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Community Structure and Composition of Macroalgae in Southeast Bali Island Waters, Indonesia

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ABSTRACT

The open waters of Southeast Bali are influenced by Indian Ocean currents and nutrient influx, supporting diverse marine life, including macroalgae. Macroalgae serve as effective indicators of environmental health due to their community structure and species composition. This study aimed to characterize the community structure and composition of macroalgal species in Southeast Bali waters. Purposive sampling was conducted using quadrat transects at three stations: Serangan, Benoa Bay, and Gunung Payung coast. A total of 80 macroalgal species were identified, comprising 21 Chlorophyta, 17 Ochrophyta, and 42 Rhodophyta species. Percent cover of macroalgae ranged from 12.86 to 48.54% for Rhodophyta, 0.09 to 10.89% for Ochrophyta, and 30.08 to 63.37% for Chlorophyta. The average diversity index (H') was 2.346, indicating moderate diversity; the evenness index (E) averaged 0.642, reflecting high species evenness; and the dominance index (C) was 0.213, indicating low dominance. These results demonstrate a high composition and diversity of macroalgal communities in Southeast Bali waters, suggesting favorable environmental conditions that support macroalgal growth.

INTRODUCTION

Marine waters have high biodiversity, which is the difference that a living thing has based on its type, species, and even ecosystem **(Costello & Chaudhary, 2017)**. One of the marine living things that is highly diverse is macroalgae, a low-level plant that, in its growth, attaches to certain substrates such as mangroves, seagrasses, mud, rocks, sand, corals, coral fragments, and other hard objects. In addition to inanimate objects, macroalgae can grow epiphytically on other plants in the sea **(Melsasail *et al*., 2018; Wirawan *et al*., 2022)**. The distribution of macroalgae in an area can be seen from the place of attachment or substrate, season, and type. Most macroalgae grow attached to substrate types such as sandy, muddy substrates and hard substrates (corals and coral fragments) **(Arsad *et al*., 2022; Widyartini *et al*., 2023)**. Macroalgae recorded in Indonesia are 729 species divided into Chlorophyta 196 species, Rhodophyta 452 species, and Ochrophyta 134 species **(Arista *et al*., 2022)**.

Macroalgae, commonly known as seaweed, are multicellular photosynthetic organisms with a body called a thallus. The thallus is a part of the plant body that has not undergone differentiation or has true roots, stems, and leaves. Macroalgae contain pigments that differentiate them into three main divisions, namely Chlorophyta, Rhodophyta, and Ochrophyta **(Asmida *et al*., 2017; Aprilia *et al*., 2023; Dewi *et al*., 2025)**. In aquatic ecosystems, macroalgae act as a nursery for small fish **(Suhariningsih *et al*., 2020; James & Whitfield, 2022)** and a bioindicator of water quality, participate in bioaccumulation and bioremediation processes, and produce about 80% of oxygen, which is then used by terrestrial organisms for respiration **(Naw *et al*., 2020; Adarshan *et al*., 2023)**. In addition, their ability to accumulate heavy metals such as lead, arsenic, and chromium makes macroalgae a valuable tool for monitoring environmental changes **(Rakib *et al*., 2021; Yanuhar *et al*., 2024)**. It is further explained that macroalgae living in the sea can be associated with coral reefs and seagrass ecosystems so that they can act as a defense against waves and become a food source for other biota **(Salimi *et al*., 2021)**. Macroalgae, in their growth process, require a substrate to attach to or live on **(Setyorini *et al*., 2021)**. Macroalgae generally live on the seabed with substrates like sand, coral fragments, dead coral, and hard objects submerged in the seabed. Coastal areas that have coral reef flats are also places where macroalgae grow, including several areas found in the waters of Southeast Bali **(Ampou *et al*., 2020)**.

The southeast waters of Bali Island have great marine resource potential. Based on Bali Island's geographical location, the waters in the southeast of the island and its surroundings contain mangrove, seagrass, and coral reef ecosystems as well as biota with high economic value. The waters to the southeast of Bali Island have a diversity of marine biota with a fairly abundant composition of species and distribution, one of which is macroalgae **(Sumarni *et al*., 2019; Maharani *et al*., 2021; Rosiana *et al*., 2022)**. For example, **Sumarni *et al*. (2019)** found 11 genera of macroalgae from the Rhodophyta class and one genus each from the Ochrophyta and Chlorophyta classes in the southeast area of Serangan Island. **Maharani *et al*. (2021)** found 10 species of macroalgae in Mengening Beach and eight species of macroalgae in Geger Beach. The distribution of macroalgae in the waters of southeast Bali is high because the waters are influenced by Indian Ocean currents and nutrient flows that support the growth of various types of macroalgae **(Basyuni *et al*., 2024)**. The waters of Southeast Bali are among the regions with high marine biodiversity, including notable diversity of macroalgae.

The abundance of macroalgae species in a water body indicates its ecological condition and productivity. Macroalgae, when highly abundant, can be a source of basic ingredients for medicines and functional foods **(Overland *et al*., 2018)**. According to **Adarshan *et al*. (2023)**, macroalgae have a high nutritional content and are a promising food source. Some types of macroalgae that are often consumed are *Saccharina japonica*, *Undaria pinnatifida*, *Pyropia* spp., *Sargassum fusiforme*, *Eucheuma* spp., and *Gracilaria* spp. **(Rahikainen *et al*., 2021)**. In addition, macroalgae contain many bioactive metabolites that have the potential to treat various diseases. For example, **Saha and Bhattacharya (2010)** highlighted the pharmaceutical potential of macroalgae as a complementary medicine as a gelling agent and thickener in various industries.

The potential of macroalgae as a valuable marine biological resource is very high. The high diversity of macroalgae species indicates high ecosystem productivity **(Melsasail *et al*., 2018)**. However, to optimize the utilization of macroalgae, a deeper understanding of the community structure and the percentage pattern of macroalgae species cover is needed. Studying the macroalgae community structure and composition in Southeast Bali waters is important for further developing macroalgae management and utilization by providing evidence of its structure and composition.

This study presents novelty by offering a comprehensive and up-to-date quantitative analysis of the macroalgae community structure and species cover patterns in the Southeast Bali marine ecosystem, an area influenced by complex oceanographic and nutrient dynamics yet understudied in this regard. The findings provide essential baseline data that can support sustainable management and further utilization of macroalgae resources in this biodiverse region.

MATERIALS AND METHODS

1. Time and location of research

This research was conducted from May 1 to August 1, 2024. Macroalgae sampling was carried out in the southeast waters of Bali Island, including the waters of Serangan, Benoa Bay, and the coastal waters of Gunung Payung. Data analysis and identification of macroalgae were carried out in the laboratory of Udayana University, Denpasar, Bali.

2. Research procedures

Macroalgae sampling was carried out using the observation method. Purposive sampling was done at three stations, namely the Serangan waters station, the Benoa Bay station, and the Gunung Payung coastal station (Fig. 1). Macroalgae sampling was based on differences in water conditions and human activities around the research station. The conditions of the macroalgae sampling stations can be seen in Table (1).

