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Short Communication: Species diversity of macroalgae in Teluk Bidara Beach, Dungun, Terengganu, Peninsular Malaysia

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Abstract. *Kauj NK, Roslan SNL, Zainee NFA, Razali NB, Ismail NA, Izam NAM, Farinordin FA. 2024. Short Communication: Species diversity of macroalgae in Teluk Bidara Beach, Dungun, Terengganu, Peninsular Malaysia. Biodiversitas 25: 4370-4378.* Macroalgae are a diverse group of organisms with varying physical characteristics, genetic relationships, morphologies, sizes, colors, and chemical compositions. Research on macroalgae in Malaysia has shown significant expansion. Nevertheless, the current inventory of macroalgae in the East Coast of Peninsular Malaysia is limited. This study was conducted to analyze the species diversity and morphologies of macroalgae in Teluk Bidara, Terengganu, Malaysia. Specimens were collected at low tides. Wet specimens were preserved in 10% formalin while herbarium preparation was conducted to preserve dried specimens. Specimens were observed under microscopes to determine the distinguishable morphological characteristics. There were 17 species of macroalgae recorded with Ochrophyta was the phylum with the greatest number of species (47%), followed by Rhodophyta (35%), and Chlorophyta (18%). The calculated Shannon-Wiener's Index (2.833) and Simpson's Index (0.9412) indicate a significant amount of species diversity, suggesting that the community includes many species with an even distribution of individuals. The diverse range of *Sargassum* is attributed to their habitat diversity, adaptability, reproductive strategies, genetic diversity, distribution patterns, ecological interactions, and anthropogenic activities. Malaysia's coastal and island ecosystems are known to house a significant number of macroalgae species, providing suitable habitats for maintaining their diversity. Macroalgae diversity and its habitats, being part of the natural heritage, should be adequately preserved.

Keywords: Diversity, marine, *Sargassum*, seaweeds

INTRODUCTION

Seaweed, the macroscopic marine algae, are primitive non-flowering photosynthetic macrophytes that do not produce flowers (Min et al. 2021). Seaweed consists of structurally and phylogenetically various species with a wide range of forms, sizes, colors, and chemical profiles (Min et al. 2021). Like terrestrial plants, seaweed serves as the primary producer of food chains in aquatic habitats. Based on the color of the thallus and chemical composition, seaweed is taxonomically organized or classified into three different divisions, namely red algae (Phylum Rhodophyta), brown algae (Phylum Ochrophyta, Phaeophyceae), and green algae (Phylum Chlorophyta) (Zawawi et al. 2014; Leandro et al. 2019).

Macroalgae provide numerous ecosystem services, playing critical roles in supporting biodiversity in marine ecosystems. The submerged macroalgal beds are a component of food webs, providing habitat, food, and shelter for a diverse array of organisms (Zawawi et al. 2015; Isa et al. 2017; Zainee et al. 2019; García 2021), many of which are of economic value and conservation at various trophic levels, thereby increasing biodiversity (Menaa et al. 2020). The study of seaweed diversity provides necessary information that can potentially be used in evaluating ecosystem conditions. Furthermore, the study of seaweed diversity highlights the importance of understanding the potential of marine macroalgae as it contributes to coastal defense by preserving a high bed level on tidal flats and absorbing hydrodynamic energy from waves, avoiding erosion of those tidal zones (García-Poza et al. 2020).

Environmental factors play a crucial role in shaping the primary productivity of macroalgal communities in marine ecosystems by influencing their physiological processes, growth patterns, and overall ecological performance. The presence of numerous seaweed species affects the hydrodynamic ecosystem, stabilizing the sediment, and altering the environment through changes in light, sedimentation rates, and hydrodynamics. The chemical structure of seaweeds and the presence or absence of macroalgae are highly variable in response to a variety of environmental parameters such as transparency, geographical habitat, salinity, and ambient conditions, which include nutrient content, the intensity of light, as well as the temperature of the water and ocean acidification (Menaa et al. 2020).

A broad range of marine macroalgae thrive in Malaysia's extensive coastline, numerous islands, and mangrove forests, which provide a variety of beneficial settings for their growth (Zawawi et al. 2014; Rajkumar and Takriff 2016; Phang et al. 2019). The identification of marine algae resources has aided in the development and expansion of existing research areas in the country. For instance, Phang et al. (2008) studied the biodiversity of seaweed in the Straits of Malacca based on the expedition to the marine algae of Pulau Jarak, the Sembilan Group of Islands, and Perak Island. Furthermore, spatial patterns of the distribution of seaweed in Malaysia using Geographic Information Systems (GIS) were extensively studied by Lian et al. (2008). Other research studies include the diversity of marine algae in Bachok, Kelantan by Phang (2010), and the biodiversity of seaweeds in Blue Lagoon, Port Dickson, as reported by Asmida et al. (2017). While it has been demonstrated that the abundance of macroalgae is significantly related to fecal coliforms and nutrients, high levels of overall suspended particles and oil in the water have resulted in a low diversity of macroalgae in the environment (Bolton et al. 2007).

