

Research Paper

SPATIAL DISTRIBUTION PATTERNS AND SPECIES DIVERSITY OF BENTHIC MACROALGAE ALONG UJUNG GENTENG COAST, WEST JAVA, INDONESIA

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ARTICLE HIGHLIGHTS

- The study in Ujung Genteng coast presents clear evidence of moderate macroalgae diversities and community structure linked to environmental parameters and substrate type
- The biological indices scores illustrated a spatial distribution pattern of macroalgae assemblages
- Understanding these ecological dynamics of macroalgae is crucial for both conservation and sustainable seaweed cultivation.

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ABSTRACT

This study examined the spatial distribution patterns of benthic macroalgae in Ujung Genteng in relation to the environmental parameters that support growth and influence marine ecosystem health. Field work was conducted from May to December 2023. Observation sites were selected using a purposive sampling method across three coastal zones distinguished by physical landscape characteristics and substrate types. Data were collected using the line transect-quadrat method. A total of 41 benthic macroalgal species representing 28 genera and 19 families were identified. The green alga *Boergesenia forbesii* emerged as the dominant species, comprising 16.8% of the assemblage; however, this dominance was not statistically significant. Macroalgal distribution exhibited noticeable spatial variation, with the East Zone representing the most favorable habitat, supporting 32 species and 312 individuals. The marine ecosystem of Ujung Genteng was in relatively good condition, as indicated by moderate Shannon Diversity Index (H') values (2.52 to 2.70), high Evenness Index (E) values (0.73 to 0.82), and low Dominance Index (D) values (0.09 to 0.11). Measured abiotic parameters, including pH, temperature, salinity, current velocity, and water clarity, were within ranges conducive to benthic macroalgal growth. Understanding macroalgal ecological dynamics in natural habitats is essential for conservation efforts and the sustainable development of seaweed cultivation.

Keywords: benthic macroalgae, spatial, distribution patterns, Ujung Genteng

INTRODUCTION

Indonesia's marine ecosystems support a rich and diverse assemblage of benthic macroalgae species (seaweeds), with at least 325 documented species, including 103 Chlorophyceae (green algae), 167 Rhodophyceae (red algae), and 55 Phaeophyceae (brown algae) (Basyuni *et al.* 2024). This high biodiversity is influenced by multiple environmental factors, including nutrient availability, grazing pressure, competition, physical tolerance, light intensity, water circulation, and habitat type. Scientific research on Indonesian macroalgae began with the Siboga Expedition (1899 – 1900), which

documented more than 700 macroalgal species in Indonesian waters (Weber-van Bosse 1928 in Tampubolon *et al.* 2013). Subsequent studies included the Danish Expedition to Kei Island (1992), the Snellius-II Expedition (1984 – 1985), and the Bugenesia Program (1980 – 1988).

Benthic macroalgae are autotrophic organisms that attach to the seafloor or substrates such as rocks, sand, and coral reefs. These organisms provide substantial ecological and economical benefits. Species such as *Ulva* sp., *Enteromorpha* sp., and *Caulerpa* sp. are commonly consumed as food, whereas *Encheuma* sp., *Gracilaria* sp., *Gelidium* sp., *Boergesenia forbesii*, and *Sargassum* sp. are utilized

not only as food but also as raw materials for pharmaceutical, cosmetic, and paper industries (Tampubolon *et al.* 2013; Rumengan *et al.* 2014; Melati 2021). Ecologically, benthic macroalgae serve as habitats and food sources for diverse marine organisms, including crustaceans, molluscs, echinoderms, fish, and microalgae. Their complex morphology also contributes to wave attenuation and coastal protection.

Macroalgal presence is widely recognized as an indicator of marine ecosystem health, as many marine communities depend on macroalgae for food and shelter. The distribution, diversity, and abundance of macroalgae are influenced by environmental factors such as temperature, light availability, salinity, nutrient concentration, current velocity, tidal exposure, and depth, which collectively regulate photosynthetic capacity and growth (Karleskin *et al.* 2010). Macroalgal species exhibit substrate-specific preferences, and substrate types plays a critical role in shaping community structure and spatial distribution. Initial colonization often occurs through random settlement during propagule stage, whereas subsequent survival and growth are governed by biological interactions and abiotic conditions (Ko *et al.* 2024). In intertidal ecosystems, substrates such as rock, sand, mud, coral reefs, and artificial structures strongly influence macroalgal growth, distribution, and ecological interactions, thereby affecting overall ecosystems health (Imchen 2015).