Table 1. Condition of macroalgae sampling station

Sampling Location	Station Conditions
Station 1	The waters of Serangan Island are open waters that comprise a conservation area under the management of Bali Turtle Indonesian Development.

Station 2	The waters of Benoa Bay are closed waters where community activities occur, namely fishing and tourism. These waters are surrounded by mangrove forests.
Station 3	The waters of Gunung Payung in East Kutuh Village are open waters with tourism activities.

The sampling process was conducted during the lowest tide (low water) phase. Sampling at stations 1 and 3 was carried out by drawing lines at each observation point from the shoreline to the edge using a 1x1 m^2 quadrat transect with a distance of 10m between quadrat transects. This was repeated three times with a distance of 100m between lines. Meanwhile, at Station 2, sampling was carried out by dividing one into five sampling points. This was repeated 10 times at each sampling point so that there were 50 total sampling points at Station 2. Macroalgae samples found in each quadrat transect were sampled and put into plastic for further analysis in the laboratory. The sampling location map is presented in Fig. (1), and the layout of the transect placement at stations 1 and 3 is presented in Fig. (2).

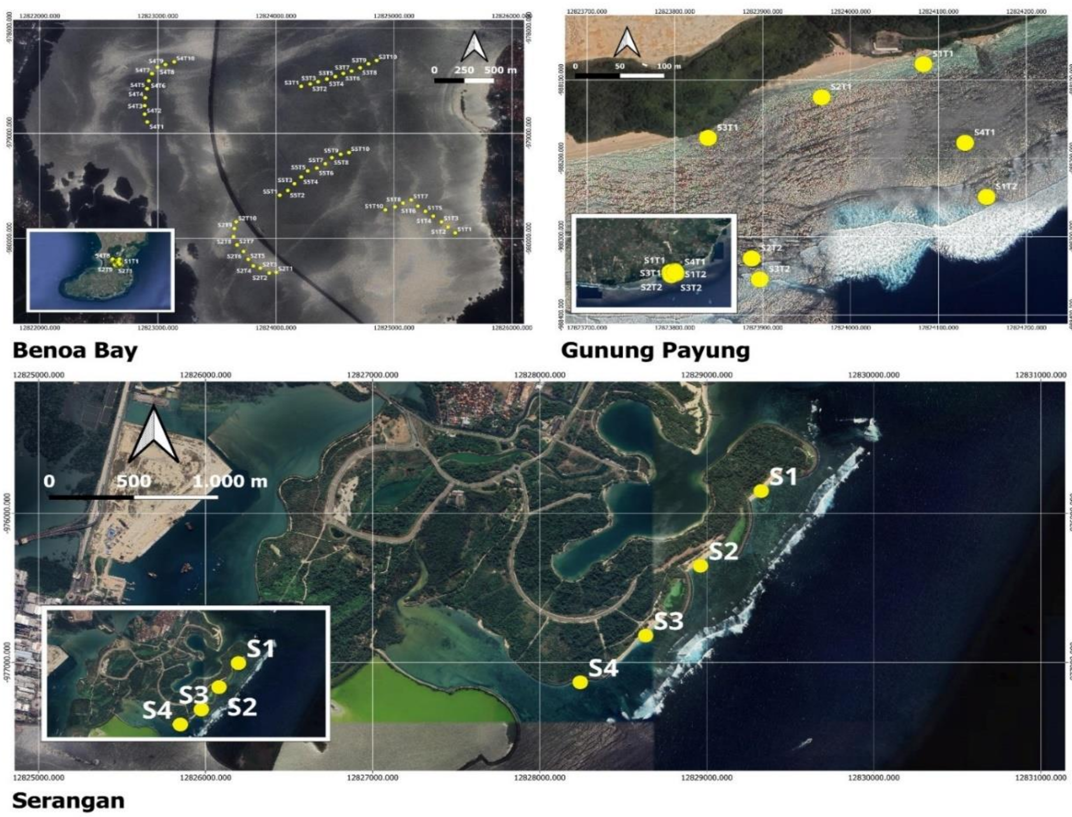


Fig. 1. Macroalgae sampling locations

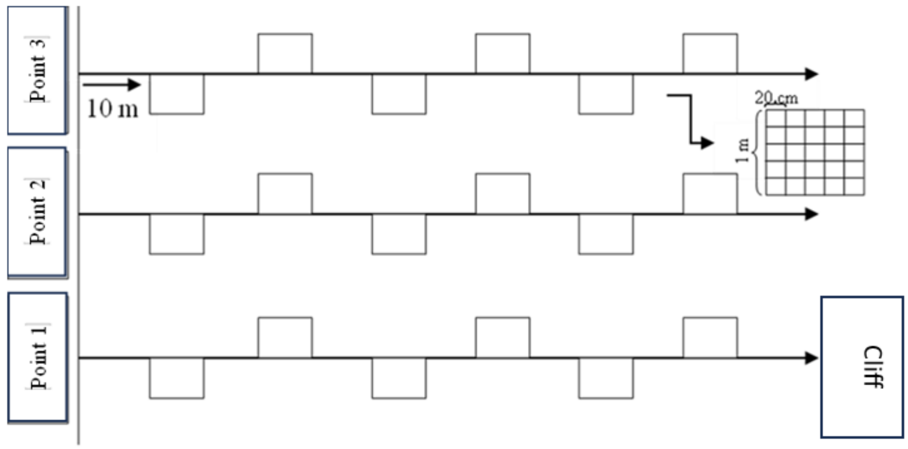


Fig. 2. Illustration of the layout of transect placement at stations 1 and 3

3. Identification of macroalgae

Macroalgae from each station were separated and identified according to the type of species. The species of macroalgae found were identified using the **Niem (1998)** identification book and algabase.org and classified using the World Register of Marine Species (WORMS) (https://www.marinespecies.org/).

4. Data analysis

The data obtained on macroalgae species, macroalgae composition, percent cover, diversity index (H'), evenness index (E), and dominance index (D) were statistically analyzed and are presented in the form of images, tables, and graphs. The data were analyzed descriptively and compared with relevant literature. Data on the percent cover of macroalgae and the macroalgae community structure, including the diversity index (H'), evenness index (E), and dominance index (D), were calculated using the following formulas.

a. Percent cover of macroalgae

Percent cover of macroalgae is defined as the proportion or percentage of a given benthic area that is occupied or covered by macroalgae, usually expressed as a percentage of the total surveyed substrate area. The calculation of the percent cover of macroalgae is done using the following equation **(Dewinta *et al.*, 2021)**.

$$C = \Sigma Ci/A \times 100\%$$

Where

C = percent cover of macroalgae;

$\sum Ci$ = number of cover units of each type of macroalgae; and

A = total number of grids (quadrants) used.

