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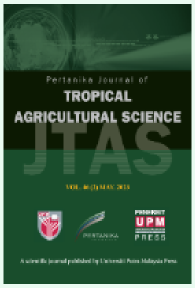

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Diversity, Abundance, and Distribution of Macroalgae in Coastal Ecotourism Areas — A Case Study at Baluran National Park, Situbondo, Indonesia

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ABSTRACT

Indonesia is a mega biodiversity country with abundant macroalgae. The macroalgae are distributed along the coast and function to maintain the balance of the coastal marine ecosystem, including in Bama Beach, Baluran National Park, Situbondo, Indonesia. This study was to determine the abundance, distribution, and diversity of macroalgae in Bama Beach Baluran National Park, East Java, between April 2019 and June 2019. The research was conducted with a purposive sampling method at two stations, each consisting of five substations using transect blocks. Five species of macroalgae from the Phaeophyceae class (*Padina australis*, *Sargassum aquifolium*, *Polycladia myrica*, *Eucheuma edule*, and *Dictyota pinnatifida*), a Rhodophyta (*Jania pumila*), and Chlorophyta (*Halimeda macroloba*) were found in the study site. *Padina australis* was a species that had the highest abundance and dominated the observation station. Nonetheless, according to the Shannon-Weaver Index in the study area, overall macroalgae diversity was classified as a low category with a value of 0.35. The high availability of nutrients influences these conditions in ecosystems

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with the domination of *Padina australis*, followed by *Sargassum aquifolium* at Station I and II.

Keywords: Baluran National Park, diversity, macroalgae

INTRODUCTION

Indonesia is a maritime country with a coastline of 95,161 km and has a high potential for marine resources, such as macroalgae (Kusmana & Hikmat, 2015). Previous studies have shown that Indonesia produces the highest macroalgae in biomass culture in Southeast Asia, surpassing the Philippines (Hurtado et al., 2019; Rimmer et al., 2021). Another study also stated that 555 seaweed species are found in Indonesia, and 55 of them have high economic value, such as *Gracilaria* and *Euchema* (Meinita et al., 2021). As the primary producer in the coastal ecosystem, macroalgae are not a plant but an informal group of protists (Eliáš, 2021). Macroalgae are divided into three groups: brown algae (Phaeophyceae), green algae (Chlorophyta), and red algae (Rhodophyta) (Oryza et al., 2017). The presence of macroalgae is essential due to its function as a nursery, spawning, and feeding grounds for small fish and herbivorous animals (Burkepile et al., 2013; Rasher et al., 2013). It maintains the biodiversity of the coastal ecosystem (Wade et al., 2020).

Baluran National Park represents the forest ecosystem in Java Island (Indonesia), which consists of savanna, beach, coastal mangrove forests, and jungles (Nuzula et al., 2017). Bama Beach, with a length of 42 km, has a high diversity of macroalgae due to its clean and well-maintained sandy substrate (Arisandy et al., 2012). Therefore, Bama Beach is a suitable place to host a variety of aquatic organisms. At least eight macroalgae species were found in the recent study, with the dominance of *Padina australis* (Anugrah et al., 2019). This area also has a seagrass bed with a 48.9% abundance composition dominated by *Cymodocea serrulata* (Ulkhaq et al., 2016). Bama is often visited for tourism, research, and educational purposes. However, using this area as a tourist area threatens the preservation of existing ecosystems, including coastal areas. According to a previous study, there was an increase in visitors during the 2014–2015 period, which reached nearly sixty thousand visitors, an increase of 50% from the previous year due to its beautiful coastal area (Nuzula et al., 2017). A previous study stated that the development of the tourism sector degrades the quality of the ecosystem and organisms in Baluran National Park (Purnomo et al., 2020). Therefore, it will be a threat to the existing macroalgae ecosystem.

The purpose of this study was to observe the distribution of macroalgae to find out the phenomena and dynamics of ecosystems that occur as a basis for area management. The distribution of macroalgae in intertidal ecosystems depends on environmental conditions, such as location, shore level, salinity, temperature, and organic nutrients (Thongroy et al., 2007). This information is important to base an integrated understanding of conservation and restoration policies because if the water conditions change and are not following their living conditions, macroalgae will be threatened. Furthermore, the movement of water and nutrients also distributed therein has an important role in determining seaweed productivity (Anderson et al., 2005). Baluran National Park has a dry climate type F with temperatures of 27.2 – 30.9 °C, average humidity of 77%, and wind speed of 7 knots (Nuzula et al., 2017). Furthermore, the rainy season occurs from November to April, while the dry season starts from April to October (Istomo & Ghifary, 2021).