Benthic macroalgae are distributed across diverse coastal regions of Indonesia, including the Ujung Genteng coastal area in Sukabumi District, West Java Province. However, studies describing macroalgal diversity and spatial distribution in this region remain limited, despite their importance for sustainable coastal and macroalgal resource management. The Ujung Genteng coastal ecosystem remains relatively natural and includes seaweed beds, seagrass meadows, coral reefs, and mangrove forests, with substrates composed of sand, mud, coral fragments, coral crevices, and rock. The surrounding coral reef ecosystem is classified as fringing reef and is generally degraded, with coral cover below 10% (Erlania *et al.* 2015). Ujung Genteng Beach is part of the Ciletuh Palabuhanratu Geopark, a National Geopark known for its green turtle conservation area and high tourism activity. Tourism development may cause pressure on this sensitive ecosystem, highlighting the need for sustainable management to protect macroalgal communities and the broader

marine environment. Therefore, this study aimed to analyse the community structure of benthic macroalgae and evaluate the influence of local environmental parameters on their distribution patterns. Understanding these relationships is crucial for studying intertidal ecological dynamics and supporting effective and sustainable coastal management strategies in Ujung Genteng waters.

MATERIALS AND METHODS

Study Area

This study was conducted from May to December 2023 in the Ujung Genteng Coastal Area (7°22'54.2" S; 106°24'25.2" E), a popular local tourist destination. Data were collected using the line transect-quadrat method (English *et al.* 1994). Observation sites were determined using a purposive sampling method covering three coastal zones, based on the physical landscape structure and distinct substrate types (Zebua 2017; Aprilia *et al.* 2023), i.e., the West Zone (the western part of the coast), the South Zone (the southern part), and the East Zone (the eastern part) (Fig. 1).

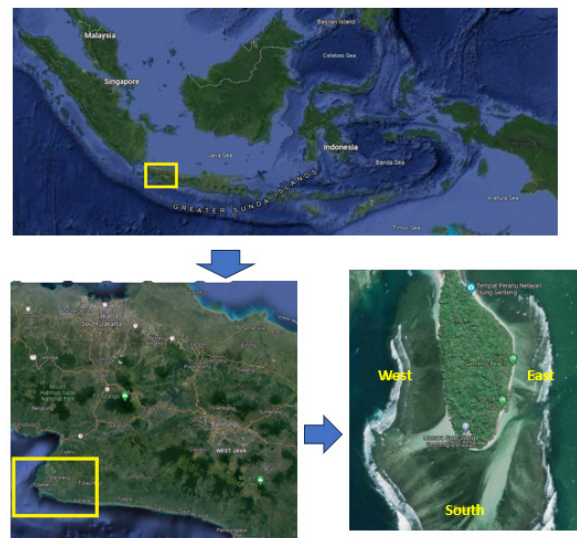


Figure 1 Location of the study and sampling sites along the coastline of Ujung Genteng

Source : <https://maps.google.com>

Sample Collection and Identification

Biotic and abiotic data were collected at the designated zones/stations (West, South, and East) following the procedure suggested by Handayani *et al.* (2020). In each zone, five haphazardly placed 100-meter transect lines were established perpendicular to the coastline (Fig. 2). Along each transect, five quadrats (size of 1 m x 1 m each) were positioned at regular 20 m intervals to quantify

macroalgal cover and species composition (Ariani *et al.* 2017). A total of 25 macroalgal samples were collected from each zone.



