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### Diversity of macroalgae in the intertidal zone of Iboih Beach, Sabang, Indonesia

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#### ABSTRACT

The intertidal zone of Iboih Beach in Sukakarya District, Sabang, has significant macroalgae diversity with different substrate variations. This study examined the diversity, distribution, and ecological significance of macroalgae using the quadrat method with purposive sampling technique on three plots measuring  $2 \times 2 \text{ m}^2$  (coral, sand, and rock substrates), each replicated three times. Measurements of environmental parameters including temperature (using a thermometer), salinity (refractometer), and depth (Secchi disk) were carried out prior to sampling to ensure that environmental conditions were recorded. The results showed *Galaxaura rugosa* as the dominant species (INP 63.22), followed by *Halimeda opuntia* (38.42) and *Chaetomorpha crassa* (35.27), which showed a preference for hard substrates rich in nutrients. In contrast, *Caulerpa* sp. had the lowest INP (9.33), indicating specific habitat adaptation. The Shannon-Wiener diversity index ( $H' = 1.57$ ) was in the moderate category, with an average INP of 28.575 reflecting a diverse community occupying different ecological niches. The coral substrate supported the highest abundance due to its stability and nutrient availability. This finding confirms the crucial role of substrate characteristics in the structure of intertidal macroalgal communities.

#### Introduction

As an archipelagic nation, Indonesia hosts one of the world's richest marine biodiversities, with maritime zones constituting approximately 70% of its total area (Coordinating Ministry for Maritime Affairs and Investment, 2023). The coastal ecosystems of Aceh Province, strategically located in western Indonesia, feature several distinctive characteristics, including an extensive 2,666 km coastline (BPS Aceh, 2022), Sumatra's most expansive mangrove forests covering 52,000 hectares, and coral reef systems spanning 39,000 hectares (Burke *et al.*, 2012). These marine environments provide critical habitats for 590 documented reef fish species (Allen & Erdmann, 2012) and serve as conservation areas for threatened species including the olive ridley sea turtle (Mirna *et al.*, 2021). Particularly noteworthy is Iboih Beach in Sabang, renowned for its exceptional water clarity (>15m visibility) and robust coral reef ecosystems

demonstrating an 82% health index (Giyanto *et al.*, 2022), establishing it as a prime research site for macroalgae ecological studies and ecosystem health assessment.

Iboih Beach has an intertidal ecosystem that serves as an important habitat for various macroalgae species. This ecosystem is vulnerable to human activities, such as intensive tourism, waste disposal, and ship traffic. Research by (Nursika and Cintamulya, 2020) shows that uncontrolled human activities can disrupt the balance of coastal ecosystems, impacting macroalgal biodiversity. The decline in macroalgae populations can reduce primary productivity in these waters, which in turn affects aquatic food chains and ecosystem stability (Mushlihah *et al.*, 2021; Perisha *et al.*, 2022).

Macroalgae play significant ecological roles as primary producers, spawning habitats for marine biota, and pollutant absorbers. Studies by (Asharo *et al.*, 2024) emphasize that macroalgae have a high

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capacity for absorbing heavy metals, helping to maintain water quality. Besides their ecological benefits, macroalgae also have economic value as raw materials in the food, pharmaceutical, and energy industries (Shobir *et al.*, 2019; Peñalver *et al.*, 2020; Wang *et al.*, 2023; Akbar *et al.*, 2023).

The growth of macroalgae in intertidal ecosystems is highly influenced by environmental factors such as substrate, sedimentation, and interactions with other biotic communities (Akbar *et al.*, 2025). According to research by (Rophi, 2025), varied substrates support macroalgal diversity, while high sedimentation can inhibit the growth of certain macroalgae.

In Iboih Beach, Sukakarya District, Sabang, the intertidal zone is known as a dynamic transition area between land and sea. This zone experiences periodic fluctuations in temperature, salinity, and light exposure due to tides, making it a challenging habitat for various macroalgae species (Lobban and Harrison, 1994; Hurd *et al.*, 2024; Lüning, 1990; Akbar and Hasan, 2024). These conditions influence the distribution and composition of macroalgal communities, where certain species have specific adaptations to survive in environments with high ecological pressure (Connell, 1972; Robles and Desharnais, 2002).