MATERIAL AND METHODS

Research Location

The research was conducted in Bama Beach, Baluran National Park, East Java, Indonesia. The location is a semidiurnal tidal pattern described in a previous study (Putrisari et al., 2017). The location has a variety of habitats, such as mangroves, coral reefs, savanna, and beach. Moreover, these areas have a physical landscape structure for beach tourism, snorkeling, diving, and mangrove tours. Two stations were decided based on a purposive sampling method following the characteristic land uses, i.e., Station I (7°50'40.1" S and 114°27'41.5" E), which was an open tourist area. At the same time, Station II (7°50'40.7"S and 114°27'40.3"E) was an area protected with mangrove vegetation (Figure 1). The consideration for choosing this location is that both stations are in an open-access area for visitors. Other areas are inaccessible because there are many wild animals in the national park.

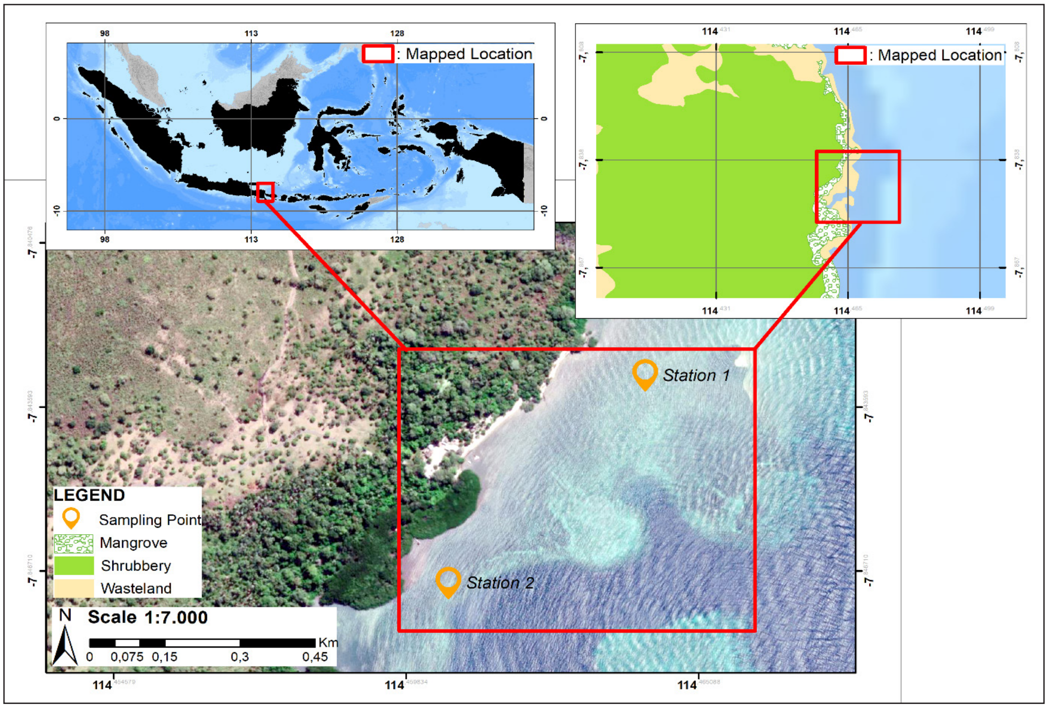

Figure 1. Map location of this study

Data Collection

The data collection was done in April, May, and June 2019. The sampling was conducted using the modified 2 m × 2 m transect block method installed from the coastline 50 m into the sea (Lelloltery et al., 2021). Furthermore, there were five sub-stations in each sample station with a distance between each sub-station of 10 m as replication. A camera (SeaLife Micro 3.0, Sony, Japan) observed the number of macroalgae samples when the tidal was low by diving at each sub-station. The representative macroalgae were taken at each transect block plot, preserved with 4% formaldehyde (Merck, German), and labeled to be analyzed in the laboratory (Khalil et al., 2021).