Figure 2 Systematic sampling design illustrating 1 m x 1 m quadrat plots in each zone, with five replicate measurements along each transect line. Source: <https://maps.google.com>

Macroalgal samples were collected from each quadrat along the transect lines during low tide using photographic and destructive sampling techniques (Nurmiyati 2013; Piazzzi *et al.* 2019). The photographic method was used to document dominant taxa and morphological groups, while the destructive method is widely recognized as appropriate for assessing assemblage structure, biodiversity, and biomass (Piazzzi *et al.* 2019). Both approaches are considered suitable and cost-effective for monitoring macroalgal assemblages and conducting environmental impact assessments (Cecchi *et al.* 2014). During sampling, macroalgal assemblages were photographed for documentation, and then carefully removed from the substrate using a sharp knife to ensure collection of the complete assemblage, including the holdfast. Samples were carefully placed into labeled, airtight plastic bags without compression and preserved in 70% ethanol prior to transport to the laboratory for further processing and analysis.

In the laboratory, macroalgal samples were identified to species level based on morphological characteristics of the thallus, including overall form, size, color variation, branching pattern, growth form, texture, holdfast type, and reproductive

structures. Identification was conducted using standard and credible taxonomic references, including Coppejans *et al.* (2009), Sukiman (2011), Al-Yamani *et al.* (2014), and Handayani *et al.* (2014).

Abiotic parameters such as substrate type, temperature, current velocity, water clarity, pH, and salinity were measured *in situ* (Sukiman 2011). Substrate type was visually assessed and documented directly. Water temperature was measured using a thermometer, current velocity was assessed with a current drogue, water clarity was determined using a Secchi disk, pH was measured with a pH meter, and salinity was gauged using a salinity meter.

Data Analysis

The data collected during the study were analyzed using descriptive statistics to describe, illustrate, and summarize the data. It was expected that a specific pattern might emerge in tables and graphs, describing the macroalgal distribution in Ujung Genteng. The spatial distribution of macroalgae was analyzed using one-way ANOVA in SPSS version 16.0 to investigate significant differences in distribution patterns and community structure among the three coastal zones. The ecological functioning of macroalgae communities was assessed using several biological indices proposed by Indarjani and Nurhayati (2022), including Shannon-Wiener Index (H') for measuring taxa diversity, the Evenness Index (E) to analyze the distribution of taxa within the community, and the Simpson Dominance Index (D) to identify dominant taxa associated with the assemblages.

RESULTS AND DISCUSSION

Characteristics of the Ujung Genteng Intertidal Zone

Ujung Genteng coastal area ($7^{\circ}22'54.2''$ S; $106^{\circ}24'25.2''$ E) is relatively protected from wave breaks with a wide intertidal area reaching up to about 150 m toward the center and a depth of up to 85 cm. The area features a diverse range of habitats, including seagrass meadow, edge-of-the-sea coral beds, and coral flats in the mid-intertidal area near the wave break zone, where macroalgae were abundant. The coast is characterized by diurnal tides, with two high tides and two low tides each day. Variations of land use in Ujung Genteng ranging from plantations and agriculture, fishery ports, shrimp farms, tourism areas, and conservation areas. Anthropological activities

around this coastal area highly affect the macroalgal communities.

For benthic organisms, substrate types greatly influence the presence of macroalgae. The West Zone is dominated by sand and seagrass meadow, with some coral, while the South Zone has substrate type consisting of sand, seagrass meadow, and reef crevices. The East Zone has a substrate characteristic dominated by sand, coral, and a little seagrass. This finding aligns with other research (Johan *et al.* 2015; Effendi *et al.* 2024), which showed that the substrate types influence the structural community of macroalgae assemblages.

Environmental Analysis

Diverse marine environmental conditions significantly influence the composition of macroalgae in each zone. To explore this connection, measuring key factors such as temperature, pH, current velocity, water clarity, salinity, and substrate types was crucial. Comprehensive details regarding the environmental parameters are presented in Table 1.

Generally, environmental conditions along the Ujung Genteng Coast support the growth rates and community composition of benthic macroalgae. pH ranged from 7.90 to 8.69 is ideal, as most benthic macroalgae can thrive at pH 6.6 to 9.9 (Ulfah *et al.* 2017). pH influences the metabolic and respiratory processes of macroalgae existence of organisms by disrupting metabolic and respiratory (Kartikasari *et al.* 2025). Additionally, water temperatures at all observation sites ranged from 28.1 °C to 32.8 °C, which was within the normal range. Temperature affects the photosynthesis process of benthic macroalgae growth. Arfah and Simon (2016) suggested that the optimal temperature for macroalgae growth in tropical waters was between 15 °C and 30 °C, with a growth threshold at 34.5 °C.