Despite all the prior studies, there has been less documented research accessible to date regarding seaweed biodiversity on the East Coast of Peninsular Malaysia. The lack of studies on macroalgae may result in an insufficient understanding of their functions and ecological diversity. Consequently, it is unfortunate that our understanding of the molecular mechanisms that underpin the macroalgae biodiversity and generate these findings is inadequate. Our inability to understand our source material is one of the primary reasons for the decline in interest in biological species. More efforts, however, are required to comprehend its current state fully. Therefore, a more detailed analysis of the macroalgae diversity is needed. This study aims to identify the diversity of macroalgae and to assess the morphological descriptions of macroalgae in Teluk Bidara Beach, Dungun, Terengganu Malaysia. It is anticipated that the outcomes of this study will aid in more exploration of macroalgal diversity and information particularly in Terengganu, the East Coast of Peninsular Malaysia.

MATERIALS AND METHODS

Study area

In this study, seaweed collection was conducted at Teluk Bidara Beach, Dungun, Terengganu along the shoreline of the Terengganu State, which is located on the east coast of Peninsular Malaysia. Teluk Bidara Beach is roughly 70 kilometers off the coast of Kuala Terengganu and around 368 kilometers from Malaysia's capital city, Kuala Lumpur. Teluk Bidara is described as a beach with a great view, but along the seashore, there was an abundance of washed-off trash comprising of plastic bottles, fishing nets, glasses and other garbage. The seaweed was collected along the coastal area between 4°48'03.22" N, 103°25'43.15" E. The area was selected as there were many rocky shores which are natural habitats to macroalgae. The geographical locations of this sampling site are depicted in Figure 1.

Procedures

Field sampling

Teluk Bidara Beach comprises rocks of various sizes, ranging from tiny, fine pebbles to massive, rough boulders. Small pools of saltwater are seen on the beach, contained between the rocks, during low tide. These tidal pools provide as habitats for a diverse range of marine organisms, including crabs, starfish, tiny fish, and seaweed. During low tides, a lot of garbage was seen washed out on the shorelines. A random sampling of seaweed from the intertidal zones was carried out during the low seawater level and low tide. The condition of the study site is shown in Figure 2.

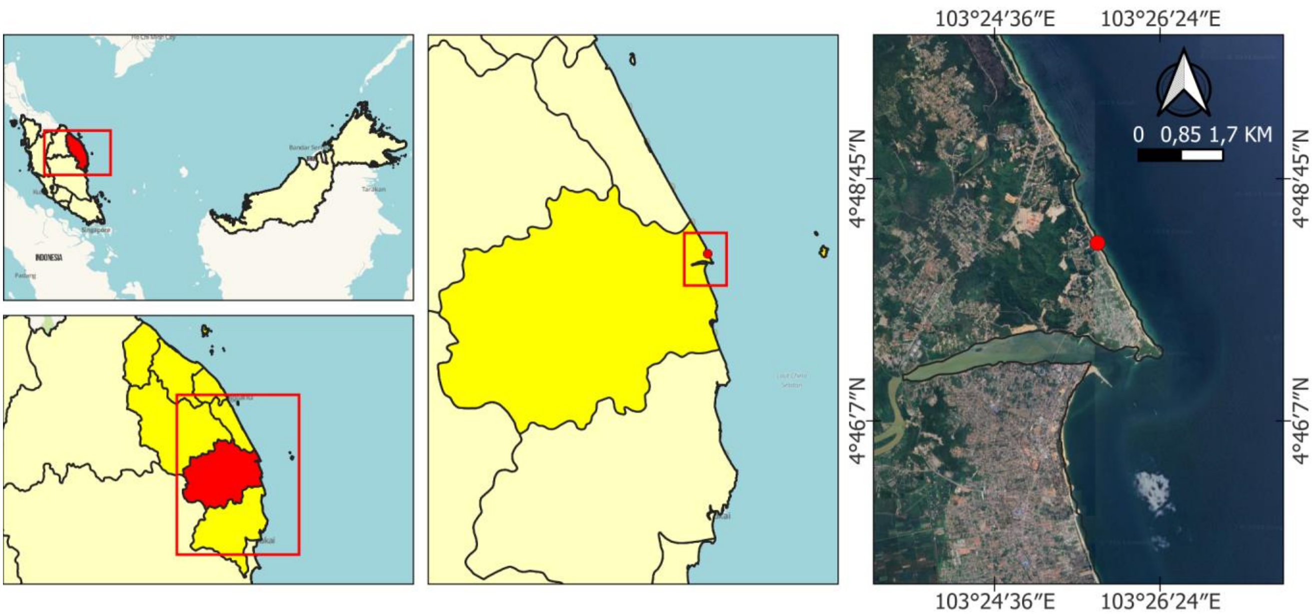

Figure 1. Map of the study area in Teluk Bidara Beach, Dungun, Terengganu, Peninsular Malaysia

Figure 2. A. The view of Teluk Bidara Beach, Dungun, Terengganu, Peninsular Malaysia; B. Rocky shores as important macroalgae habitat; C. The amount of trash that washed up on the shorelines is appalling and concerning; D-E. Macroalgae specimens found at Teluk Bidara Beach, Terengganu.