Analytical Method

The macroalgae identification was conducted by comparing external morphological characteristics in the previous study (Al-Yamani et al., 2015). The identified characteristics were body shape, color patterns, and thallus shape. Each characteristic was compared with the pictures in the references book, and the type of macroalgae was identified according to the compatibility between the sample and the references book. Also, chemical and physical parameters were measured from each station simultaneously with biota collection. It consists of in-situ parameters, i.e., temperature (AMTAST EC910, USA), sea surface current (Secchi Disk APAL-SCD, Indonesia), pH (AMTAST EC910, USA), salinity (refractometer; Atagao, Japan), and dissolved oxygen (DO) (AMTAST EC910, USA). In the meantime, the *ex-situ* parameters (nitrate and phosphate) were conducted using a volume sampler of 250 mL polyethylene bottle and kept in a cold box for analysis in the laboratory (Takarina et al., 2019). The nutrient analysis was conducted by spectrophotometer (Model AMV01 AMTAST, USA), as described in a previous study (Emilia, 2019). Soil and sediment samples from the two sampling stations were analyzed using the gravimetric triangle method to determine the criteria, the percentage of sediment composition, and the type of constituent textures (Anggraini et al., 2020).

Data Analysis

The distribution of macroalgae found at each research station was tabulated and presented descriptively. Furthermore, to determine the diversity of macroalgae (*H'*) by quantitative data (involving a number of individuals of each species or ni and the number of individuals of all types or N), the Shannon-Weaver formula was used (Shanon & Weaver, 1949). In addition, the evenness index value (*E*) was used to describe the individual components of each species contained in a community, and the dominance of macroalgae in waters was determined according to the Simpson Dominance Index (*C*) (Simpson, 1949). Finally, the Important Value Index (IVI) was added for assessing the importance of population structure (Curtis & Mcintosh, 1950).

$$\boldsymbol{H' = -\sum\left(\frac{ni}{N}\right) x \ ln\,(\frac{ni}{N})}$$

Note.
H' = index of diversity
ni = number of individuals of each species
N = number of individuals of all types

$$E = \left(\frac{H'}{ln\ S}\right)$$

Note.
E = equitability index
H' = index of diversity
S = number of species

$$C = \sum \left(\frac{ni}{N}\right)^2$$

Note.
C = Index of dominance
ni = The number of individuals of each species
N = Number of individuals of all types

$$\mathbf{IVI = RD + RF + RDO}$$

Note.
IVI = Important Value Index
RD = Relative density
RF = Relative frequency
RDO = Relative dominance

The data was presented in graphs or images, then descriptively analyzed based on the relevant literature in discussing and concluding the results.

RESULTS AND DISCUSSION

Water Parameters

The results of the water parameters at both stations were generally suitable for the survival of macroalgae (Table 1). The data salinity, pH, and temperature from Station I showed 29.41 g.L^{-1}, 8.03, and 28.87 ^{o}C, while the data salinity, pH, and temperature from Station II showed 30.6 g.L^{-1}, 8.16, and 30.06 ^{o}C. Climate change impacts the temperature of seawater (Doney et al., 2012; Gaitán-espitia et al., 2014). The ideal temperature for macroalgae survival is 25–35 ^{o}C. Meanwhile, good salinity for macroalgae learning and success is 28–33 g.L^{-1}. Salinity that is too high or too low disrupts macroalgae growth (Kamer &

Table 1
Physical-chemical water quality measurement in the site study (90 samples size for each parameter at each station)

Parameters	Unit	Station I	Station II	Macroalgae's habitat standard
Temperature	^{o}C	28.87 ± 1.35	30.06 ± 1.17	24 – 32
Dissolved oxygen	mg.L^{-1}	7.33 ± 0.40	7.73 ± 0.47	8.4 – 9.2
Salinity	g.L^{1}	29.41 ± 1.80	30.6 ± 1.21	28 - 33
Sea surface current	cm.s^{-1}	50.36 ± 13.8	43.12 ± 14.79	20 – 40
pH		8.03 ± 0.11	8.16 ± 0.35	7 – 8.5
Nitrate (NO_3)	mg.L^{-1}	8.63 ± 1.19	13.33 ± 1.52	>0.04
Phosphate (PO_4)	mg.L^{-1}	0.26 ± 0.01	0.25 ± 0.02	>0.1
Substrate percentage		sand (45%), loam (20%), clay (35%)	sand (40%), loam (40%), clay (20%)	*Depend on macroalgae species
Substrate categories		Sandy clay	Sandy loam	

Fong, 2000). On the other hand, because pH is a carbon dioxide (CO_2) balance in the water, small fluctuations in value can affect macroalgae life (Gaitán-espitia et al., 2014). A common feature of these changes is a deterioration in water quality enriched with resources, particularly nitrogen nutrients, from land-based activities (Wahl et al., 2015).