Salinity along the Ujung Genteng Coast varied from 20.0 to 39.5 ppt, falling within the optimum range for benthic macroalgae. Salinity influences metabolic process and reproductive capacity, which in turn determines their distribution and abundance in the intertidal zone (Larsen & Jensen 2006). Luning (1990), as cited in Arfah and Simon (2016), indicated that many species of benthic macroalgae can thrive across a broader salinity range. This was supported by Palalo (2013), who observed that macroalgae grow in waters with salinity levels from 13 to 37 ppt. Variation in salinity across the three coastal zones of Ujung Genteng waters may be attributed to differences in depth during measurement, as salt concentration tends to be higher at lower depths (Yulianda 2009). The current research reported that salinity levels in two different observed zones along Ujung Genteng waters were 34 and 35 ppt (Effendi *et al.* 2024).

Abiotic factor potentially detrimental to macroalgae growth is current velocity, which influences the distribution of nutrients necessary for photosynthesis. In this study, current velocity ranged from 7.7 cm/s to 25 cm/s, considered ideal for macroalgae growth. Current velocity above 40 cm/s may damage cultivation structures and break macroalgal assemblages (Marianingsih *et al.* 2013).

Sunlight availability is essential for photosynthesis. Water depth and clarity influence light penetration, determining which species can thrive. Our study found that water transparency at the three coastal zones was 100% at depths of 5 – 70 cm, indicating that macroalgae can grow optimally since sunlight can reach the bottom. Previous research reported that the depth for photosynthetic activity in macroalgae ranges from 0.6 to 6.5 meters or more (Arfah & Simon 2016).

Table 1 Environmental parameters in each zone of Ujung Genteng coastal area

Abiotic factors	West zone	South zone	East zone
pH	7.9 – 8.37	7.75 – 8.6	7.99 – 8.69
Temperature (°C)	28.6 – 30.4	28.8 – 30.0	30.4 – 32.8
Salinity (ppt)	20.0 – 28.8	31 – 38.2	37.3 – 39.5
Current (cm/second)	9.1 – 25	7.7 – 20	9.1 – 12.5
Clarity	100%	100%	100%
Substrate type	Sand, sea grass, coral fragments	Sand, sea grass, reef crevices	Sand, coral fragments and reef crevices

Variation of substrate types was observed across the three coastal zones of Ujung Genteng waters. The substrates primarily consisted of sand, coral fragments, reef crevices and seagrass. Different macroalgae possess varying attachment mechanisms. Rocky substrates support diverse communities, while seagrass can trap nutrients while limiting the growth of macroalgae that require full sunlight (Han *et al.* 2014). In contrast, sandy substrates, which are often unstable, may restrict macroalgal attachment; however, some opportunistic species can thrive in nutrient-rich sandy environments (Ko *et al.* 2024).

Benthic Macroalgae Compositions

Variation of types, species, and forms of macroalgae reflects the rich diversity of macroalgae in Ujung Genteng coastal waters (Tables 2 & 3). Benthic macroalgae collected during the study in Ujung Genteng comprised three divisions (Rhodophyta, Chlorophyta, and Phaeophyta), 19 families, 28 genera, and 41 species, totalling 1,909 individuals. This number was relatively comparable to a previous study in Ujung Genteng conducted by Johan *et al.* (2015), who found 24 genera, 34 species from Rhodophyta, Chlorophyta and Phaeophyta, and the current study (Effendi *et al.* 2024), which reported 19 genera, 23 species, and 3,884 individuals of macroalgae assemblages in Ujung Genteng waters.