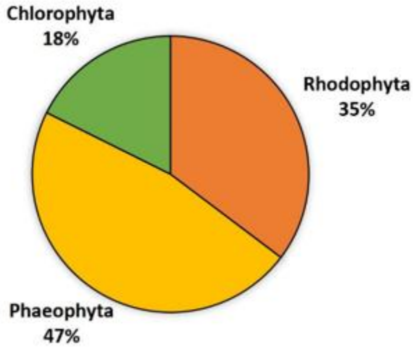

Figure 3. Percentage of species by divisions of benthic macroalgae found off the coast of Teluk Bidara Beach, , Dungun, Terengganu, Peninsular Malaysia

Specimen collection

In shallow water, seaweed samples (pieces of the whole thalli) were obtained from the intertidal and subtidal zones of the sampling region in March 2022, which was near the end of monsoon season. The macroalgal specimens were removed from their substrates and placed in zip-lock bags (Asmida et al. 2017). The cut seaweed was promptly rinsed with seawater to remove any sediments, invertebrates, or other debris that had become attached to them during the cutting process. Different species were divided into zip lock bags with clearly labeled compartments based on morphologies, coloration, and physical characteristics. Pictures of macroalgae were taken in-situ. A variety of macromorphological structures, including the thallus (plant body), holdfast, and stipe, were observed, and documented (Taylor et al. 2002; Littler and Littler 2011). In addition, on-site data collection was recorded, including the specimen's shape and color. These data were used to assist in the identification of species. Subsequently, specimens were brought to Biology Laboratory 1 of UiTM Pahang Branch, Jengka Campus, for further observation.

Preservation of wet specimens

Specimens were washed with tap water in the laboratory to remove all attached impurities, fixed into the vials with 10% formalin solution and kept at an ambient temperature and dark place (Zainee and Taip 2017). The preservation of algal samples is necessary to protect them from microbial degradation.

Preparation of herbarium

The dry preservation of marine macroalgae was accomplished using the herbarium technique. The specimen was cleaned and placed in a large tray of water to float on the water's surface. Forceps can come in handy for untangling delicate branches. After that, the herbarium paper with the specimen was carefully removed, allowing the water to drain away from it. For the preparation of the herbarium, the algae with the paper were placed on a piece of herbarium paper. Specimens were covered with a piece of newspaper, tissues, or cardboard paper and placed between another newspaper to dry and build up a series of pressings. All specimens were piled, and the straps were firmly tightened so that the pressure helped flatten and stick them to the herbarium paper.

Microscopic observation

The micromorphology structures of macroalgae such as thallus, holdfast, stipe, and blades were observed under a high-resolution microscope.

Data analysis

Diversity index analysis

The Shannon-Wiener Index and Simpson’s Index were used to determine the macroalgae's species richness and evenness. PAST software was used to conduct statistical analyses.

RESULTS AND DISCUSSION

Seaweed diversity

A total of 17 seaweed species were successfully obtained through sampling at the study location. Seaweeds found in Teluk Bidara are classified into three major phyla, namely Chlorophyta, Ochrophyta, and Rhodophyta. All 17 species belong to nine orders, nine families, and 12 genera. Based on the results obtained, Ochrophyta had the highest number of species recorded, representing 47% of the total number of species recorded. This is followed by Rhodophyta, which has six species, comprising 35% of the total species richness, and Chlorophyta (18%). Out of the total 17 species, the genus *Sargassum* from Ochrophyta contributes to the greatest number of species, with six species namely *Sargassum paniculatum* J. Agardh, 1848, *Sargassum henslowianum* C. Agardh, 1848, *Sargassum congkinhii* P. H.Hô, 1967, *Sargassum polycystum* C. Agardh, 1824, *Sargassum tenerrimum* J.Agardh, 1848, and *Sargassum baccularia* (Mertens) C.A. Agardh, 1824. The macroalgae species checklist is shown in Table 1 while the percentage by divisions is depicted in Figure 3.