Water quality parameters were measured, in parallel with sampling campaigns, including temperature, pH, and dissolved oxygen or the waters.

b. Macroalgae community structure

- Diversity index (H')

The diversity index (H') was calculated using the Shannon-Wiener formula (H’) which is shown in the following equation **(Krebs, 1989)**:

$$H' = -\sum_{i=1}^{s}(pi)(\log pi)$$

Where:

H’ = is the Diversity Index;

S = is the number of colonies of each species; and

Pi = is the number of colonies of all species.

The criteria for the diversity index value H’≤ 1 is low diversity; 1<H’<3 is moderate diversity; and H’≥3 is high diversity.

- Evenness index (E)

The evenness index (E) is calculated using the formula Pielou’s evenness index from **Odum (1971)**, namely:

$$E = \frac{H'}{lS}$$

Where:

E = is the Evenness Index;

H’ = is the diversity index; and

S = is the number of species.

The Evenness Index value criteria are divided into 3 categories, namely high evenness (E> 0.6); moderate evenness (0.4 ≤ E ≤ 0.6); and low evenness (E <0.4).

- Dominance index (C)

The macroalgae type dominance index is calculated based on the Simpson's dominance index **(Odum, 1975)**, namely:

$$C = \sum_{i=1}^{S}(pi)^2$$

Where:

C = is the dominance index;

Pi = is the ratio of the proportion of the i-th individual;

i = is the species; and

S = is the number of species found.

The criteria for the dominance index value are divided into 3 categories, namely high dominance (0,75 < C ≤ 1); moderate dominance (0,50 < C ≤ 0,75); and low dominance (0 < C ≤ 0,50).

RESULTS

1. Macroalgae composition

The results of macroalgae identification in the waters of Southeast Bali are grouped into three main divisions, they are Cholorophyta, Ochrophyta, and Rhodophyta. The Cholorophyta group found in this study was 19 species (Fig. 3), consisting of 9 main genera, namely *Boergesenia*, *Boodlea*, *Caulerpa*, *Chaetomorpha*, *Cladophora*, *Codium*, *Halimeda*, *Neomeris*, and *Ulva*. The Ochrophyta group found in this study was 16 species (Fig. 4), consisting of 14 main genera, namely *Canistrocarpus*, *Colpomenia*, *Dictyocta*, *Dictyopteris*, *Dictyosphaeria*, *Dictyota*, *Ectocarpus*, *Hormophysa*, *Padina*, *Polycladia*, *Sargassum*, *Sphacelaria*, *Treptacantha*, and *Turbinaria*. The identification results show that the Rhodophyta group is the largest macroalgae after the Chlorophyta and Ochrophyta groups, namely 42 species (Fig. 5). The species consist of 25 main genera, namely *Acanthophora*, *Amansia*, *Arthrocardia*, *Centroceras*, *Cheilosporum*, *Chondrus*, *Dichotomaria*, *Galaxaura*, *Gelidiela*, *Gelidium*, *Gracilaria*, *Grateloupia*, *Hydropuntia*, *Hypnea*, *Jania*, *Kappaphycus*, *Laurencia*, *Mastocarpus*, *Mazzaella*, *Odonthalia*, *Osmundea*, *Palisada*, *Palmaria*, *Portieria*, and *Rhodymenia*.