Comprehensive studies on macroalgae in Iboih Beach are still limited and this is an initial study on macroalgae. However, a deep understanding of the diversity and distribution of macroalgae has important implications for coastal ecosystem conservation and sustainable marine resource management. In addition, the ecological value of macroalgae includes their role in maintaining coastal substrate stability and as a food source for marine herbivores (Connell, 1972; Lobban and Harrison, 1994).

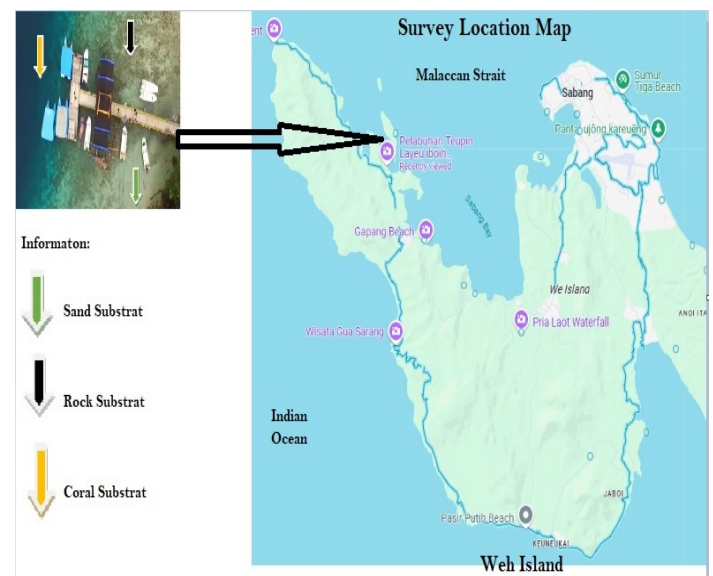
Based on this background, this study aims to explore the diversity, distribution, and ecological significance of macroalgae in the intertidal zone of Iboih Beach, Sukakarya District, Sabang. This research is expected to provide useful information for conservation efforts and sustainable utilization of macroalgal resources in this region.

## Materials and Methods

### Location and time of research

Field investigations were carried out over a four-day period (May 23-26, 2019) in the coastal ecosystem of Iboih Beach, located within Sabang's Sukakarya District (Figure 1). The research design incorporated examination of three heterogeneous substrate categories across established monitoring

plots: (I) granular sedimentary matrices dominated by fine particulate matter, (II) lithic formations serving as stable attachment surfaces for benthic flora, and (III) cnidarian-derived frameworks creating specialized niches for marine vegetation. This tripartite substrate classification was implemented to account for the known ecological variation in macroalgal community assemblages across different microhabitats. Data collection was strategically timed to coincide with tidal minima, ensuring optimal exposure of intertidal biological communities for accurate taxonomic assessment.



**Figure 1.** Survey location map, Iboih, Sabang - Aceh

### Tools and Materials

The tools and materials used included Google Map of GPS for location determination, writing tools for recording, and an underwater camera for visual documentation. Labels were used for sample identification, while a measuring tape and raffia rope assisted in setting up research plots. A refractometer (Atago Master-S/Mill $\alpha$ ) measured salinity, a thermometer (Hanna Instruments HI145) monitored water temperature, and a Secchi disk (Strickland & Parsons, 1972) measured water depth and clarity. Sample bottles were used to store macroalgae, and 70% alcohol served as a temporary preservative.

### Research Object

The research object was all macroalgae in the intertidal zone of Iboih Beach, Sukakarya, Sabang. The population included all macroalgae within the transect area, while samples were taken from each transect plot using purposive sampling (Etikan, 2016). Samples were selected to represent the

population, aiming to optimally study macroalgal diversity and distribution.

## Data Collection Techniques

### Observation

Observation was conducted through direct field observation to study macroalgae at the research site. This involved systematic observation and recording of macroalgal specimens found in each plot. The quadrat method (Cox, 1990) with purposive sampling (Etikan, 2016) was used. Research was conducted on three plots measuring 2 x 2 m<sup>2</sup>, each with different substrates: Point II: Coral substrate, Point II: Sand substrate, and Point III: Rock substrate (Kasim, 2016). Sampling was done three times at each plot. Environmental measurements such as temperature, salinity, and depth were taken using a thermometer (Hanna Instruments HI145), refractometer (Atago Master-S/Millα), and Secchi disk (Strickland & Parsons, 1972) before sampling.

