. The results of the measurement of seawater salinity in the waters of Seribu Islands ranged between 25.05 and 31.3 ppt. This condition still supports macroalgae growth, as stated by Kadi (2017) that the range of salinity which is good for the growth of macroalgae is 32-34 ppt

Table 3. Water quality at each research site in Seribu Islands, Jakarta Bay, Indonesia

Parameters		Island					
		Semak Daun	**Kotok Besar**	**Karang Bongkok**	**Pramuka**	**Kongsi**	**Pari**
Physical							
Temperature	(°/C)	30.4	29.8	29.9	27.5	31.3	31.3
Salinity	(ppt)	25.05	25.9	28.75	31	30.78	31.3
Current	($m.s^{-1}$)	0.15	0.11	0.13	0.19	5.33	4.14
Depth	(m)	0.58	0.58	0.34	0.33	0.69	0.74
Substrate		Sand	Sand, coral shards	Sand, coral shards	Sand, dead coral	Sand, muddy sand	Sand, muddy sand
Chemical							
pH		8.06	7.95	8.05	8.15	8.10	8.13
DO	($mg.L^{-1}$)	6.54	7.31	6.18	4.85	6.38	6.38
Orthophosphat	($mg.L^{-1}$)	<0.002	<0.002	<0.002	<0.002	0.039	0.021
Nitrate	($mg.L^{-1}$)	0.147	0.178	0.148	0.174	0.234	0.23
Heavy metal							
Hg	($mg.L^{-1}$)	0.0007	0.0007	0.0008	0.0005	0.001	0.001
Pb	($mg.L^{-1}$)	0.008	0.007	0.005	0.007	0.020	0.02
Cu	($mg.L^{-1}$)	0.007	0.008	0.005	0.007	0.021	0.21

The degree of acidity or pH affects the growth of macroalgae. According to Hamzah et al. (2020), the optimum pH conditions for macroalgae growth ranged from 6.8 to 8.2. Low pH will suppress the growth rate of macroalgae, and even the acidity level can be deadly, and there will not be any reproduction rate in macroalgae. The degree of acidity (pH) in the waters of Seribu Islands ranged between 7.95 and 8.15. The pH measurements showed that the conditions were ideal for macroalgae growth.

Observations of depth in the waters of Seribu Islands on sand substrate ranged from 0.33-0.74 m at the lowest tide. According to Farito et al. (2018) macroalgae in Indonesia grow well at a depth of 0.20-0.30 m because, generally, the penetration of sunlight is still good and reaches that depth. Water that is too shallow will inhibit the growth of seaweed because, in addition to the bottom of the water is easily stirred, causing turbidity that interferes with the photosynthesis process; plants will also be easily reached by predators such as turtles and sea urchins. A good current for macroalgae growth is 20-40 cm/second. Measurement of current/wave velocity on the sand substrate was 11-19 cm/second. Based on this range, the current velocity at the study site is below the optimal flow velocity for macroalgae growth. Kregting et al. (2016) stated that when waves with relatively strong pressure cause damage to the macroalgae thallus, however, some types of macroalgae can survive during large waves.

The development of macroalgae cannot be separated from external influences, such as competition between types of macroalgae, predation by marine animals, such as the presence of sea urchins, sea cucumbers, sea stars, and herbivores which can damage the thallus of macroalgae by eating them so that it will reduce the number of spores and inhibit the spread of macroalgae.

The relationship between macroalgae diversity and water quality

The relationship between macroalgae diversity and water quality was analyzed using Principal Component Analysis (PCA). Environmental variables, such as Hg, Pb, Cu, DO, temperature, depth, current speed and Total Dissolved Solids (TDS), provide quite consistent results. Environmental variables, such as orthophosphate, DO, temperature, depth, current speed and salinity had a weak and positive correlation with macroalgae diversity, while nitrate, Hg, Pb, brightness and TDS had a weak negative correlation. The correlation between macroalgae diversity and water quality parameters in Seribu Islands is presented in Figure 4.

The diversity of macroalgae in Pari Island had a positive correlation with high salinity and pH, while in Karang Bongkok Island and Kongsi Island had a positive correlation with depth, current velocity, temperature, Do, orthophosphate, Cu. Macroalgae diversity in Semak Daun Island and Pramuka Island had a positive correlation with TDS. On the other hand, the diversity of macroalgae on Kotok Besar Island had a negative correlation with Hg, Pb, Nitrate and brightness. This means such parameters are very influential to macroalgae diversity.

Figure 5 shows the characteristics of the research station waters based on its constituent parameters. Pramuka Island and Semak Daun Island are characterized by TDS. Pari Island is characterized by high pH and salinity. Kongsi Island and Karang Bongkok Island are characterized by diversity, DO and temperature high, Cu, Otrhophosphate, current speed, depth. Kotok Besar Island is characterized by nitrate, Hg, Pb, brightness.