Boergesenia forbesii


Boodlea composita


Caulerpa cupressoides


Caulerpa filiformis


Caulerpa racemosa


Chaetomorpha antennina


Chaetomorpha linus


Chaetomorpha spiralis


Cladophora glomerata


Codium fragile

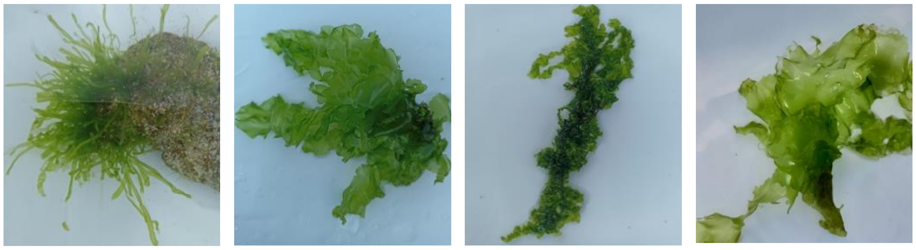

Codium prostratum


Codium repens


Halimeda macroloba


Halimeda opuntia


Neomeris annulata



Ulva flexuosa *Ulva lactuca* *Ulva reticulata* *Ulva rigida*

Fig. 3. Macroalgae Chlorophyta species

Fig. 4. Macroalgae Ochrophyta species


Acanthophora muscoides


Amansia glomerata


Arthrocardia flabellate


Centroceras clavulatum


Cheilosporum cultratum


Chondrus giganteus


Dichotomaria obtusata


Galaxaura rugosa


Gelidiela acerosa

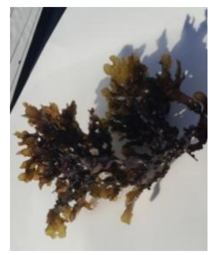

Gelidium Corneum

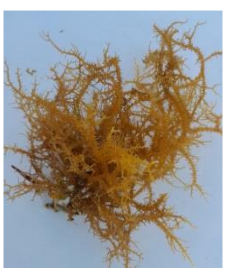

Gelidium crinale


Gelidium spinosum


Gracilaria arcuata


Gracilaria coronopifolia


Gracilaria corticata


Gracilaria dura


Gracilaria edulis


Gracilaria Salicornia


Gracilaria sp


Gracilaria spinulosa


Gracilaria textorii


Gracilaria tikvahiae


Gracilaria greville


Gracilaria cornea


Grateloupia crispata

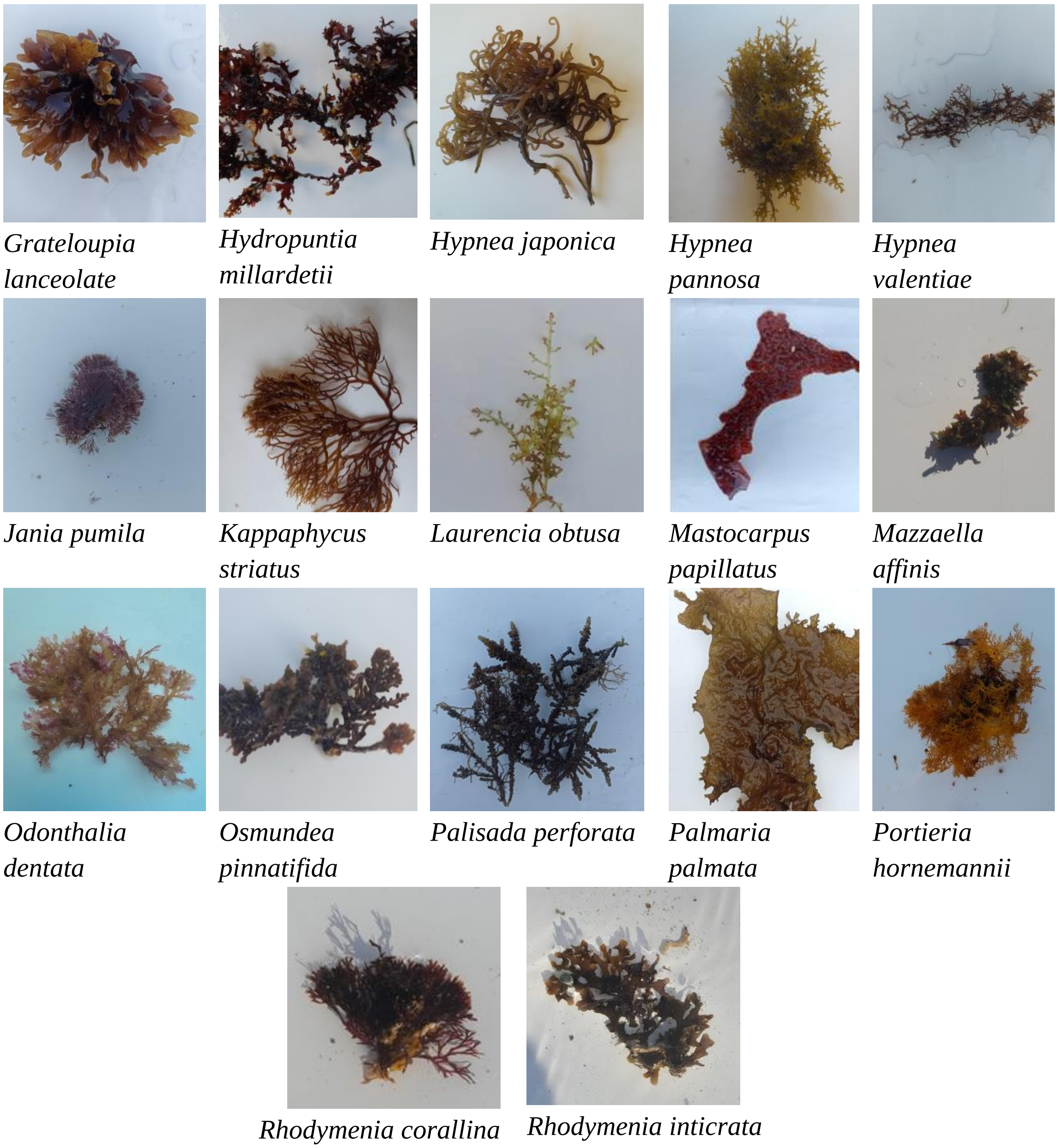


Fig. 5. Macroalgae Rhodophyta species

The composition of macroalgae found in the waters of Southeast Bali contains 80 species consisting of 21 species of Chlorophyta, 38 species of Ochrophyta, and 42 species of Rhodophyta. The results show that at the Serangan station, the composition of macroalgae species consists of 16 species of Chlorophyta, 14 species of Ochrophyta, and 22 species of Rhodophyta. Meanwhile, at Gunung Payung station, the composition of macroalgae species consists of 12 species of Chlorophyta, seven species of Ochrophyta, and 32 species of Rhodophyta. In addition, at Benoa Bay station, the composition of macroalgae species consists of seven species of Chlorophyta, two species of Ochrophyta, and seven species of Rhodophyta. The highest composition of macroalgae was found at

Serangan station (52 species), followed by Gunung Payung station (51 species) and Benoa Bay station (16 species). The macroalgae composition results can be seen in Table (2) for Chlorophyta species, Table (3) for Ochrophyta species, and Table (4) for Rhodophyta species.

Table 2. Composition of macroalgae from Chlorophyta group

No	***Species Name***	**Serangan**	**Benoa Bay**	**Gunung Payung**
1	*Boergesenia forbesii*	x		x
2	*Chaetomorpha antennina*	x		
3	*Chaetomorpha linus*	x		
4	*Chaetomorpha spiralis*	x		x
5	*Codium fragile*	x		
6	*Halimeda macroloba*	x		x
7	*Halimeda opuntia*	x		x
8	*Ulva flexuosa*	x	x	x
9	*Ulva lactuca*	x	x	x
10	*Ulva rigida*	x	x	x
11	*Codium prostratum*			x
12	*Codium repens*			x
13	*Ulva reticulata*		x	x
14	*Boodlea composita*	x		x
15	*Caulerpa racemosa*	x	x	x
16	*Cladophora glomerata*	x	x	
17	*Neomeris annulate*	x		
18	*Caulerpa cupressoides*		x	x
19	*Caulerpa filiformis*			x

Table 3. Composition of macroalgae from Ochrophyta group

No	***Species Name***	**Serangan**	**Benoa Bay**	**Gunung Payung**
1	*Colpomenia sinuosa*	x		x
2	*dictyocta dichotoma*	x	x	
3	*Dictyopteris woodwardia*	x		
4	*Dictyota bartayresiana*	x		
5	*Hormophysa cuneiformis*	x		x
6	*Polycladia indica*	x		
7	*Treptacantha squarrosa*	x		
8	*Turbinaria decurrens*	x		
9	*Turbinaria ornata*	x		
10	*Dictyosphaeria versluysii*			x
11	*Ectocarpus simpliciusculus*		x	

12	*Canistrocarpus cervicornis*	x		
13	*Padina minor*	x		x
14	*Sargassum ilicifolium*	x		x
15	*Sargassum polycystum*	x		x
16	*Sphacelaria rigidula*			x

Table 4. Composition of macroalgae from Rhodophyta group

No	***Species Name***	Serangan	Benoa Bay	Gunung Payung
1	*Acanthophora muscoides*	x	x	x
2	*Arthrocardia flabellate*	x		x
3	*Centroceras clavulatum*	x		x
4	*Chondrus giganteus*	x	x	
5	*Galaxaura rugosa*	x		x
6	*Gelidiela acerosa*	x		x
7	*Gelidium crinale*	x		x
8	*Gracilaria edulis*	x		x
9	*Gracilaria spinulosa*	x		
10	*Gracilaria textorii*	x		x
11	*Hydropuntia millardetii*	x		x
12	*Hypnea japonica*	x		
13	*Hypnea pannosa*	x		x
14	*Hypnea valentiae*	x		x
15	*Jania pumila*	x		x
16	*Kappaphycus striatus*	x		x
17	*Laurencia obtuse*	x		
18	*Osmundea pinnatifida*	x		x
19	*Palisada perforate*	x		x
20	*Portieria hornemannii*	x		x
21	*Rhodymenia inticrata*	x		
22	*Amansia glomerata*			x
23	*Dichotomaria obtusata*			x
24	*Gelidium Corneum*		x	
25	*Gelidium spinosum*			x
26	*Gracilaria arcuate*			x
27	*Gracilaria coronopifolia*			x
28	*Gracilaria dura*		x	
29	*Gracilaria Salicornia*		x	x
30	*Gracilaria sp*		x	
31	*Gracilaria tikvahiae*			x
32	*Gracilaria Greville*			x