### Identification

Macroalgae identification was generally based on algae identification keys, including morphological characteristics such as color, thallus shape, cell structure, and other specific features (Lobban and Harrison, 1994; Dawes, 1998). Sources used for identification included specialized algae guidebooks and scientific journals on algae taxonomy, as explained by (Bold and Wynne, 1985) in "Introduction to the Algae: Structure and Reproduction" and (Lee, 2008) in "Phycology". Additionally, (Brodie et al., 2007) in "The Green Seaweeds of Britain and Ireland" emphasized algae identification methods based on morphology and habitat.

### Documentation

The documentation method was used to collect data in the form of written notes, photos, and relevant field records. Documentation included photos of macroalgae, environmental condition records, and supporting information from relevant literature.

### Data Analysis

Data analysis was conducted by calculating several ecological parameters to describe macroalgal communities, including:

a. Diversity Index  $H' = - \sum P_i \cdot \ln P_i$

$$P_i = n_i/N$$

$H'$  = Shannon-Wiener diversity index

$n_i$  = Number of individuals for the observed species

$N$  = Total number of individuals

$P_i$  = Proportional abundance of species upto  $i$

b. Density Formula:

$$Km = \frac{(\text{Number of a species})}{(\text{Area of sample plot})}$$

$$Kr = \frac{(\text{Absolute Density of a species})}{(\text{Total density of all species})} \times 100\%$$

$Km$  = Absolute Density

$Kr$  = Relative Density

c. Dominance Index

$$D = \sum P_i^2$$

$$P_i = n_i/N$$

$D$  = Dominance Index

$P_i$  = Proportion of individuals in the species

$N_i$  = Number of individuals in the species

$N$  = Total number of individuals

d. Frequency Formula

$$F = \frac{(\text{Number of sample plots occupied by } i \text{ species})}{(\text{Total number of sample plots})}$$

$$Fr = \frac{(\text{Absolute Frequency of species})}{(\text{Total frequency of all species})} \times 100\%$$

$F$  = Absolute Frequency

$Fr$  = Relative Frequency

e. Formula of Importance Value Index:

$$IVI = Kr + Fr$$

$IVI$ : Importance Value Index

$Kr$ : Relative Density

$Fr$ : Relative Frequency

## Results

Based on Table 1, it shows variations in temperature, salinity, and depth related to the type of substrate. Coral substrates tend to have the highest temperature and depth, while sand substrates have the lowest temperature and depth. These differences can influence the composition and distribution of macroalgae and other organisms living in the intertidal zone of Iboih Beach, Sabang.

**Table 1.** Physical Environmental Conditions at Iboih Beach, Sukakarya District, Sabang

| Substrate Type | Temperature (°C) | Salinity (‰) | Depth (cm) |
|----------------|------------------|--------------|------------|
| Sand           | 28               | 32           | 74         |
| Rock           | 30               | 30           | 110        |
| Coral          | 32               | 30           | 149        |

**Table 2.** Types and Quantities of Macroalgae at Iboih Beach, Sukakarya District, Sabang

| No           | Family         | Species                      | Substrate (Number of Individuals) |           |            | Total Individuals |
|--------------|----------------|------------------------------|-----------------------------------|-----------|------------|-------------------|
|              |                |                              | Sand                              | Rock      | Coral      |                   |
| 1            | Dictyoceae     | <i>Padina australis</i>      | -                                 | 5         | 12         | 17                |
| 2            | Halimedaceae   | <i>Halimeda opuntia</i>      | 4                                 | 14        | 32         | 50                |
| 3            | Galaxauraceae  | <i>Galaxaura rugosa</i>      | 23                                | 36        | 54         | 113               |
| 4            | Gelidiaceae    | <i>Gelidium carolinianum</i> | -                                 | 3         | 11         | 14                |
| 5            | Cladophoraceae | <i>Chaetomorpha crassa</i>   | 1                                 | 18        | 23         | 42                |
| 6            | Dasycladaceae  | <i>Neomeris sp.</i>          | -                                 | 4         | 6          | 10                |
| 7            | Caulerpaceae   | <i>Caulerpa sp.</i>          | -                                 | -         | 8          | 8                 |
| <b>Total</b> |                |                              | <b>28</b>                         | <b>80</b> | <b>146</b> | <b>254</b>        |

Table 2 presents data on the diversity and number of macroalgae individuals found on the three main substrate types at Iboih Beach, namely sand, rock, and coral. A total of seven families and seven species of macroalgae were identified, with an overall count of 254 individuals.