The results of PCA analysis on Pramuka Island and Semak Daun Island show that the diversity of macroalgae on these two islands is positively correlated with Total Dissolved Solids (TDS). TDS reflects the amount of salts and dissolved compounds in water. As residential zones with high levels of human activity, such as recreation and water flow from the mainland, these two islands are affected by the impact of human activities which affect water quality. The positive correlation between macroalgal diversity and TDS indicates that macroalgae on these islands may be better to adapt to higher levels of salt and dissolved compounds, and this could be related to the preference of certain macroalgal species for these conditions. Pari Island, which is a marine tourism destination, is characterized by high pH and salinity. These unique water conditions can support the growth and diversity of certain macroalgae species in this island. Kongsi Island and Karang Bongkok Island have characteristics of high levels of Dissolved Oxygen (DO), high temperatures, concentrations of copper (Cu), orthophosphate, current speed, and depth. This environment creates conditions that support the growth of various types of macroalgae, including those that require high levels of dissolved oxygen and have certain temperature preferences. The availability of orthophosphate and copper can also influence the growth of macroalgae on these two islands.

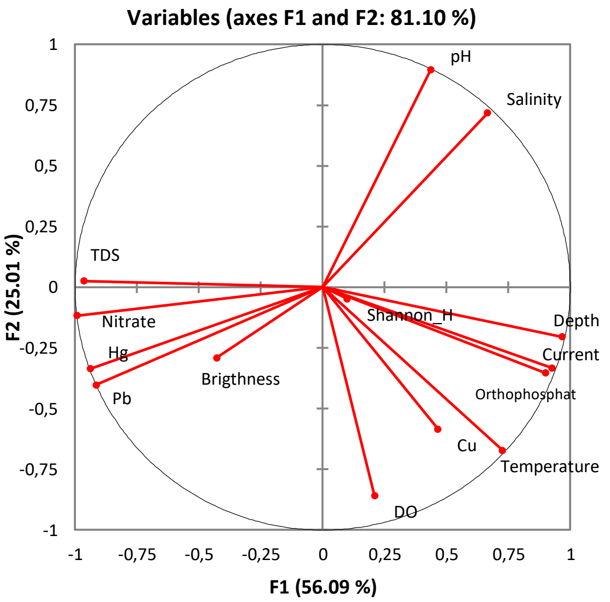

Figure 4. Correlation between macroalgae diversity and water quality in Seribu Islands water, Jakarta Bay, Indonesia

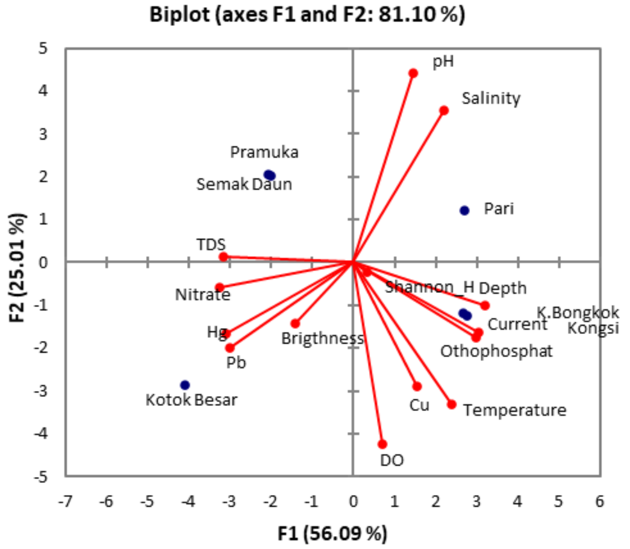

Figure 5. Clustering of environmental parameters and sites in the Kepulaun Seribu waters, Jakarta Bay, Indonesia

Meanwhile, Kotok Besar Island is characterized by high concentrations of nitrate, mercury (Hg), lead (Pb), and brightness levels that are negatively correlated with macroalgae diversity. This indicates that environmental factors such as nitrate, Hg, Pb, and brightness may not have a significant impact on macroalgae diversity on Kotok Besar Island.

In conclusion, the macroalgal diversity in the waters of Seribu Islands, Jakarta, Indonesia, remains relatively high, despite indications of the impact of polluted environmental conditions. The discovery of 41 species of macroalgae indicates that the islands in Seribu Islands have significant ecological potential. However, it should be noted that the moderately classified diversity index signals that marine ecosystem protection in this area requires further attention. The importance of physicochemical factors such as temperature, depth, currents, salinity, Total Dissolved Solids (TDS), pH, dissolved oxygen (DO), copper (Cu), and phosphate as determinants of macroalgal diversity highlights the significance of monitoring and managing these parameters to ensure the sustainability of marine ecosystems in Seribu Islands. Recommendations based on the findings of this research include the necessity for further conservation measures to protect and preserve macroalgal diversity in this region. Environmental recovery and management efforts, such as pollution reduction and coral reef protection, need to be strengthened to ensure the survival of macroalgae and the overall marine ecosystem.

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