33	*Grateloupia cornea*			x
34	*Grateloupia crispate*			x
35	*Grateloupia lanceolate*		x	
36	*Hypnea boergesenii*			x
37	*Mastocarpus papillatus*			x
38	*Mazzaella affinis*			x
39	*Odonthalia dentata*			x
40	*Palmaria palmata*		x	x
41	*Rhodymenia corallina*			x
42	*Cheilosporum cultratum*	x		

2. Percent cover of macroalgae

The results of the percent cover of macroalgae measurements are divided into three groups. The results show that the highest percent cover of Rhodophyta macroalgae is at Gunung Payung station, with a percent cover value of 51.01%, followed by Benoa Bay station (25.55%) and Serangan station (16.04%). The highest percent cover value of Ochrophyta macroalgae is at Serangan station, with a percentage cover value of 7.39%, followed by Gunung Payung station (2.37%) and Benoa Bay station (0.09%). The percent cover value of Chlorophyta macroalgae is at Serangan station, with a percent cover value of 29.44%, followed by Gunung Payung station (27.04%) and Benoa Bay station (11.38%). The results of percent cover of macroalgae measurements can be seen in Table (5).

Table 5. Percent cover of macroalgae in the waters of Southeast Bali

Location	Phylum (%)		
	Rhodophyta	**Ochrophyta**	**Chlorophyta**
Serangan	31.25	10.89	22.36
Benoa Bay	63.37	0.09	12.86
Gunung Payung	30.08	2.37	48.54

Every station has a different percent cover of Chlorophyta macroalgae. The results show that the percent cover of macroalgae from all species of Chlorophyta at all stations ranges from 0.01–49.62%. The species with the highest percent cover is the *U. lactuca* found at Teluk Benoa station, with a percent cover of 49.62%. *U. rigida* was found at Gunung Payung station with a percent cover of 20.60%, and *C. racemosa* was found at Serangan station with a percent cover of 8.93%. The percent cover values of Chlorophyta macroalgae can be seen in Fig. (5).

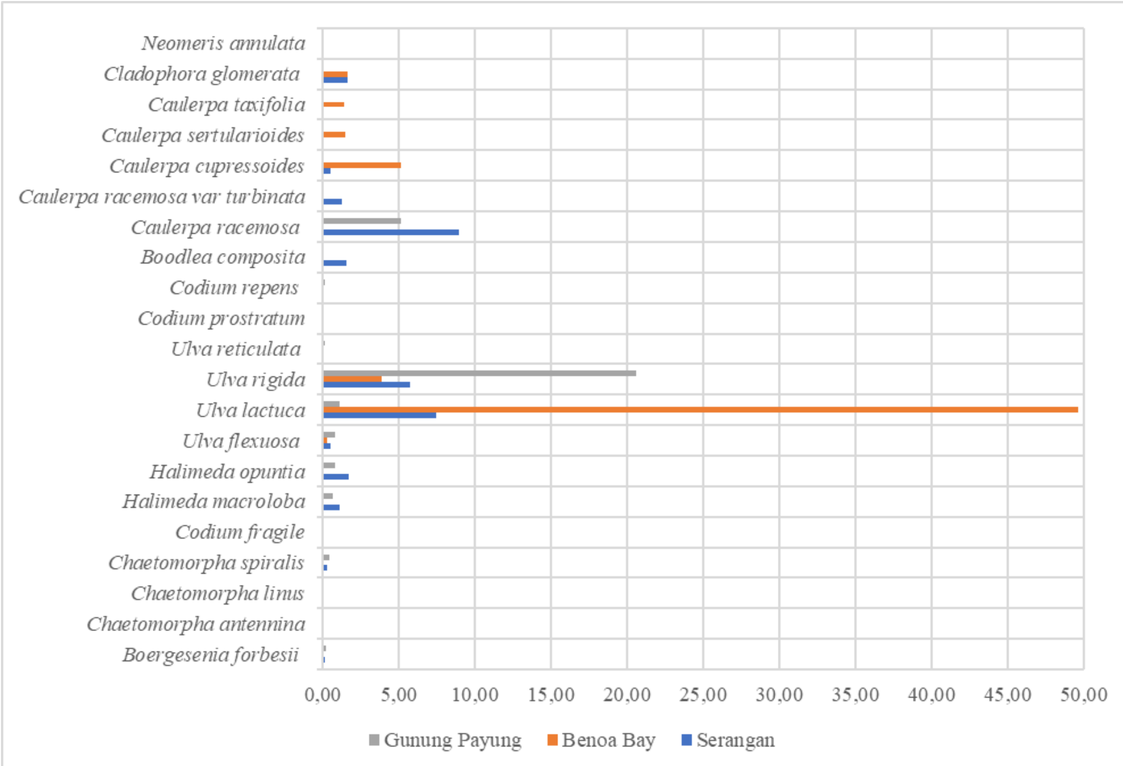


Fig. 5. Percent cover value of Chlorophyta macroalgae

Every station has a different percent cover of Ochrophyta macroalgae. The percent cover of macroalgae from all Ochrophyta species at all stations ranges from 0.01–3.50%. The two species with the highest percent cover of macroalgae were the *P. australis* and *T. ornata* species found at Serangan station, with the respective percent cover values of 3.50% and 3.05%. The percent cover values of Ochrophyta macroalgae can be seen in Fig. (6).

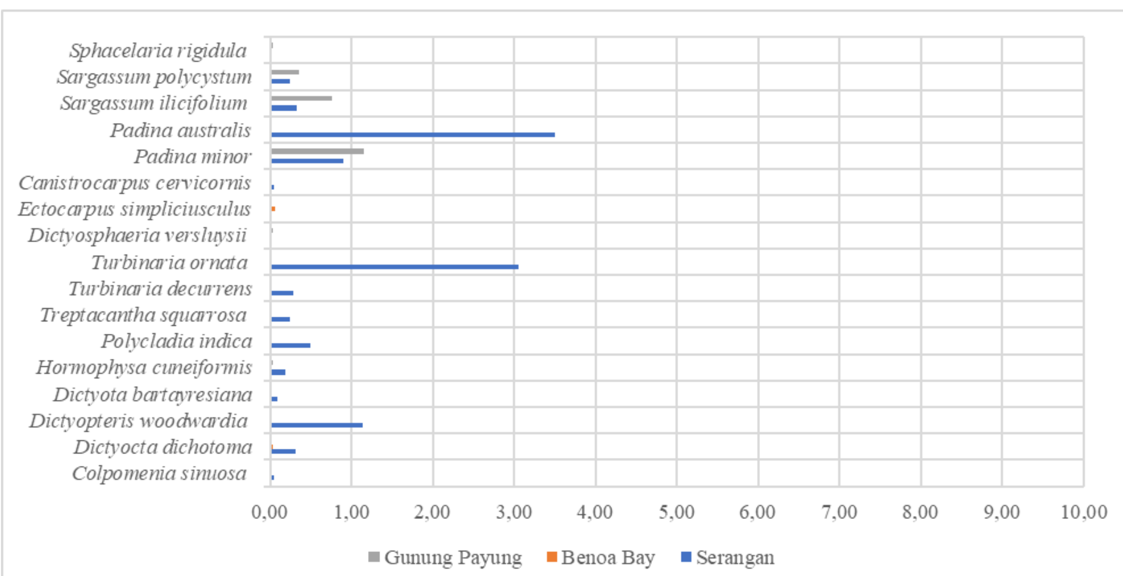


Fig. 6. Percent cover of Ochrophyta macroalgae

Every station has a different percent cover of Rhodophyta macroalgae. The percent cover of macroalgae from all Rhodophyta species at all stations ranges from 0.01–8.82%. The three species with the highest percent cover of macroalgae are the *G. salicornia* found at Benoa Bay station, with a percent cover of 9.67%, the *H. valentiae* found at Gunung Payung station (8.82%), and the *G. edulis* found at Serangan station (6.96%). The percent cover of Rhodophyta macroalgae can be seen in Fig. (7).