*Galaxaura rugosa* from the family Galaxauraceae showed the highest number of individuals (113 individuals) and was found distributed across all substrates, with dominance on coral substrates (54 individuals). This is consistent with the natural habitat of *Galaxaura rugosa*, which tends to grow on hard substrates such as rocks and corals in tropical to subtropical waters (Abbott, 1999; Littler and Littler, 2000). The phycobilin pigments possessed by this algae support photosynthesis at relatively greater depths (Lee, 2008).

Another species that also showed dominance is *Halimeda opuntia* (50 individuals) from the family Halimedaceae, with the highest distribution on coral substrates (32 individuals). *Halimeda opuntia* is a *Calcareous algae* often found on hard substrates with high light intensity, as the calcification of its body requires sufficient calcium ion availability in tropical aquatic environments (Dawes, 1998; Wei et al., 2022).

In contrast, *Caulerpa sp.* from the family Caulerpaceae was found exclusively on coral substrates (8 individuals), indicating a specific habitat preference. *Caulerpa sp.* is known to thrive well on porous coral substrates with good water circulation, which supports nutrient exchange for its growth (Littler et al., 1983).

The distribution of other macroalgae, such as *Padina australis* (17 individuals), *Gelidium sp.* (14 individuals), and *Chaetomorpha crassa* (42 individuals), showed variations between rock and coral substrates, with minimal presence on sand substrates. Sand substrates have a structure that is less supportive of algal thallus attachment, which tends to affect the number of individuals found (Lobban & Harrison, 1994).

Classification and description of the macroalgae species found at Iboih Beach, Sukakarya District, Sabang:

#### a. Classification of *Padina australis*



**Figure 2.** *Padina australis*

Regnum: Plantae  
Divisio : Phaeophyta  
Classis : Phaeophyceae  
Ordo : Dictyotales  
Familia : Dictyoceae  
Genus : *Padina*  
Species : *Padina australis*

*Padina australis* (Figure 2) a brown macroalgae from the family Dictyotaceae, has a fan-shaped thallus with thin, lobed structures and radial striations. Its yellowish-brown color can turn white due to calcification (Trono, 1997). Macroalgae, including *Padina australis*, possess a fundamental anatomical structure comprising the epidermis and parenchyma (Bold & Wynne, 1985). The mineral composition of marine algae, rich in elements such as calcium, sodium, potassium, magnesium, and iron, underscores their significant nutritional value (McDermid, 2004).

Ecologically, macroalgae play an important role in coastal ecosystems (Johnson *et al.*, 2017), contributing to environmental productivity and dynamics (Mann, 1973). In addition, macroalgae have important bioeconomic value, especially in aquaculture and climate change mitigation and adaptation (Duarte *et al.*, 2017). Its role includes carbon sequestration and as a sustainable raw material for various industries (Chung *et al.*, 2013). Macroalgae cultivation has been recognized as a promising blue economy initiative to support ecological balance as well as economic development (Hoegh-Guldberg *et al.*, 2019). Thus, a comprehensive understanding of macroalgae such as *Padina australis* includes its biological, ecological, and economic dimensions. Furthermore, *Padina australis* can heal organ and tissue damage in fish caused by detergent exposure (Sani, Oedjoe, & Lukas, 2022).

b. Classification of *Halimeda opuntia*



**Figure 3.** *Halimeda opuntia*

Regnum: Plantae  
Divisio : Chlorophyta  
Classis : Ulvophyceae  
Ordo : Bryopsidales  
Familia : Halimedaceae  
Genus : *Halimeda*  
Species : *Halimeda opuntia*

*Halimeda opuntia* (Figure 3), a member of the Halimedaceae family, is a green macroalgae with a rigid, kidney-shaped thallus that has irregular branching. It can grow up to 8 cm in height, with segment widths of approximately 0.7 cm. This species forms colonies in shallow tropical waters up to a depth of 10 meters, particularly in coral reef areas with calm coastal conditions. Its rhizoids function as attachments to the substrate. Halimedaceae is known as a major contributor to limestone deposits in tropical marine ecosystems (Littler and Littler, 2000),

playing a significant role in the formation of reef substrates (Borowitzka and Larkum, 1987).

c. Classification of *Galaxaura rugosa*



**Figure 4.** *Galaxaura rugosa*

Regnum : Plantae  
Divisio : Thallophyta  
Classis : Rhodophyceae  
Ordo : Nemalionales  
Familia : Galaxauraceae  
Genus : *Galaxaura*  
Species : *Galaxaura rugosa*