Variations of macroalgae organisms were presumably due to the cover area of sampling sites, the plot site, and time. Macroalgae assemblages collected in Ujung Genteng waters were still considerably higher than in other places in Indonesian waters. A study in Ambon Bay, Moluccan waters, identified 21 species of macroalgae, comprising 10 species of Rhodophyta, six species of Chlorophyta, and five species of Phaeophyta (Litaay 2014). In addition, a study in Batu Putih National Park, Belitung Island, identified 18 species, comprising 15 families, across three divisions (Rhodophyta, Chlorophyta, and Phaeophyta) (Langoy *et al.* 2012). Meriam *et al.* (2016) observed macroalgae assemblages in Mantehage Island waters, North Sulawesi, which consisted of green algae (Chlorophyta) comprised 3 orders, 6 families, 11 genera, and 23 species, while brown algae (Phaeophyta) included 3 orders, 3 families, 5 genera, and 5 species. Red algae (Rhodophyta) had 4 orders, 8 families, 10 genera and 16 species. The difference in the number of species was due to varying local natural conditions

and environmental factors, which influence the presence of macroalgae in a specific location.

Rhodophyta division was found to be more diverse than Chlorophyta and Phaeophyta. The Rhodophyta Division (red algae), considered having the highest diversity, consisted of 22 species across 13 genera and 10 families and contributed 56% to the macroalgae assemblages, which were dominated by *Gracilaria coronopifolia*. In comparison, the Chlorophyta (green algae) comprised 13 species, distributed across 11 genera and six (6) families and made up 32% of the assemblages, which were dominated by *Boergesinia forbesii*. The division with the lowest diversity was Phaeophytan (brown algae), with 6 species from 4 genera and 3 families and dominated by *Padina australis*.

These findings align with research conducted by Johan *et al.* (2015), which identified 15 species of Rhodophyta, 14 species of Chlorophyta, and 5 species of Phaeophyta in the waters of Ujung Genteng beach. Mudrikah *et al.* (2024) noted that the significant diversity of Rhodophyta may be attributed to its effective sexual and asexual reproduction methods, which facilitate rapid growth and reproduction. Additionally, its adaptability to different environments allows it to flourish in both intertidal zones and deep-sea regions.

Conversely, *B. forbesii* from Chlorophyta was observed as the dominant species, with 312 individuals, or 16.8% of the total macroalgae found in this area. This situation was comparable with a previous study in Ujung genteng that Chlorophyta had the highest coverage (46.40%) compared with Rhodophyta and Phaephyta (Johan *et al.* 2015) and a similar situation with the current study (Effendi *et al.* 2024). This species is commonly found in intertidal areas where fluctuating environmental conditions are often occur. Besides, this algae species typically attaches to hard substrates like crevices, fragmented dead coral, rock and even other algae (Guiry *et al.* 2014) which was also observed in this study.

In the intertidal zone, Chlorophyta plays a crucial role in aquatic ecosystems as primary producers in the food chain, with their growth heavily reliant on high levels of sunlight. Besides this, greean algae was able to grow in various types of substrate, as observed in Ujung Genteng waters.

Table 2 Taxonomic composition of macroalgae assemblages in Ujung Genteng coastal area