Table 1. List of benthic macroalgae species found off the coast of Teluk Bidara Beach, Dungun, Terengganu, Peninsular Malaysia

Phylum	Order	Family	Species
Chlorophyta	Ulvales	Ulvaceae	*Ulva intestinalis* Linnaeus, 1753
	Siphonocladales	Boodleaceae	*Boodlea composita* (Harvey) F. Brand, 1904
	Cladophorales		*Cladophoropsis membranacea* (Hofman-Bang ex C. Agardh) Børgesen, 1905
Rhodophyta	Rhodymeniales	Lomentariaceae	*Ceratodictyon intricatum* (C. Agardh) R.E. Norris, 1987
	Nemaliales	Galaxauraceae	*Galaxaura rugosa* (J. Ellis and Solander) J.V. Lamouroux, 1816
		Liagoraceae	*Ganonema farinosum* (J.V. Lamouroux) K.C. Fan and Yung C. Wang, 1974
			Liagora ceranoides J.V. Lamouroux, 1816
	Bangiales	Bangiaceae	*Bangia* sp.
	Corallinales	Corallinaceae	*Jania spectabilis* (Grunow) J.H. Kim, Guiry & H.G. Choi, 2007
Ochrophyta	Dictyotales	Dictyotaceae	*Lobophora variegata* (J.V. Lamouroux) Womersley ex Oliveira, 1977
			Padina minor Yamada, 1925
	Fucales	Sargassaceae	*Sargassum polycystum* C. Agardh, 1824
			Sargassum baccularia (Mertens) C.A. Agardh, 1824
			Sargassum henslowianum C. Agardh, 1848
			Sargassum paniculatum J. Agardh, 1848
			Sargassum tenerrimum J.Agardh, 1848
			Sargassum congkinhii P. H.Hô, 1967

Types of phyla

Phylum Chlorophyta

The Chlorophyta was represented by three orders, two families, three genera, and three species. Family Ulvaceae is represented by *Ulva intestinalis*, while family Boodleaceae is represented by *Cladophoropsis membranacea*, and *Boodlea composita* (Harv.) F.Brand.

Phylum Rhodophyta

The Rhodophyta was represented by four orders, six families and six species. The order Corallinales was represented by one species namely *Jania spectabilis* (Harvey ex Grunow) J.H.Kim, Guiry & H.-G.Choi, 2007 while the order Nemaliales was represented by three species: *Galaxaura rugosa* (J. Ellis and Solander) J.V. Lamouroux, 1816, *Ganonema farinosum* (J.V. Lamouroux) K.C. Fan and Yung C. Wang, 1974, and *Liagora ceranoides* J.V. Lamouroux, 1816. The order Rhodymeniales consists of one family which was Lomentariaceae, consisting of *Ceratodictyon intricatum* (C. Agardh) R.E. Norris, 1987. The genus *Bangia* was only represented by one species, *Bangia* sp.

Phylum Ochrophyta

There were three genera found in Ochrophyta. Of the three genera, *Sargassum* was the dominant genus, represented by six species namely *S. paniculatum*, *S. henslowianum*, *S. congkinhii*, *S. polycystum*, *S. tenerimum*, and *S. baccularia*. It was followed by *Lobophora variegata*, the second dominant genus. The Dictyoataceae family was represented by *Padina minor*. The photo of each macroalgae species is shown in Figure 4 below.

Species description

Phylum Chlorophyta

Order: Ulvales

Family: Ulvaceae

Species: *Ulva intestinalis* Linnaeus, 1753

Ulva intestinalis was previously known as *Enteromorpha intestinalis.* Thallus bright green or yellowish green, unbranched, and tubular fronds emerge from short stipe that is attached by a discoid holdfast.

Habitat: Brackish water or attached to rocks.

Order: Siphonocladales

Family: Boodleaceae

Species: *Boodlea composita* (Harvey) F. Brand, 1904

Thallus becomes segmented, resulting in the formation of an amorphous and spongiose mass of net-like filaments. In most parts of the thallus, the branching is pinnate, alternating, and irregular.

Habitat: On a sandy rock in litoral and sublitoral zone which is exposed during low tide.

Order: Cladophorales

Family: Cladophoraceae

Species: *Cladophoropsis membranacea* (Hofman-Bang ex C. Agardh) Børgesen, 1905

Thalli are made up of siphonous and intertwining filaments and form cushion-like in appearance. In another specimen, branching is irregular, with no septum and dichotomy to alternating. Unilateral to irregularly organized terminal branch systems and apical cell diameter.

Habitat: Coral reefs and along rocky coastlines

Phylum Rhodophyta

Order: Rhodymeniales

Family: Rhodymeniaceae

Species: *Ceratodictyon intricatum* (C. Agardh) R.E. Norris, 1987

Thallus greenish brown. Thalli are very coarse and form densely matted clumps of up to 3 cm high. Few and irregularly spaced branches. Branching is irregular, alternating, and sometimes dichotomous.