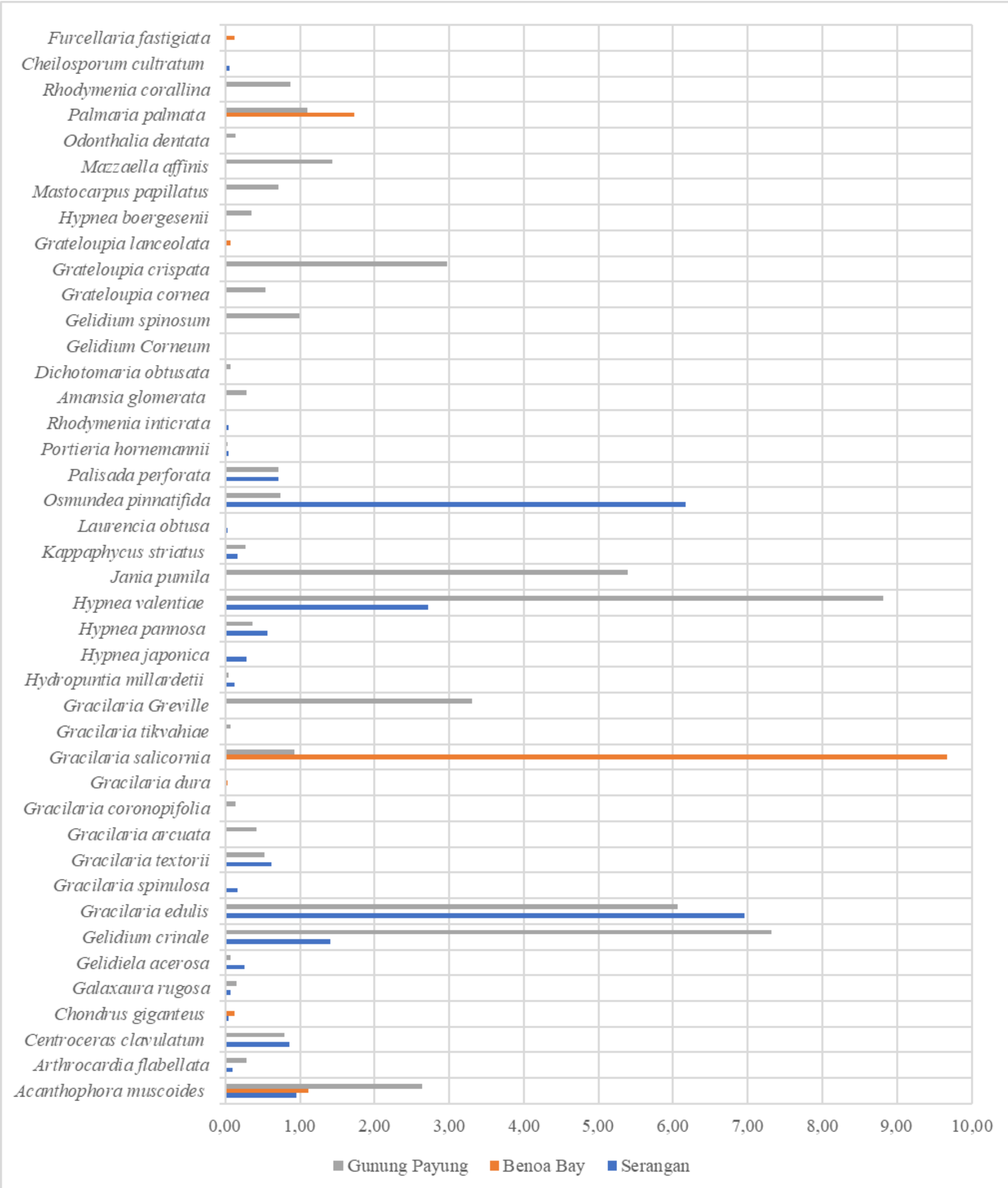


Fig. 7. Percent cover of Rhodophyta macroalgae

3. Macroalgae community structure

The analysis of each station's ecological indices, including diversity, evenness, and dominance, showed varying ecological community structures. The highest diversity value was recorded in Serangan (3.013), followed by Gunung Payung (2.713), with the lowest in Benoa Bay (1.312). High diversity indicates a more complex and stable community, while low diversity may reflect environmental stress or the dominance of certain species. Evenness was also highest in Serangan (0.763), suggesting a more even distribution among species. Conversely, Benoa Bay had the lowest evenness (0.473), indicating the presence of highly dominant species. The highest dominance index was found in Benoa Bay (0.448), indicating that one or a few species dominance the community. This value is inversely related to the diversity and evenness indices. Serangan had the lowest dominance value (0.073), reflecting a more balanced community. The measurements of the structure of the macroalgae community, including including diversity, evenness, and dominance, can be seen in Table (6).

Table 6. Macroalgae community structure in Southeast Bali waters

Location	Diversity	Evenness	Dominance
Serangan	3.013	0.763	0.073
Benoa Bay	1.312	0.473	0.448
Gunung Payung	2.713	0.690	0.119
Average	2.346	0.642	0.213

DISCUSSION

The distribution results of macroalgae species from the Chlorophyta group (Table 2) show a varied distribution of macroalgae at each station. Based on the diversity of macroalgae species from the Chlorophyta group found, Serangan station exhibited the highest species diversity with 16 species, while Teluk Benoa station had the lowest diversity with 7 species. Gunung Payung station recorded a macroalgae species diversity of 12 species. This variation is influenced by various factors, one of which is substrate type, which can affect the growth and distribution of macroalgae in aquatic environments. **Karimi *et al.* (2021)** stated that substrate incompatibility can alter morphology and nutrient absorption efficiency, which in turn may impact macroalgae productivity.

Serangan station tends to have sandy substrates and dead coral. These conditions support the growth and distribution of macroalgae at Serangan station, considering the hard texture of dead coral is utilized by macroalgae for anchoring their thalli and surviving. Serangan station, classified as a protected area, is also a strong reason why this area exhibits a high diversity of marine biota, supporting a healthy and natural aquatic ecosystem. **Boulenger *et al.* (2024)** stated that ecological and sedimentological characteristics indicate that protected areas have higher species diversity compared to unprotected ones.