No	Division	Species	West Zone	South Zone	East Zone	Total Abundance
1	Chlorophyta	<i>Boergesinia forbesii</i>	83	99	130	312
2	Chlorophyta	<i>Boodlea</i> sp.	3	5	0	8
3	Chlorophyta	<i>Caulerpa peltata</i>	1	0	0	1
4	Chlorophyta	<i>Chaetomorpha crassa</i>	13	67	43	123
5	Chlorophyta	<i>Cladhopora</i> sp.	10	0	1	11
6	Chlorophyta	<i>Dictyosphaeria carnevosa</i>	3	5	1	9
7	Chlorophyta	<i>Enteromorpha intestinalis</i>	9	4	6	19
8	Chlorophyta	<i>Halimeda gracillis</i>	9	1	6	16
9	Chlorophyta	<i>Ulva latuca</i>	0	0	8	8
10	Chlorophyta	<i>Ulva reticulata</i>	17	25	15	57
11	Chlorophyta	<i>Valonia fastigiata</i>	1	2	19	22
12	Chlorophyta	<i>Valonia ventricossa</i>	4	0	0	4
13	Chlorophyta	<i>Valoniopsis pachinema</i>	6	4	11	21
14	Phaeophyta	<i>Hydroclatus clathratus</i>	2	0	2	4
15	Phaeophyta	<i>Padina australis</i>	3	62	151	216
16	Phaeophyta	<i>Sargassum binderi</i>	0	4	0	4
17	Phaeophyta	<i>Sargassum duplicatum</i>	0	1	2	3
18	Phaeophyta	<i>Sargassum</i> sp.	0	6	2	8
19	Phaeophyta	<i>Tubinaria ornata</i>	0	0	3	3
20	Rhodophyta	<i>Acanthophora muscoides</i>	46	57	102	205
21	Rhodophyta	<i>Acanthophora spicifera</i>	1	38	15	54
22	Rhodophyta	<i>Amphiroa anceps</i>	0	0	1	1
23	Rhodophyta	<i>Amphiroa fragilissima</i>	16	22	5	43
24	Rhodophyta	<i>Ceramium</i> sp.	0	1	0	1
25	Rhodophyta	<i>Cheilosporum acutibolum</i>	1	0	0	1
26	Rhodophyta	<i>Condrus crispus</i>	0	2	1	3
27	Rhodophyta	<i>Euchema spinosum</i>	7	11	0	18
28	Rhodophyta	<i>Gelidiella acerosa</i>	2	3	5	10
29	Rhodophyta	<i>Glacilaria arcuata</i>	15	19	74	108
30	Rhodophyta	<i>Glacilaria coronopifolia</i>	75	34	110	219
31	Rhodophyta	<i>Glacilaria corticata</i>	0	2	0	2
32	Rhodophyta	<i>Glacilaria salicornia</i>	57	23	91	171
33	Rhodophyta	<i>Glacilaria verrucosa</i>	0	0	1	1
34	Rhodophyta	<i>Halymenia</i> sp.	0	0	1	1
35	Rhodophyta	<i>Hypnea asperi</i>	10	31	20	61
36	Rhodophyta	<i>Hypnea cerviconis</i>	0	8	25	33
37	Rhodophyta	<i>Hypnea spinella</i>	9	39	53	101
38	Rhodophyta	<i>Kappaphycus</i> sp.	0	0	1	1
39	Rhodophyta	<i>Laurencia papilosa</i>	11	2	7	20
40	Rhodophyta	<i>Laurencia</i> sp.	1	2	0	3
41	Rhodophyta	<i>Peyssonellia</i> sp.	0	0	3	3
Total Abundance						1,909

Table 3 Brief morphological description of the dominant and common species representing each division of macroalgae found in Ujung Genteng coastal area

No	Species	Description
1.	<i>Boergesinia forbesii</i> (Chlorophyta)	The thallus is round and resembles a fluid-filled sac, featuring a wider tip that narrows toward the base. Its surface is smooth, transparent, and green. It is unbranched and forms clumps with holdfast rhizoids, growing up to 5 cm tall. The thallus has a gelatinous texture. It is typically found in seagrass meadows, coral reefs, and sandy environments, attaching to dead coral, rocks, and various types of algae (Handayani <i>et al.</i> 2020)
2.	<i>Gracilaria coronopifolia</i> (Rhodophyta)	The thallus is cylindrical, fleshy, and smooth, displaying colors ranging from brownish-green to reddish-brown or yellowish-brown (blonde). It adheres to the substrate with small discs and can grow either upright or flat, forming clusters or spreading out. The branching pattern is dichotomous, alternate, and irregular. The upper part of the clump is typically dense, featuring pointed thallus tips of varying lengths. The thallus has a cartilaginous texture and can grow up to 20 cm long. It is commonly found in seagrass meadows, flooded coral reefs, protected coral flats, and breakwaters, attaching to sandy substrates, coral flats, coral rubble, mollusc shells, sponges, or as an epiphyte on seagrass (Sukiman 2011; Handayani <i>et al.</i> 2014)
3.	<i>Padina australis</i> (Phaeophyta)	The thallus has a fan shape, is flat and thin, with a smooth, unbranched edge. It appears blond brown with white stripes on its surface. It grows upright in clusters, often curling into a funnel shape. The thallus measures 2 – 7 cm in height and 3 – 8 cm in width. It adheres to the substrate using holdfasts shaped like rhizoids and typically grows attached to coral, coral debris, and sand, often found in coral crevices (Johan <i>et al.</i> 2015; Handayani <i>et al.</i> 2020)

This study observed that the East Zone exhibited the highest relative abundance of macroalgae, which contributed 48% of the total abundance, followed by the South Zone with 30% and the West Zone was the site with the lowest one and contributed only 22% of the total individuals collected during the study.