Habitat: On top of coral colonies or rocky ledges

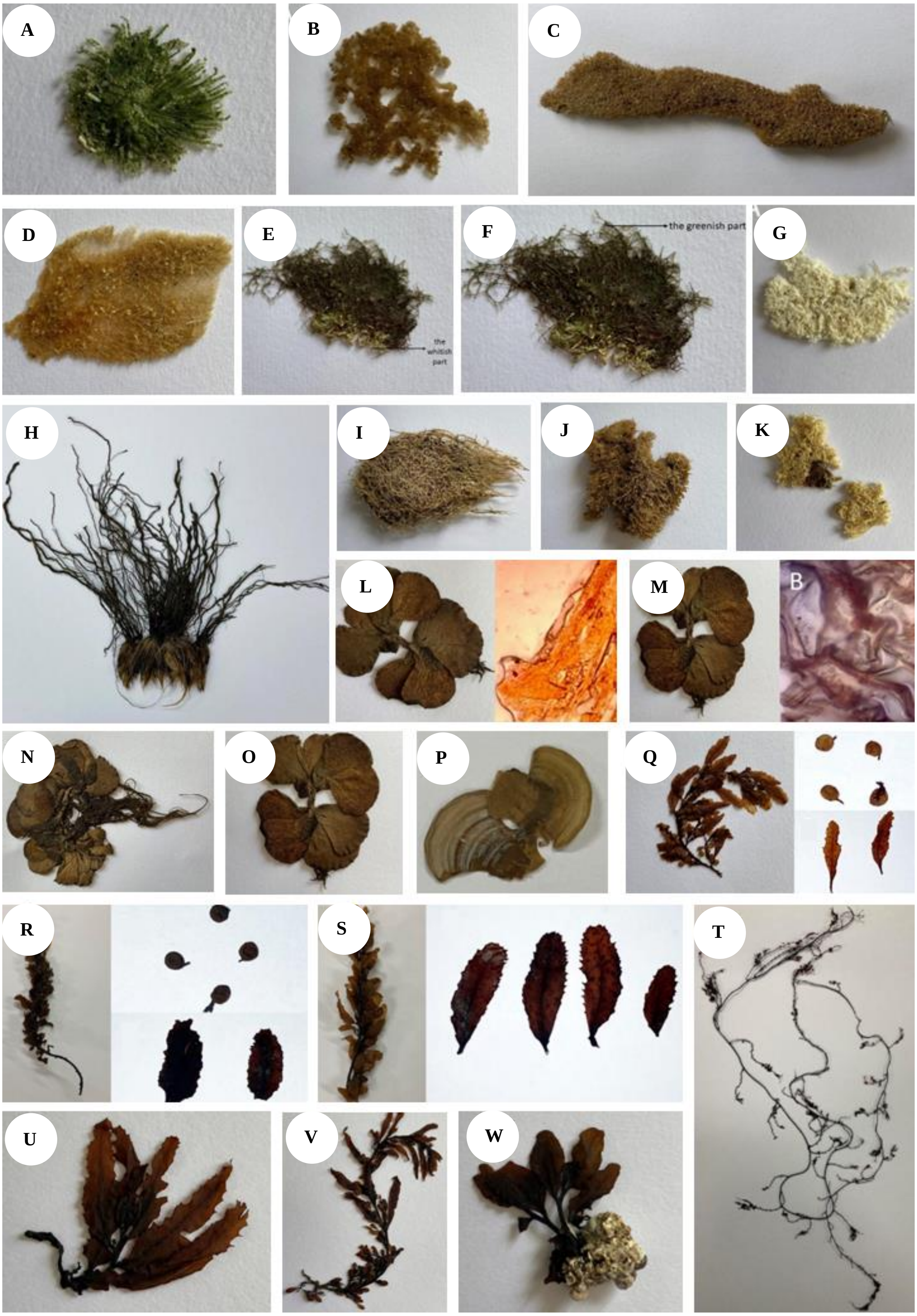

Figure 4. List of species collected from the coast of Teluk Bidara Beach, Dungun, Terengganu, Peninsular Malaysia. A. *Ulva intestinalis;* B. *Boodlea composita;* C-D. *Cladophoropsis membranacea;* E. *Ceratodictyon intricatum;* F. *Galaxaura rugosa;* G. *Jania spectabilis;* H. *Bangia* sp.; I. *Ganonema farinosum;* J-K. *Liagora ceranoide;* L-O. *Lobophora variegata;* P. *Padina minor;* Q-R. *Sargassum polycystum;* S. *Sargassum paniculatum;* T. *Sargassum baccularia;* U. *Sargassum henslowianum;* V. *Sargassum tenerrimum;* W. *Sargassum congkinhii*

Species: *Galaxaura rugosa* (J. Ellis and Solander) J.V. Lamouroux, 1816

Thallus whitish and lightly calcified. Branching widely dichotomous, alternate. Branches short, crowded, cylindrical, 1-3 mm in diameter, densely covered with stiff hair-like filaments. The filaments are cylindrical. Attachment by inconspicuous holdfast.