In this study, the dissolved oxygen, nitrate, and phosphate values from Station I were 7.33 $mg.L^{-1}$, 8.63 $mg.L^{-1}$, and 0.26 $mg.L^{-1}$, respectively, with a substrate of sandy clay. Meanwhile, the dissolved oxygen, nitrate, and phosphate values from Station II were 7.33 $mg.L^{-1}$, 13.33 $mg.L^{-1}$, and 0.25 $mg.L^{-1}$ with a substrate of sandy loam. Seaweed cannot survive in water with a low-brightness mud substrate. Therefore, clear waters ranging from 2 to 12 m with a sandy mud substrate are ideal. Furthermore, based on surface sea current measurements taken during observations, the speed range of the sea surface currents around the sampling range is approximately 30 $m.s^{-1}$ (Figure 2). The speed of ocean currents significantly impacts macroalgae colony survival because they transport organic material that affects brightness. Furthermore, the high current velocity can uproot macroalgae from the substrate. Therefore, the ideal current for macroalgae growth ranges between 20 and 40 $m.s^{-1}$ (Marianingsih et al., 2013).

Macroalgae Diversity

A total of seven macroalgae species were found during the study (Table 2). They consisted of the Phaeophyta class with five species (*Padina australis*, *Sargassum aquifolium*, *Polycladia myrica*, *Euleuma edule*, and *Dictyota pinnatifida*) and

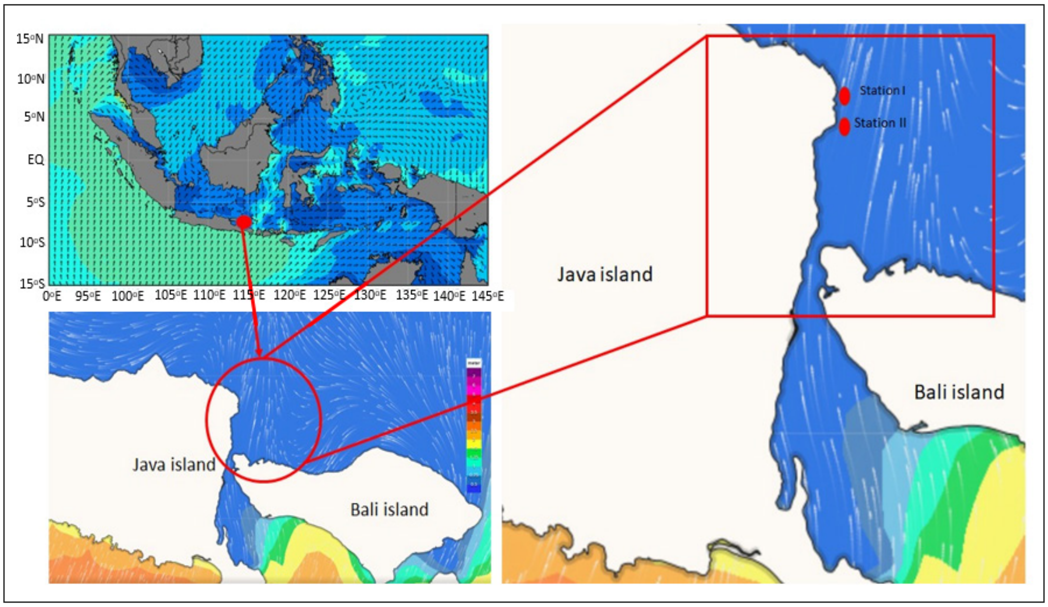

Figure 2. Characteristics of the sea at the study site (Badan Meteorologi, Klimatologi, dan Geofisika [BMKG], 2022)

Table 2
Macroalgae distribution at site study and habitat in the study location

Species	April 2019		May 2019		June 2019		Type of substrate
	St. I	St. II	St. I	St. II	St. I	St. II	
Padina australis	+	+	+	+	+	+	Sand and coral
Sargassum aquifolium	+	+	+	+	+	+	Sandy
Polycladia myrica	+	+	+	+	+	-	Sandy
Jania pumila	-	-	-	-	+	-	Coral and stone
Eucheuma edule	-	-	-	-	+	+	Coral and stone
Dictyota pinnatifida	+	-	-	-	-	-	Sandy
Halimeda macroloba	+	-	-	-	-	-	The mud around the seagrass

Note. + = Present; - = Absent

one species from the Rhodophyta and Chlorophyta classes (*Jania pumila* and *Halimeda macroloba)*. *Padina australis*, *Sargassum aquifolium*, and *Polycladia myrica* were found at each station for most of the observation. In contrast, *Jania pumila* and *Eucheuma edule* were only found at Station I in June. Furthermore, *Dictyota pinnatifida* and *Halimeda macroloba* also were only found in April.