Spatial Distribution of Macroalgae

The distribution pattern of macroalgae contains data regarding the presence of species and the interaction among individuals of the same species or between different species within their habitat. Studies investigated how various factors, such as environmental conditions, influence the

distribution and diversity of macroalgae. As benthic organisms, the substrate characteristics play a crucial role in shaping the composition and distribution of macroalgae by affecting their ability to attach, grow, and compete, which in turn determines the marine ecosystem dynamics and biodiversity. Ariani *et al.* (2017) observed that the variation of macroalgae composition was due to the type of holdfast and substrate suitability.

In the case of the Ujung Genteng areas, the spatial distribution of macroalgae was represented by the zoning division, specifically the West Zone, South Zone, and East Zone (Fig. 3).

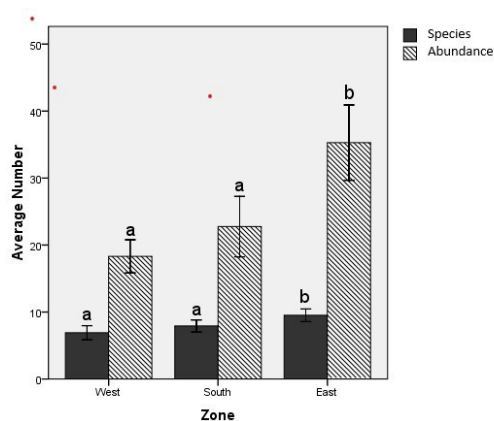


Figure 3 Mean abundance and species richness of macroalgae on three coastal zones of Ujung Genteng Notes: Different letters (a and b) signify a significant difference in the ANOVA test result ($P < 0.05$).

The East Zone exhibited a significantly different pattern of community structures compared to the other two zones (Fig. 3) and was primarily characterized by a substrate dominated by coral and reef crevices. Substrates in the West Zone and South Zone mainly consisted of sand and seagrass beds. These findings align with the study of Kadi (2006), who noted that substrate structures have a significant influence on the diversity of macroalgae species. In coral-dominated areas, a greater variety of macroalgae was observed, including tubular and filamentous macroalgae of various shapes and larger sizes (Palallo 2013). Additionally, our study identified species such as *B. forbesii*, *G. coronopifolia* and *P. australis*, which were found to be common across all three zones. These species are well-adapted to rock and coral substrates through disc-shaped holdfasts that securely attach to hard surfaces, allowing them to withstand waves and ocean currents, and tolerate drought during low tide (Palallo 2013; Johan *et al.* 2015; Arfah & Simon 2016).

Given the abundance of these macroalgal species, bioprospecting of these common species in Ujung Genteng warrants consideration. *Boergesinia forbesi* contains bioactive compounds such as steroids, flavonoids, phenolics, and saponins with antioxidant properties, indicating potential applications in medical and pharmaceutical fields (Gazali *et al.* 2023 in Effendi *et al.* 2024). *Gracilaria coronopifolia*, a widely utilized seaweed in Indonesia, has potential as an alternative food resource, including gelatin production, and exhibits antiviral, antifungal, and antibacterial activities (Indarjani & Nurhayati 2022; Li *et al.* 2019 in Effendi *et al.* 2024). *Padina australis* contain alkaloids, flavonoids,

saponins, tannins with antioxidant, antimicrobial, and antifungal properties (Rachmawati *et al.* 2021b in Effendi *et al.* 2024). *Acantophora muscioides* exhibits promising bioactive potential for pharmaceutical applications (Sunarpi *et al.* 2018).

Community Structure of Macro Algae Assemblages

The community structure of macroalgae assemblages was analysed using biological indices. to examine patterns of biodiversity, community dynamics, and ecological relationships in Ujung Genteng coastal waters (Fig. 4).