Habitat: Growing on hard substrates, dead coral blocks, in the upper subtidal zone.

Order: Nemaliales

Family: Liagoraceae

Species: *Ganonema farinosum* (J.V. Lamouroux) K.C. Fan and Yung C. Wang, 1974

Thallus is soft, slightly calcified, forms thick clumps, ranges in color from brownish to white, and has an appearance that is similar to farinose. The lower part has an irregular branching pattern, while the upper part is repeatedly dichotomous with numerous proliferations between the dichotomies. Attachment by inconspicuous, disc-like holdfast.

Habitat: Growing on rocks, dead coral blocks, and shells on sandy bottom in the lower intertidal to upper subtidal zones.

Species: *Liagora ceranoides* J.V. Lamouroux, 1816

Thallus is mainly soft, compact, and tangled, and it is slightly to mildly calcified. Thalli grow in clumps that are 2-4 cm high and are white to brown in color. The branching is dense and dichotomous both repeatedly and extensively in the upper part. Attachment by inconspicuous, discoid holdfast. In another specimen, annulations on the upper sections of branches are missing and cortical cell hairs are hyaline, thalli are saxicolous form, somewhat calcified except towards the base, fragile and farinaceous when dried, slightly soft and flaccid when fresh; attached to substratum through discoid holdfast with robust stipe.

Habitat: Growing on rocks, dead coral fragments, occasionally epiphytic, in the lower intertidal to upper subtidal zones.

Order: Bangiales

Family: Bangiaceae

Species: *Bangia* sp.

Thallus is an unbranched, narrow, hair-like filament of dark red cells, tapering to a base just one cell wide, with cells forming rhizoidal extensions that help attach the filament to the substrate. Filaments are 10 cm long. *Bangia* sp. is composed of filiform embedded in a firm gelatinous matrix. It is attached by down-growing rhizoids, usually in dense purple-black to rust-colored clumps. Like tangled hair. Thallus is dark brown in color.

Habitat: Attached to rocks.

Order: Corallinales

Family: Corallinaceae

Species: *Jania spectabilis* (Grunow) J.H. Kim, Guiry & H.G. Choi, 2007

Thallus with dichotomous branching. The marginal formation of intergenicula with conceptacles. Thalli forming a clump, white in color, measuring 1-3 cm in height, and attached to the substratum by a discoid holdfast.

Habitat: Plants grow in the subtidal zone.

Phylum Ochrophyta

Order: Dictyotales

Family: Dictyotaceae

Species: *Lobophora variegata* (J.V. Lamouroux) Womersley ex Oliveira, 1977

Thallus crust-like, fan-shaped, reniform, clustered, overlapping, light to dark brown thallus with slight concentric zones and radiating yellowish lines. Blades 1-3 cm long. Completely adheres to a rocky substrate by rhizoids at the base of the thallus. In another specimen, the segments grow in an overlapping manner; small segments overlap large segments, so there are as many as 3-4 segments overlapping together on top of one growth point. The segment is dark brown in color at the base. Another specimen exhibits an encrusting form, an erect ruffled form, and a decumbent or reclining form that grows flattened against the substrate. Thallus is typically a very dark brown color. Both of the thalli's surfaces are covered with sporangial sori in a dispersed manner. One specimen shows continuous growth of the lateral blades, the ruffled form develops in ball-like clumps of wavy fronds rather than in individual fronds.

Habitat: Growing loosely or tightly attached to intertidal and subtidal rocks, dead corals, in moderately to strongly exposed areas.

Species: *Padina minor* Yamada, 1925

Thallus is small, flabellate, and has broadly rounded lobes. It is shortly stipitate, and it splits into fan-shaped blades with heights ranging from 1-3 cm and widths ranging from 1-3 cm. It is moderately calcified, and yellowish-brown fluffs cover the lower portion of the upper surface. Several hair lines are visible on the blade's lower surface.

Habitat: Growing on rocks and dead corals in the middle intertidal to subtidal zones exposed to moderate wave action.

Order Fucales

Family Sargassaceae

Species: *Sargassum polycystum* C. Agardh, 1824

These plant-like species are firmly attached to rocks that are exposed to strong waves. Thallus is coarse and bushy. Main axis is cylindrical, slightly compressed, and has proliferations that are somewhat simple or Y- shaped. The primary branches are terete and have spines that are branching. Vesicles that are stalked (terete), tiny, spherical, or oval, are surrounded with a leaflet or mucronate. Attachment by a discoid holdfast. Another specimen exhibits holdfast that is discoid, stem terete, warty, up to 10-20 cm long. Primary branches frequently muricate with prolifically branched spines, changed into a stolon and secondary holdfasts, leaves elliptical, lanceolate to linear, simple, with asymmetrical to cuneate bases.

Habitat: Growing on rocks and stones in the lower intertidal to subtidal zones.