*Galaxaura rugosa* (Figure 4) is a red algae with a cylindrical, dichotomously branched thallus, reaching a height of 5–7 cm and a branch diameter of 1.5–5 mm. Its color is a dark reddish-brown, with stiff and compact branching. The structure of this algae includes a disc-shaped holdfast that functions to attach to substrates such as sand, coral rocks, and dead coral. Its unique morphology, resembling Japanese grass with circular, segmented spines, provides high adaptability in coral reef ecosystems. This algae is important as a primary food source for fish and other marine organisms, supporting the dynamics of shallow tropical marine ecosystems (Guiry & Guiry, 2023).

d. Classification of *Gelidium carolinianum*



**Figure 5.** *Gelidium carolinianum*

Regnum : Plantae  
Divisio : Rhodophyta  
Classis : Florideophyceae  
Ordo : Gelidiales  
Familia : Gelidiaceae  
Genus : *Gelidium*  
Species : *Gelidium carolinianum*

*Gelidium carolinianum*, (Figure 5) a red algae (Rhodophyta), is known for its reddish-brown or blond thallus, which is caused by the pigment phycoerythrin. This algae can grow up to 20 cm in length and has a width of approximately 1.5 mm, with a branched thallus consisting of a primary stem, secondary branches, and a rounded growth point (apical pit) at its tip. *Gelidium carolinianum*. is equipped with a disc-shaped holdfast that allows it to attach to substrates, enabling adaptation to wave action in the intertidal zone. The carrageenan content in its body gives it a chewy texture, making it an important raw material for products such as agar, pasta, and bread. Additionally, *Gelidium carolinianum*. is rich in protein and various vitamins, contributing to its high nutritional value (Guiry and Guiry, 2023; Dawes, 1998).

e. Classification of *Chaetomorpha crassa*



Figure 6. *Chaetomorpha crassa*

Regnum: Plantae  
Divisio : Chlorophyta  
Classis : Ulvophyceae  
Ordo : Cladophorales  
Familia : Cladophoraceae  
Genus : *Chaetomorpha*  
Species : *Chaetomorpha crassa*

*Chaetomorpha crassa*, (Figure 6) a member of the class Ulvophyceae, is known as "green hair algae" due to its unbranched filamentous structure, often resembling a fishing line ball. Its body structure

consists of a thallus with elongated cells growing end-to-end. This algae thrives in the intertidal zone, frequently covering substrates such as rocks or sand, and forms dense colonies. *Chaetomorpha crassa* has the ability to absorb nitrates and phosphates from water, thereby helping to reduce excess nutrient levels and supporting aquatic ecosystems by providing a habitat for microfauna. Additionally, research has shown that this algae has pharmaceutical potential as an antibacterial agent and an anti-fertility compound (Dawes, 1998; Guiry and Guiry, 2023).

f. Classification of *Neomeris* sp.

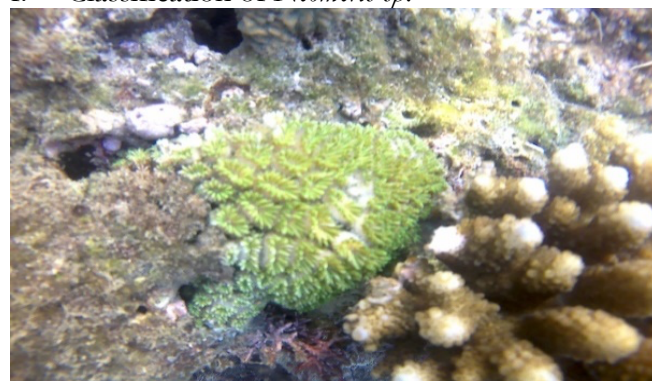


Figure 7. *Neomeris* sp

Regnum: Plantae  
Divisio : Chlorophyta  
Classis : Chlorophyceae  
Ordo : Dasyclades  
Familia : Dasycladaceae  
Genus : *Neomeris*  
Species : *Neomeris* sp.