The abundance data of macroalgae is presented in Table 3 and Figure 3. *Padina australis* and *Sargassum aquifolium* appeared consistently in each station. The previous study showed that *Padina* and *Sargassum* were found in Situbondo (Anugrah et al., 2019; Indahyani et al., 2019; Siswanto, 2005). Their presence indicated that water quality parameters in Bama Beach showed optimal values for the growth of *Padina australis* and *Sargassum aquifolium*, especially for nitrate and phosphate (Supardi & Nugroho et al., 2019; Wahyuningtyas et al., 2020). Nitrates and phosphorus also have a role in increasing the growth of macroalgae (Xu et al., 2020).

Interestingly, the presence of *Jania pumila*, *Euchema edule*, *Dictyita pinnatifida*, and *Halimeda macrobola* was not stable between April to June. The increase or decrease of macroalgae species in an area normally occurs. Previous research stated that this was caused by the natural process of species succession in the community (Jung & Choi, 2022). This phenomenon happens immediately with the appearance of ephemeral species after the detachment of old algae (Tytlyanov et al., 2014). For example, the presence of *Jania pumila* and *Eucheuma edule* only appeared in June might be due to currents that carried these types of seaweed from other areas and grew in Bama Beach. Meanwhile, ocean currents brought *Dictyota pinnifida* and *Halimeda macroloba* to Bama Beach in April. A previous study stated that in May and June (the new dry season), a southeast monsoon would appear in Indonesia and cause the macroalgae to bloom and more abundance (Setyawidati et al., 2018). However, when the southeast monsoon comes, the current will flow from Australia to Indonesia and

Table 3
Macroalgae abundance at site study and habitat in the study location

Species	April 2019		May 2019		June 2019		Total	
	St. I	St. II	St. I	St. II	St. I	St. II	St. I	St. II
Padina australis	2	5	2	1	2	1	6	7
Sargassum aquifolium	0	1	1	1	0	0	1	2
Polycladia myrica	1	1	0	1	0	0	1	2
Jania pumila	0	0	0	0	1	0	1	0
Eucheuma edule	0	0	0	0	1	1	1	1
Dictyota pinnatifida	2	2	0	0	0	0	2	2
Halimeda macroloba	1	0	0	0	0	0	1	0

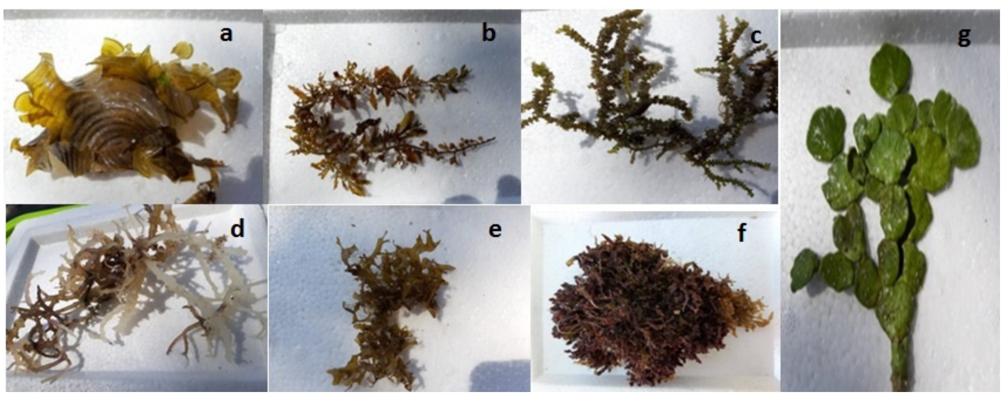

Figure 3. Macroalgae species discovered at the study site: a: *Padina australis*, b: *Sargassum aquifolium*, c: *Polycladia myrica*, d: *Eucheuma edule*, e: *Dictyota pinnatifida*, f: *Jania pumila*, g: *Halimeda macroloba*

change other water quality parameters (temperature, DO, pH) due to upwelling so that it can change the abundance of aquatic organisms (Hasyim et al., 2022).