Species: *Sargassum baccularia* (Mertens) C.A. Agardh, 1824

Primary branches are smooth, cylindrical, up to 36 cm long, and have a diameter of 2 mm; secondary branches are smooth, cylindrical, up to 18 cm long, approximately 1 mm in diameter, and alternate at intervals of 2-4 cm. They are surrounded with receptacles, leaves, and vesicles. Vesicles are spherical or sometimes elliptical, and they have complete apices or sometimes mucronate apices. The stalks are terete and are often shorter than the vesicles.

Habitat: Drifted ashore, subtidal zone.

Species: *Sargassum henslowianum* C. Agardh, 1848

Thalli are dark brown in color and emerge from discoid holdfasts. The major axes are small and cylindrical, about 1.5 cm in length, and they bear primary branches from their sections. The primary branches are compressed, and their axils bear a large number of subsidiary branches. Vesicles that are spherical or oval, rounded at their apices and have lengthy stalks that are straight.

Habitat: Growing on subtidal rocks or subtidal zones.

Species: *Sargassum paniculatum* J. Agardh, 1848

Holdfast and axis are not available. Primary branches are cylindric, and smooth, secondary branches arise from the axils of the primary leaves, alternate at intervals of 3-5 cm, cylindric and smooth, and branchlets are small and covered in vesicles and receptacles. Leaves lanceolate. Ovoid or spherical vesicles. Receptacles form dense clusters, are repeatedly branched, and have short leaf stems.

Habitat: Growing on subtidal rocks.

Species: *Sargassum tenerrimum* J.Agardh, 1848

Vesicles are elliptical and receptacles triquetrous. Leaves with delicate, microscopic striations.

Habitat: Attached to the rocky shores.

Species: *Sargassum congkinhii* P. H.Hô, 1967

Vesicle that is not located in the middle of the leaf, receptacles that are cylindrical or flattened, and that are longer than 1 cm. Attachment by a discoid holdfast.

Habitat: Attached to rocks that are exposed to strong waves.

Diversity index

Two species diversity indices were used, namely the Shannon-Wiener Diversity Index and Simpson's Diversity Index. The calculated Shannon-Wiener's index of the macroalgae diversity was 2.83. This suggests a quite high level of species diversity, meaning the community has a relatively large number of species with an even distribution of individuals among those species. Meanwhile, the calculated Simpson's index was 0.94. This implies a high diversity, suggesting that no single species dominates the community and that there is a high degree of evenness.

Both indices indicate that the community has high species diversity. The high values in both indices suggest that the ecosystem has a good mix of species (richness) and that the individuals are distributed relatively evenly among those species (evenness). High diversity values highlight the importance of conserving this ecosystem, as it supports a wide range of species, which contributes to its resilience and stability. High diversity generally indicates a healthy, stable ecosystem with a variety of niches and interactions among species, which can provide numerous ecological benefits like resilience to disturbances and high productivity.

Discussion

Seaweed collection in Teluk Bidara Beach, Dungun, Terengganu has successfully recorded 17 species of macroalgae, where Sargassum were noted as dominant genus with highest number of species (6 species; *S. baccularia, S. congkinhii, S. henslowianum, S. paniculatum, S. polycystum,* and *S. tenerimum*). Overall, the sampling site has recorded high diversity indices value (Shannon-Wiener Index: 2.83; Simpson Diversity Index: 0.94), that fall within the range of high diversity, 1.5-3.0.

The diversity index for current study shows the highest value compared to Zainee and Rozaimi (2020). Based on the comparison of similar themes, their studies have been conducted in Tanjung Lompat, Telok Gorek, Pulau Mawar and Pantai Pasir Lanun, on the east coast of Johor. All the study sites had recorded lower diversity index value compared to current study, which were 1.54, 0.52, 0.53 and 0.85, respectively. Their study monitored the macroalgal diversity for 14-months along the Mersing coast. Despite the sampling effort (Zainee and Rozaimi 2022), with total of 31 species collected in Tanjung Lompat, our current research had collected 17 species of macroalgae with highest evenness value, approaching to 1, that indicates high diversity. In comparison to their study, the evenness index is consistently in the range of 0.46 to 0.58, which is almost half of our current findings. Thus, our research demonstrates high macroalgal diversity compared to other studies in similar theme in east coast region of Peninsular Malaysia.