According to the data in Table (2), Benoa Bay station has the lowest species diversity, with only 7 species of green macroalgae from the genera *Caulerpa* and *Ulva*. The genus *Caulerpa* is one that thrives optimally on muddy substrates. The nutrients present in muddy substrates serve as a nutrient source supporting the growth and distribution of *Caulerpa* sp. at Teluk Benoa station. The study by **Yanti *et al.* (2024)** demonstrated that muddy substrates and coral rubble yield positive growth for *Caulerpa*, both in terms of absolute weight and specific growth rate (SGR). Muddy substrates can provide adequate nutrients and support *Caulerpa* stands in the water column. A mixture of mud with coral fragments or oyster shells also produces good growth, with no significant difference compared to pure mud.

The genus *Ulva* is included among genera capable of thriving on two substrate types, namely coral sand and sandy-mud, which are the dominant substrates at Benoa Bay station. Benoa Bay station features predominantly muddy substrates with relatively high organic matter content. **Pangesthu *et al.* (2021)** found that the organic pollution status in Benoa Bay waters ranged from mild to moderate, with higher organic matter content near ports and other human activities. **Suteja *et al.* (2020)** added that Benoa Bay is an enclosed water body with six river estuaries: Bualu, Sama, Mati, Badung, Buaji, and Loloan Rivers, each distributed around Benoa waters. This underlies the input of organic matter, such as nitrate and phosphate, into Teluk Benoa waters, serving as nutrients for macroalgae to support the growth and distribution of *Ulva* sp. and *Caulerpa* sp.

The distribution of macroalgae species from the brown algae group at the three stations (Table 3) shows that Serangan station has the highest species diversity of Ochrophyta, with 14 species, followed by Gunung Payung station with 7 species, and Benoa Bay station with the lowest diversity of Ochrophyta. The high diversity of Ochrophyta species at Serangan station is attributed to substrate factors and aquatic conditions that support a healthy ecosystem for Ochrophyta growth at this station. **Wu *et al.* (2023)** stated that most Ochrophyta species attach to hard substrates, forming small discs.

Benoa Bay station is the station with the lowest diversity of Ochrophyta species, with only two species, namely *Dictyota dichotoma* and *Ectocarpus simpliciusculus*. According to **Wu *et al.* (2023)**, Ochrophyta are a class of algae susceptible to environmental changes. **Martinez *et al.* (2024)** added that abiotic factors affecting Ochrophyta growth include changes in light intensity, temperature, UV radiation, nutrients, water movement, salinity, as well as sedimentation and substrate. Poor environmental conditions can cause oxidative stress in algae, i.e., excessive production of reactive oxygen species (ROS), which can damage lipids, proteins, and DNA if the algae's antioxidant mechanisms are insufficient.

The predominantly muddy conditions at Benoa Bay station are also suspected to be one of the causes of the low number of Ochrophyta species at this station. **Lopes *et al.* (2024)** stated that substrate type greatly influences the composition and diversity of

Ochrophyta species in an area. Substrate differences can also affect the variation in the number and types of Ochrophyta species at different locations. Hard and stable substrates allow Ochrophyta to grow in intertidal and subtidal zones exposed to tides and waves. This is important because Ochrophyta require sufficient light exposure and good water flow for photosynthesis and nutrient supply. Unstable substrates, such as fine sand and mud, tend to be less supportive of Ochrophyta growth due to the risk of detachment or burial by sedimentation.

The distribution of macroalgae species from Rhodophyta group represents the highest species richness compared to Chlorophyta and Ochrophyta. Table (4) shows that Gunung Payung station has the highest distribution, followed by Serangan station, with Benoa Bay station having the lowest. Gunung Payung station, in terms of Rhodophyta distribution, exhibits the highest species diversity compared to the other stations. This may be due to the ecological conditions at Gunung Payung, which feature fine sandy and coral substrates. **Wu *et al.* (2023)** stated that the Rhodophyta group generally grows on hard substrates such as coral rocks, dead coral, volcanic rocks, and other massive objects.

Gunung Payung station is also categorized as a station with large waves but relatively calm currents or flows. Gunung Payung is a type of beach with abundant coral reefs along the shoreline towards the breakwater. This supports optimal growth of the Rhodophyta group. Clear waters support optimal light penetration, aiding the photosynthetic process of Rhodophyta. **Arianti *et al.* (2024)** found that the physical conditions of the waters at Sire Beach, which has large waves with relatively calm currents and clear waters, support the growth of Rhodophyta. These conditions allow optimal light penetration for Rhodophyta photosynthesis and provide a stable substrate for attachment and development.

Benoa Bay station has the lowest diversity of Rhodophyta species compared to the other stations. This is because Benoa Bay station is an enclosed water body with high organic matter content. **Ghazali *et al.* (2024)** stated that increased organic matter in a water body can lead to eutrophication. This can trigger the growth of certain macroalgae species, such as *Ulva* sp., which can grow faster under increased nutrient and changing water acidity conditions, while other macroalgae species do not thrive under such conditions. The predominantly muddy substrate is also not an optimal habitat for Rhodophyta group. Muddy substrates characterize waters with relatively calm currents and waves, which can hinder the dispersal and nutrient processes for Rhodophyta. **Karimi *et al.* (2021)** stated that substrate incompatibility is a major factor, aside from nutrients, that can affect macroalgae distribution.

The composition of macroalgae in marine is generally considered an indicator of marine environmental health because of its role in the arrangement and function of marine ecosystems **(Gil-Diaz *et al.*, 2021)**. The composition of macroalgae species found at each station was very different, as the composition of macroalgae species at the Serangan and Gunung Payung stations was higher than at the Benoa Bay station. This is caused by several factors, such as the type of water, the substrate, and the human activities around the station. The type of water at Serangan and Gunung Payung stations is open sea water, which is rich in nutrients carried by waves **(Stark *et al.*, 2019)**. Additionally, sampling during the lowest tide allows light to be more effectively absorbed and utilized by macroalgae, and the sandy, rocky, and coral substrate conditions found at the station are ideal for living macroalgae **(Handayani *et al.*, 2020; Marques *et al.*, 2020)**. Another factor that influences the composition of macroalgae is the human activity that occurs around the station. Human activities at Serangan and Gunung Payung stations are lower than at Benoa Bay. High human activities greatly affect the distribution, abundance, and productivity of macroalgae **(Handayani *et al.*, 2022)**. The community activities in Benoa Bay include water tourism such as banana boating, jet skiing, parasailing, flyboarding, snorkeling, and scuba diving; a harbor for fishing vessels; as well as household activities in the surrounding areas of Benoa Bay.