DO parameters in this study were also low (7.33 ± 0.40 for Station I and 7.73 ± 0.47 for Station II). It causes the presence of *Jania pumila*, *Euchema edule*, *Dictyita pinnatifida*, and *Halimeda macrobola* to be unstable at the study site. DO is essential since macroalgae will invert it as oxygen for life (Subur et al., 2021). DO deficiency can cause mortality in macroalgae (Solidoro et al., 1997). This case differs from *Padina australis*, which is present every month in this study. Previous research stated that *Padina australis* could live with a DO value of only 3.51 ± 0.53 mg.L^{-1} at Lae-lae Island Makassar Marine Waters, South Sulawesi, Indonesia (Supardi & Nuhroho, 2019). Likewise, *Sargassum aquifolium* was also found in this study every month. Wahyuningtyas et al. (2020) stated that these macroalgae could live at DO 5.8 mg.L^{-1} in Sumenep, Madura, Indonesia. It indicated that the two macroalgae could be tolerant of low DO.

Species succession is also related to the different abilities of macroalgae to adapt to the environment. Environmental changes such as climate changes, land-use changes in coastal areas, and pollution affect the distribution, abundance, and physiological changes in aquatic organisms, including macroalgae (Firth & Hawkins, 2011). Macroalgae are sessile organisms; thus, they are susceptible to environmental changes and have a limited distribution (Coleman et al., 2011; Prathep et al., 2008). Janah et al. (2021) explain that there were at least three patterns in the distribution patterns, namely uniform, random, and clustered patterns. In addition, each species of macroalgae has a different distribution and habitat, which could affect the morphological characteristics, such as color, the shape of the thallus, and holdfast (Poloczanska et al., 2013).

This study revealed that *Sargassum aquifolium, Polycladia myrica*, and *Dicolota pinnatifida* have the form of stolon, distributed in sandy substrates. Meanwhile, *Jania pumila* are disk-shaped and found on rocky substrates. The form of holdfast stolon was generally an adaptation of macroalgae to a sandy substrate, while the shape of a disc is an adaptation of macroalgae that live on hard substrates (Wahl et al., 2015).

Based on the important value index, it was found that *Padina australis* had the highest value (Figure 4). It reflects that *Padina australis* has an important role in the ecosystem and species that will affect other components. In addition, this species also has the highest abundance compared to other species. Anugrah et al. (2019) also found that this species dominated during the observation in April. *Padina australis* is an organism that has fairly high adaptability, grows and attaches strongly to rocky substrates, and survives even in dry conditions (Kautsari & Ardiansyah, 2016). In contrast, *Halimeda macroloba* was the rarest species in April at Station I in seagrass areas with sand substrate, with the lowest abundance. *Halimeda macroloba* is often found on sandy substrates with a combination of coral fragments but not on dead coral substrates (Ain et al., 2014). The low *Halimeda macrolaba* found at the study site is influenced by the substrate available in the ecosystem and its relatively short life cycle (Nontji, 1993).

The diversity index calculation results of the two observation stations were 0.35 and included in the low category (Figure 5). These conditions describe an imbalance in the ecosystem, which was characterized by

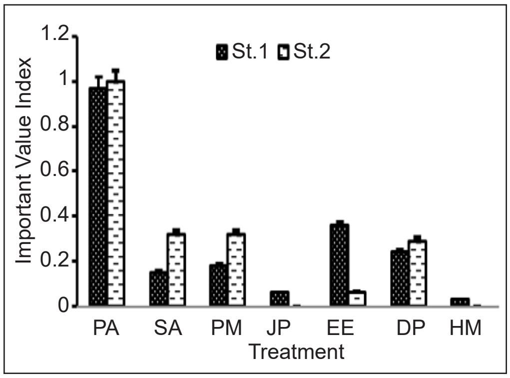

Figure 4. The important value index of macroalgae on the site study

Note. *Padina Australis* (PA), *Sargassum aquifoliu* (SA), *Polycladia myrica* (PM), *Jania pumila* (JP), *Eucheuma edul* (EE), *Dictyota pinnatifida* (DP), and *Halimeda macroloba* (HM) the emergence of the dominance of certain species in the macroalgae community. Balanced ecosystems are characterized by stable community conditions and high species diversity (Jamilatun et al., 2020). The low value of the diversity of macroalgae might be caused by tourism activity in Bama Beach. The beach can attract up to 60,000 visitors yearly (Nuzula et al., 2017), with activities such as traveling, diving, and snorkeling (Mahendra et al., 2020). This activity can cause pollution, affect ecosystems, and damage marine biodiversity (Sidauruk et al., 2022). A previous study stated that this activity destroyed Bama Beach's diversity to a depth of 3 m (Fahmi et al., 2017).