*Neomeris* sp., (Figure 7) a member of the class Bryopsidophyceae, is an algae with a cylindrical thallus that can grow up to 30 mm in length. The thallus is dark green at the tips, while the base is white due to calcium carbonate deposition. The surface of this algae is smooth and slippery, with fibrous rhizoids serving as attachment structures. *Neomeris* sp. is often found attached to substrates such as live or dead coral rocks. This algae can interfere with coral transplantation efforts due to its aggressive growth on coral substrates, making it one of the factors hindering coral reef restoration (Littler and Littler, 1992; Guiry and Guiry, 2023).

g. Classification of *Caulerpa sp.*



**Figure 8.** *Caulerpa sp.*

Regnum : Plantae  
Devisio : Chlorophyta  
Classis : Ulvophyceae  
Ordo : Bryopsidales  
Familia : Caulerpaceae  
Genus : *Caulerpa*  
Species : *Caulerpa sp.*

*Caulerpa sp.*, (Figure 8) a green algae belonging to the class Ulvophyceae, includes approximately 15 species and 5 varieties found in Indonesian waters. This algae is known as "sea grapes" due to its small, round, bead-like appearance. In addition to its ecological role in neutralizing toxins in water, *Caulerpa sp.* also helps reduce environmental contamination by absorbing toxic substances. However, this algae contains bioactive compounds that can potentially cause toxicity in fish if consumed in large quantities. These characteristics make *Caulerpa sp.* an important indicator of water quality while also requiring careful ecosystem management (Guiry and Guiry, 2023; Verbruggen et al., 2009).

**Table 3.** Importance Value Index (IVI) Analysis of Macroalgae Species at Iboih Beach, Sukakarya District, Sabang

| NoSpecies                    | Km    | Kr     | Fm   | Fr   | IVI   |
|------------------------------|-------|--------|------|------|-------|
| 1 <i>Padina australis</i>    | 0.017 | 6.69   | 0.67 | 2.55 | 19.24 |
| 2 <i>Halimeda opuntia</i>    | 0.05  | 19.69  | 1.00 | 8.73 | 38.42 |
| 3 <i>Galaxaura rugosa</i>    | 0.113 | 44.49  | 1.00 | 8.73 | 63.22 |
| 4 <i>Gelidium sp.</i>        | 0.014 | 5.51   | 0.67 | 2.55 | 18.06 |
| 5 <i>Chaetomorpha crassa</i> | 0.042 | 16.54  | 1.00 | 8.73 | 35.27 |
| 6 <i>Neomeris sp.</i>        | 0.01  | 3.94   | 0.67 | 2.55 | 16.49 |
| 7 <i>Caulerpa sp.</i>        | 0.008 | 3.15   | 0.33 | 6.18 | 9.33  |
| <b>Average</b> 0.254         | 5.34  | 28.575 |      |      |       |

Table 3 shows the analysis of the Importance Value Index (IVI) of macroalgae species at Iboih Beach, which includes the values of Relative Density (Kr), Relative Frequency (Fr), and the contribution of each species to the community. *Galaxaura rugosa* has the highest IVI (63.22), indicating its ecological dominance. This is due to its highest density (0.113) and wide distribution (Fr 18.73). This dominance reflects the species' adaptation to hard substrates such as coral and rock (Morales-Sierra et al., 2023). *Halimeda opuntia* (38.42) and *Chaetomorpha crassa* (35.27) also stand out, supporting the presence of nutrient-rich hard substrates. In contrast, *Caulerpa sp.* has the lowest IVI (9.33), indicating a more specific habitat preference. This aligns with studies on algae adaptation to certain physical conditions (Hurd et al., 2014). The average IVI (28.575) indicates a diverse macroalgal community, with dominant and sub-dominant species occupying various ecological niches.

**Table 4.** Shannon-Wiener Diversity Index Analysis of Macroalgae Species at Iboih Beach, Sukakarya District, Sabang

| No               | Species                    | Ni   | Pi   | ln Pi  | Pi ln Pi |
|------------------|----------------------------|------|------|--------|----------|
| 1                | <i>Padina australis</i>    | 17   | 0.07 | -2.659 | -0.186   |
| 2                | <i>Halimeda opuntia</i>    | 50   | 0.20 | -1.609 | -0.322   |
| 3                | <i>Galaxaura rugosa</i>    | 113  | 0.44 | -0.821 | -0.361   |
| 4                | <i>Gelidium sp.</i>        | 14   | 0.06 | -2.813 | -0.169   |
| 5                | <i>Chaetomorpha crassa</i> | 42   | 0.17 | -1.772 | -0.301   |
| 6                | <i>Neomeris sp.</i>        | 10   | 0.04 | -3.219 | -0.129   |
| 7                | <i>Caulerpa sp.</i>        | 8    | 0.03 | -3.507 | -0.105   |
| <b>Total</b> 254 |                            | 1.00 |      | -1.573 |          |