The values of diversity indices obtained are mainly affected by several factors such as sampling frequency, sampling period, tidal condition, the size of the sampling area, the availability of the substrates, and the condition of the beach (Daud et al. 2015; Asmida et al. 2017; Li et al. 2023). Teluk Bidara Beach is a rocky beach made up of rocky shores, and the presence of rocks and rocky substrate demonstrates it as essential for the growth of various seaweed species (Mushlihah et al. 2021) such as *Sargassum* sp. This could be due to the abundance of available substrates as well as the flow of water, both of which are known to produce a significant number of *Sargassum* individuals. The study found that the genus *Sargassum* was the most diverse, with six different species identified. The wide range of *Sargassum* species is due to a variety of factors, such as the diversity of their habitats (Longo et al. 2019), their ability to adapt to different environmental conditions (Liranzo-Gómez et al. 2021), their reproductive strategies (Wong 2007), their genetic diversity (Li et al. 2017), the patterns of their distribution across different regions (Yip et al. 2020), their ecological interactions (Chen et al. 2020; Marks et al. 2020), and anthropogenic activities (Devault et al. 2021; Cannon et al.

2023). The combination of these variables contributes to the extensive diversity of *Sargassum* species, enabling them to effectively adjust to a wide range of environmental conditions and specialized habitats within marine ecosystems. Comprehending these characteristics is crucial for the conservation and management of *Sargassum*. *Sargassum* is present in several marine ecosystems, spanning from shallow coastal waters to deep offshore areas. These habitats include rocky coastlines, coral reefs, mangrove forests, and open ocean environments (Azzazzy et al. 2019). The wide range of habitats available allows for the occupation of various niches by different species of *Sargassum*, resulting in the development of new species and increased biodiversity. *Sargassum* species demonstrate notable physiological and morphological adaptations to a wide range of environmental situations (Liranzo-Gómez et al. 2021). They have the ability to flourish in environments characterized by fluctuating temperatures, degrees of salinity, and concentrations of nutrients (Serebryakova 2017). The ability of diverse species to adapt enables them to live in a variety of maritime habitats, which contributes to the total diversity of marine life. In addition to that, *Sargassum* utilizes a variety of reproductive techniques, encompassing both sexual and asexual reproduction. Sexual reproduction entails the generation of gametes and their subsequent fusion, resulting in the creation of offspring with a wide range of genetic variations. *Sargassum* utilizes asexual reproduction methods, including fragmentation and vegetative propagation, to efficiently establish itself in new environments and create dense populations. This process contributes to the enhancement of genetic diversity within the species (Wong 2007).

Furthermore, *Sargassum* has significant genetic diversity both within populations and among different populations. Genetic diversity is generated by processes such as mutation, gene flow, and genetic recombination that occur during sexual reproduction (Li et al. 2017). *Sargassum* species possesses genetic variety that allows them to effectively adjust to fluctuating environmental conditions and successfully inhabit a wide range of habitats. The distribution of *Sargassum* is impacted by biogeographical factors such as ocean currents, temperature gradients, and geological history. Various regions contain distinct *Sargassum* communities that have been influenced by past biogeographic events and current environmental factors (Yip et al. 2020). The variety of geographic distributions of these species expose them to distinct environmental conditions, resulting in the emergence of distinctive adaptations and heightened biodiversity.

The ecological interactions of this species, including competition, predation, and mutualism, with other marine creatures, such as fish and invertebrates, have a substantial impact on the variety of *Sargassum* and can affect their distribution (Chen et al. 2020). These interactions can result in the formation of distinct symbiotic partnerships and enhance the species ecological functions within marine ecosystems. The distribution and abundance of *Sargassum* within ecosystems are influenced by competitive interactions with other seaweeds and marine fauna. The composition of *Sargassum* communities is influenced by predation from herbivores and grazing pressure (Marks et al. 2020). Moreover, the ecological success of *Sargassum* is enhanced by its mutually beneficial relationships with species such as epiphytic algae, bacteria, and invertebrates (Chen et al. 2020). The ecological interactions play a crucial role in shaping evolutionary processes and are responsible for the rich diversity observed in *Sargassum* populations.

Anthropogenic activities, such as changing habitats, polluting, and altering the climate, can impact the global distribution and population of *Sargassum* species (Mushlihah et al. 2021). Coastal development, pollution from runoff and aquaculture, and habitat degradation have the potential to deteriorate *Sargassum* ecosystems and diminish species diversity (Devault et al. 2021). The pristine and immaculate condition of Teluk Bidara Beach must be diligently preserved, as the accumulation of litter on the shorelines has the potential to disrupt the distribution and variety of macroalgae species. Improving the quality of this beach is expected to increase the diversity of macroalgae species that can be found in Teluk Bidara Beach.

A checklist of macroalgae species is documented through this research for future reference. Considering the fact that this research was carried out in the post-monsoon season, it is recommended that samplings be additionally conducted throughout dry seasons (April-October) in order to provide a comprehensive checklist. It is also crucial to conduct continuous studies to update the species checklist of the macroalgae in the East Coast of Peninsular Malaysia. Beaches and islands in Malaysia acquired quite high species richness and had significant potential to maintain seaweed ecosystems by providing a wide variety of habitats. Macroalgae is an important producer which also serves as food sources for various threatened species, thus they must be continuously managed sustainably.

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