Not only anthropogenic activity but the low value of the diversity of macroalgae species in the community is also due to environmental changes such as increased salinity, low availability of nitrates and orthophosphates, sunlight intensity, and the level of turbidity and sedimentation (Collado-Vides et al., 2007). Environmental changes, such as high-temperature fluctuations, influence the distribution of macroalgae, especially *Eucheuma* sp. and *Gracilaria* sp. (Martínez et al., 2012). A strong correlation between environmental variables and vegetation structure was observed in Baltic waters (Eriksson & Bergström, 2005). Interestingly, no *Gracilaria* was found in this study. *Gracilaria* is a species that is easily found almost all over the coast of Indonesia (Pamungkas & Djonu, 2022). It might be due to previous reasons regarding environmental changes and fluctuations that affected the existence of *Gracilaria* sp. It can disrupt its growth and metabolism (Hendri et al., 2018). Bama Beach's temperature changes easily due to another water parameter (Anugrah et al., 2019).

Furthermore, the evenness index for Station I in the medium category was 0.54, and the low category in Station II was 0.37 (Figure 5). One of the factors that influence the growth of macroalgae is the water flow and type of substrate, where both factors determine the form of the holdfast; it occurs due to the process of macroalgae adaptation to the environment (Eriksson & Bergström, 2005; Jamilatun et al., 2020; Litaay, 2014). Although the type of substrate determines the variation of macro types of algae that grow, the same type of substrate tends to have the same diversity (Herlinawati et al., 2017). In addition, the dominance index of the two stations was also included in the low category, which was 0.24 and 0.25, respectively (Figure 5). This condition was thought to be influenced by the basic characteristics of the waters in the study

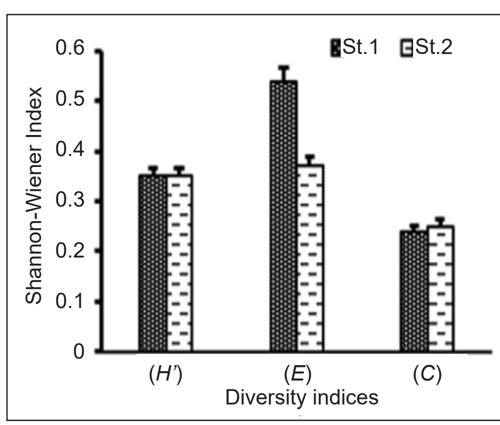

Figure 5. Diversity indices of macroalgae in the study site
Note. Diversity Index (*H'*), Evenness Index (*E*), and Dominance Index (*C*)

location and biotic component fluctuations. The dominance of seagrass in the exact location as the medium category was found during the transition season (Ulkhaq et al., 2016). In addition, International Association for Cryptologic Research (IACR) 1999 macroalgae will multiply at temperatures above 20 ^{o}C (1–2 weeks), while temperatures below 10 ^{o}C require longer (6–8 weeks).

Nonetheless, the overall state of the waters at the study site indicates that they are still within tolerance limits for macroalgae survival. Thus, the dynamics of the distribution and dominance of macroalgae on the Bama coast are likely influenced by environmental factors, such as nutrition and competition between species. Furthermore, environmental tolerance influences species distribution more strongly at high (sub-tropical) latitudes, whereas other factors, such as biotic interactions, play a more prominent role in the tropics (Keith et al., 2014).

CONCLUSION

Five species from the Phaeophyta group and one from the Chlorophyta and Rhodophyta groups were reported in Bama Beach, Baluran National Park, Situbondo, Indonesia. *Padina australis* from the class Phaeophyta was the highest distribution and abundance. However, each station's value of diversity, uniformity, and dominance was in a low category. The distribution and abundance of macroalgae showed the highest in areas with sufficient sunlight intensity and coral substrates and rocks.

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