Table 4 presents the results of the macroalgae species diversity index analysis at Iboih Beach using the Shannon-Wiener method (Magurran, 2013). This index is calculated based on the proportion of individuals of each species (Pi) and their contribution to community diversity. *Galaxaura rugosa* has the largest contribution (Pi = 0.44, Pi ln Pi = -0.36123), indicating its relative dominance in the community. *Caulerpa sp.* and *Neomeris sp.* have small Pi values (0.03 and 0.04, respectively), reflecting their limited distribution or rarity. The total diversity value (H' = -1.57314) indicates a moderate level of diversity, reflecting a community dominated by certain species with a few minor species (Huston, 1994). The coral substrate, which supports more dominant species, contributes to these research findings.

## Discussion

The results of this study indicate that the type of substrate has a significant effect on the diversity and distribution of macroalgae at the research location. This is also in line with further research conducted by [Darlina \(2022\)](#) in Sabang, that environmental factors that greatly affect the diversity and number of macroalgae individuals are substrate, salinity, and phosphate. The results of this study also show that the diversity index value ( $H'$ ) of macroalgae in Sabang City is classified as moderate, namely on Klah Island 2.06, Pasir Putih 2.18, Anoi Itam 2.01 and on Rubiah Island 1.97. This is still in line with this study conducted on Iboih Island with  $H'=1.57$  which indicates moderate criteria. This study is also in line with research conducted by [Fitria \(2015\)](#) in South Aceh with  $H'=2.15$  which shows that the macroalgae species living in the waters of South Aceh are also quite diverse.

Coral substrates showed the highest diversity due to their ability to provide space for various macroalgae species. Coral substrates have a complex structure with pores and crevices that offer more attachment areas for macroalgae. The rough surface is ideal for algal colonization ([Foster et al., 2022](#)). Coral is more stable compared to sand, which often shifts due to currents and waves. This stability allows macroalgae to grow undisturbed by substrate movement ([Connell et al., 2018](#)). Coral substrates are often found in areas with stronger currents, which help supply dissolved nutrients. This supports algal growth compared to sand or rock substrates, which may have more limited nutrient access ([Hurd et al., 2014](#)). Coral substrates are typically located in shallow waters with high light exposure. This condition supports photosynthesis, especially for light-dependent groups like Rhodophyta and Chlorophyta ([Littler et al., 2020](#)). Coral substrates often support microbial biofilms that fix nutrients on the surface, creating a conducive environment for initial macroalgal growth ([Steneck and Dethier, 1994](#)). Harder and less erodible substrates provide greater opportunities for various species to grow and compete ([Littler and Littler, 2015](#)).

The measured water temperature and salinity averaged between 27-30°C and 33-35 ppt, respectively, which are optimal conditions for macroalgal growth ([Lee et al., 2016](#)). Water depth measured with a Secchi disk showed good transparency, allowing optimal light penetration for photosynthesis. This is relevant to research by ([Hurd et al., 2014](#)), which found that light penetration and

nutrients in water significantly influence macroalgal distribution and productivity. These results align with previous studies by ([Silva et al., 2018](#)) in other tropical regions, where coral and rock substrates were found to have higher macroalgal diversity compared to sand substrates. Additionally, this study confirms the important ecological role of macroalgae in providing habitats for other organisms and contributing to primary productivity in coastal ecosystems ([Johnson et al., 2017](#)).

Overall, coral substrates support higher macroalgal diversity and abundance compared to sand and rock substrates. This reflects the role of hard substrates in providing stable attachment sites and environmental conditions conducive to macroalgal growth.

## Conclusion

The diversity of macroalgae at Iboih Beach is influenced by substrate type, physical environmental conditions, and interspecies interactions. Coral substrates proved to have the highest macroalgal diversity, density, and abundance compared to rock and sand substrates. Coral substrates have a complex structure with pores and crevices that provide more stable attachment areas for macroalgae, as well as environmental conditions that support their growth. Additionally, water temperature, salinity, and transparency also support the growth of various macroalgae species.

It is essential to maintain intertidal ecosystems, as macroalgae play a crucial role in maintaining ecosystem balance, providing habitats for coastal fauna, and contributing to primary productivity. Conservation and sustainable management of coastal areas should be prioritized to preserve biodiversity and ecological functions.

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