The percent cover of macroalgae found in the waters of southeast Bali are divided into three groups, namely Rhodophyta (12.86–48.54%), Ochrophyta (0.09–10.89%), and Clorophyta (30.08–63.37%). According to **Rahmawati *et al.* (2019)**, the percent cover value of macroalgae is divided into three categories, namely the low category (< 10%), which indicates good water quality, the moderate category (10–30%), which indicates moderate water quality, and the abundant category (> 30%), which indicates poor water quality. In our study, the percent cover value of Rhodophyta macroalgae at Serangan and Benoa Bay stations was in the moderate category, while at Gunung Payung station, it was in the abundant category. The percent cover of Ochrophyta macroalgae at all stations was in the low category, and the percent cover of Chlorophyta macroalgae at all stations was in the moderate category. High macroalgae cover values are attributed to nutrient inputs originating from terrestrial anthropogenic activities, as well as nutrients transported and redistributed by wave action **(Stark *et al.*, 2019; Sangaji, 2022)**. A low percent cover of macroalgae can be caused by the unsuitability of the substrate and various human activities such as tourism activities, as well as activities to take several types of biotas **(Maharani *et al.*, 2021)**.

The percent cover of macroalgae by species was categorized according to the highest cover observed for each group. Specifically, the highest Chlorophyta cover was recorded for *Ulva lactuca*, with a percent cover of 49.62%. Among Ochrophyta, *Padina australis* exhibited the highest cover at 3.50%. For Rhodophyta, *Gracilaria salicornia* showed the greatest cover, with a percent cover of 9.67%. The substrate conditions at each station played a significant role in influencing the high percent cover observed for these macroalgal species. According to **Dewi *et al*. (2025)**, habitat can affect the species of seaweed that grow. The substrate is a place to grow and attach macroalgae. Substrates in the form of coral fragments are very suitable for the attachment of various species of red and brown macroalgae, while green macroalgae are often found on sand substrates and dead coral fragments. This is supported by **Handayani (2019)**, who stated that macroalgae of the genera *Ulva*, *Padina*, and *Hypnea* tend to prefer hard substrates such as rocky substrates and coral reefs. This is because the three genera are attached to the substrate. **Cannon *et al.* (2023)** mentioned that other factors that influence the percentage of macroalgae cover are the availability of nutrients in the water, sunlight, exposure to wind and waves, the season, and environmental conditions like physical, chemical, and biological.

Overall, Serangan station exhibits the most favorable ecological conditions among the three locations, as evidenced by its high species diversity, even distribution of species, and low dominance by any single species. This suggests that the environment is relatively stable and experiences minimal disturbance. Conversely, Benoa Bay exhibits a less balanced community structure, potentially reflecting environmental stressors such as anthropogenic activities, pollution, or habitat modification. Gunung Payung occupies an intermediate position, characterized by relatively high species diversity alongside indications of species dominance. The structure of the macroalgal community in the waters of southeast Bali was assessed using the diversity index, evenness index, and dominance index. Our study recorded a macroalgal diversity index of 2.346, which falls within the moderate category. According to **Handayani *et al.* (2024)**, a moderate diversity index indicates that the macroalgal community is relatively stable and exhibits moderate productivity. This level of diversity reflects environmental conditions that support a balanced variety of macroalgal species, contributing to ecosystem stability without dominance by a few species.

The moderate diversity index has several ecological and environmental implications requiring further discussion. The macroalgal diversity, which falls into the moderate category, indicates that the environmental conditions in the southeastern waters of Bali are relatively stable enough to support the presence of various macroalgal species. Although it does not reach a high diversity value (> 3), this level suggests that the habitat still supports different types of macroalgae despite the dominance of certain species. This value may also result from environmental pressures that favor certain species over others, competitive interactions among species that lead to imbalances in species distribution, as well as physical or biological disturbances such as seasonal temperature changes or the activity of specific herbivores that selectively feed on certain macroalgae. The moderate diversity index suggests that the macroalgal ecosystem in the southeastern waters of Bali is still relatively balanced. Despite the dominance of certain species, the presence of other species indicates that the environment is not under significant stress or severely disturbed. According to **Handayani *et al*. (2023)**, the value of macroalgae diversity can be measured based on the diversity of species found in waters and the more species there are in a body of water, the higher the level of diversity.

The uniformity index in our study (0.642) falls into the high category, meaning that species are evenly distributed. However, differences were observed between stations. The uniformity values in Serangan and Gunung Payung range from 0.690–0.763, indicating high evenness. This suggests that in these two locations, the distribution of macroalgal individuals is more balanced or relatively equal among the existing species. In contrast, in Benoa Bay, the uniformity value is only 0.473, indicating moderate evenness. This may imply a stronger dominance of certain species or environmental pressures that lead to a less even distribution of species. **Kepel *et al*. (2019)** mentioned that the high uniformity value of macroalgae in a body of water is caused by the even division of each type of macroalgae, meaning that no particular type dominates. The uniformity value is positively correlated with the diversity index. The higher the diversity index value, the higher the uniformity index value **(Ulfah *et al.*, 2019)**.

The dominance index value in our study (0.213) is in the low category, meaning that no specific macroalgae species is dominant. However, the measurement results at each station show significant differences. The dominance indices at Serangan and Gunung Payung range from 0.073 to 0.119, indicating low dominance. This suggests that no single species overwhelmingly dominates the macroalgal community, allowing for a more even distribution of individuals. In contrast, the dominance index at Benoa Bay reaches 0.448, which falls into the category of high dominance. This indicates that a particular macroalgal species significantly dominates the community in that area. Such high dominance may be caused by various factors, such as specific environmental pressures that favor certain species over others, human activities that disrupt the ecosystem, or even substrate conditions that support the growth of only some species. **Erniati *et al.* (2023)** mentioned that the high dominance index indicates very tight competition between members of the macroalgae community. **Handayani *et al.* (2023)** added that there is an inverse correlation between the dominance index and the diversity index in macroalgal communities: a relatively high dominance index, indicating that one or a few species dominate numerically, corresponds to a lower diversity index, reflecting reduced species diversity. This relationship occurs because when individual dominance is high, fewer species coexist in significant numbers, thereby decreasing overall diversity.

CONCLUSION

The waters of Southeast Bali exhibit a macroalgal diversity index (H') of 2.346, classified as moderate, reflecting the overall community structure. The average evenness index (E) is 0.642, indicating high evenness, while the dominance index (C) is 0.213, reflecting low species dominance. A total of 80 macroalgal species were identified in the study area, comprising 21 species of Chlorophyta, 17 species of Ochrophyta, and 42 species of Rhodophyta. The percentage cover of macroalgal groups varied, with Rhodophyta ranging from 12.86% to 48.54%, Ochrophyta from 0.09% to 10.89%, and Chlorophyta from 30.08% to 63.37%. The species with the highest percent cover were *Ulva lactuca* (49.62%) among Chlorophyta, *Padina australis* (3.50%) among Ochrophyta, and *Gracilaria salicornia* (9.67%) among Rhodophyta. These results indicate that the macroalgal community in Southeast Bali waters is highly diverse and abundant, suggesting favorable environmental conditions that support the growth and proliferation of various macroalgal species.

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