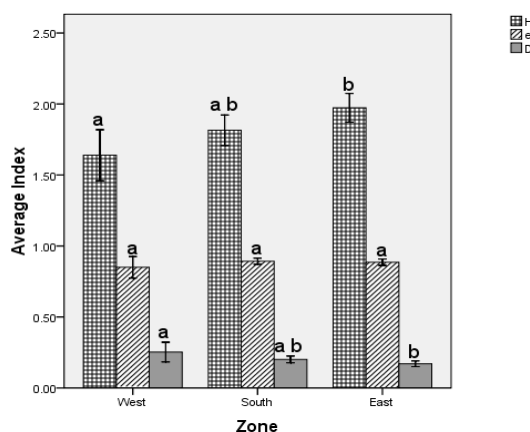


Figure 4 Mean of biotic indices values (H' , E and D) of macroalgae assemblages in three coastal zones of Ujung Genteng

Notes: Different letters (a, b, and ab) signify a significant difference in the ANOVA test result ($P < 0.05$).

Biological indices reveal significant spatial variations in the macroalgal community structures along the Ujung Genteng coastal area, particularly in terms of species diversity and species dominance. The diversity index (H') was classified as moderate, with average values ranging from 2.5 to 2.70, indicating that the communities were relatively stable and could maintain disturbances within the habitat. The East Zone had the highest diversity index value ($H' = 2.7$), which was significantly different from the other two zones, while the West Zone had the lowest value ($H' = 2.52$). Environmental conditions and the suitability of a habitat influence macroalgal growth, as evidenced by the high diversity index (H'). The type of substrate in the East Zone, which was dominated by coral fragments and coral crevices, created a heterogeneity of species composition. A stable substrate of coral fragments, rocks, and sand supported the growth and species diversity of benthic macroalgae compared to places with

a substrate consisting of sand and mud, which created an unstable substrate (Imchen 2015), such as in the West Zone

The distribution pattern of macroalgae explains information about the existence of species and relationships between the same species or between species and their habitat. The Evenness Index (E) within the three coastal zones showed no difference; the scores were categorized as high and ranged from 0.73 to 0.82, indicating that the distribution of individuals across species in the macroalgal community within the habitat was balanced. Mudrikah *et al.* (2024) also found a similar pattern at Sarangan Beach, where macroalgae assemblages were characterised through a more balanced distribution of individuals of macroalgae and a few dominant species within the communities.

The dominance index (D) is an important ecological index used to assess the structure of macroalgae communities. The Dominance Index (D) measures the concentration and distribution of dominant species. A higher index value indicates that dominance is concentrated in a single species, while a lower value suggests that multiple species share dominance. (Indarjani & Nurhayati 2022). The West Zone had the highest value ($D = 0.17$) and a significant difference from the other two zones, while the East Zone had the lowest value ($D = 0.09$) (Fig. 4), indicating that there was a concentration of certain species at each observation point on the western part of the coast.

Our study showed that locations with a high diversity index (H') likely to have a low dominance index (D). Conversely, stations with a low diversity index (H') have a high dominance index (D). The East Zone had the highest average diversity index (H') and the lowest average dominance index (D). This indicates that species diversity at each observation point was accompanied by a relatively even distribution of individuals of each species. In addition, the environmental conditions and substrate types at this location were relatively suitable for the growth of various macroalgae species. Conversely, the West Zone had the lowest average diversity index (H') and the highest average dominance index (D). This was due to the substrate types dominated by seagrasses, sand and less fragmented corals. Additionally, environmental factors such as relatively strong current velocity, significantly influence the development of macroalgae assemblages, causing the survival of

only a few macroalgae species.

CONCLUSION

Benthic macroalgal communities in the Ujung Genteng coastal ecosystem exhibited clear spatial variation and moderate ecosystem health. A total of 41 species from 28 genera and 19 families were recorded across the divisions Rhodophyta, Chlorophyta, and Phaeophyta, with environmental conditions in the intertidal zone generally favorable for macroalgal growth. Community structure differed among zones, with the East Zone providing the most suitable habitat due to favorable substrate composition, whereas seagrass presence likely constrained macroalgal development in some areas. Moderate diversity ($H' = 2.52 - 2.70$), high evenness ($E = 0.75 - 0.89$), and low dominance ($D = 0.09 - 0.11$) indicated a relatively stable assemblage without pronounced species dominance. These findings highlight the importance of environmental parameters in shaping macroalgal distribution and underscore the need for continued monitoring and sustainable management, particularly in light of increasing tourism pressure.

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