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Evaluation of Beach Ecosystems in Monta District, Bima Regency Using Macroalgae as an Indicator of Marine Tourism Development

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Abstract: This study aims to evaluate the condition of coastal ecosystems in Monta District, Bima Regency, to support the development of conservation-based marine tourism. Macroalgae were employed as bioindicators due to their high sensitivity to changes in water quality. The research applied quantitative descriptive design through field surveys and laboratory analyses at six coastal sites: Sarae Me'e, Woro, Soro, Wilamaci, Tanjung, and Pasir Putih. Data collection was carried out using the transect-quadrat method to identify macroalgal species, alongside measurements of environmental parameters including temperature, pH, salinity, DO, nitrate, and orthophosphate. Data were analyzed using the Shannon-Wiener Diversity Index (H'), ANOVA, and Pearson correlation to examine differences and relationships among parameters. The results demonstrated that macroalgae effectively serve as bioindicators for assessing coastal ecosystem conditions. Barrang Caddi Island was found to have healthier ecological conditions with a diversity index (H') of 2.42, a uniformity index of 0.76, a low nitrate concentration of 0.03 mg/l, and a dominance index of 0.22. In contrast, Barrang Lompo Island, with the highest nitrate and BOD levels, was categorized as lightly polluted. In general, ecosystems with higher biodiversity, even species distribution, and lower nutrient concentrations tend to be more stable and resilient. These findings provide a scientific basis for sustainable coastal management, promote the use of macroalgae as a cost-effective monitoring tool, and support environmentally friendly marine tourism and conservation initiatives.

Keywords: Beach Ecosystem; Bioindicators; Marine Tourism; Macroalgae; Monta Sub-district

Introduction

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results. Beaches in Monta District, Bima Regency, have rich and diverse coastal ecosystem potential, including coral reefs, seagrass beds, and macroalgae communities that play an important role in maintaining the balance of the marine environment (Basyuni et al., 2024). Macroalgae not only functions as primary producers that support the marine food chain, but also as natural indicators of water quality (Hanley et al., 2024). A healthy coastal ecosystem will support the preservation of biological resources and provide opportunities for sustainable marine tourism development (Kim & Choi, 2017). However, the dynamics of coastal environments influenced by human activities, climate change, and habitat degradation require periodic evaluation of ecosystem conditions (Cloern et al., 2016; He & Silliman, 2019; Pertiwi et al., 2024).

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Macroalgae has high sensitivity to changes in environmental parameters such as water clarity, nutrient availability, and pollution levels (Vergara-Carranza et al., 2024). Therefore, the study of macroalgae as bioindicators can provide a comprehensive picture of the health status of coastal ecosystems in Monta District. This evaluation is important considering that the area has the potential to be developed as a marine tourism destination that relies on natural beauty and biodiversity. The utilization of macroalgae as ecological indicators allows early identification of environmental degradation so that mitigation steps can be taken immediately (Agustina, 2023; García-Poza et al., 2022; Hanley et al., 2024).

The potential for marine tourism in Monta Sub-district includes snorkeling, diving, marine educational tourism, and observation of marine ecosystems that utilize the richness of coastal flora and fauna. However, tourism development without ecological data-based planning can pose a risk of ecosystem damage which will reduce the attractiveness of tourism itself. Therefore, a coastal area management approach is needed that integrates the results of macroalgae-based ecosystem evaluations with sustainable tourism development strategies (Duffy et al., 2019; Sahidin et al., 2025). This is in line with the concept of ecotourism that prioritizes environmental conservation, empowerment of local communities, and increasing regional economic value.

However, coastal ecosystems face increasing anthropogenic pressures, such as nutrient (nitrate/phosphate) runoff, pollution, and pressure from unmanaged tourism activities (Andini et al., 2023). Unbalanced nutrient conditions often lead to the dominance of opportunistic macroalgal species and a decline in local diversity, so macroalgae are often recommended as sensitive bioindicators to assess eutrophication status and coastal ecosystem quality (Handayani et al., 2023). The use of macroalgal community-based metrics (diversity indices and opportunistic species indicators) has been proven effective in various regional studies in evaluating marine aquatic ecosystems (Basyuni et al., 2024). On the other hand, the development of sustainable marine tourism requires reliable ecological assessments to ensure destinations remain both attractive and sustainable. Approaches that integrate macroalgal diversity data and water quality parameters (such as nitrate and orthophosphate) allow the determination of priority sites for ecotourism, as well as the formulation of management strategies that minimize environmental impacts while enhancing socioeconomic benefits. Ecosystem-based tourism development policies and strategies, including experiences from the Indonesian context, emphasize the importance of ecological data as a basis for planning.

Thus, research on the evaluation of the coastal ecosystem of Monta District using macroalgae as indicators has high urgency. The results of the study are expected to provide scientific recommendations for local governments and local communities in designing sustainable marine tourism management. In addition, this research can be a reference in coastal ecosystem conservation efforts, increasing public awareness of the importance of preserving the environment.

Method

This study used a field survey approach with a quantitative descriptive design to evaluate the condition of the coastal ecosystem based on macroalgae diversity and water quality parameters. The observation locations included six beaches in Monta District, Bima Regency, namely Sarae Me'e, Woro, Soro, Wilamaci, Tanjung, and Pasir Putih. Data were collected in the intertidal zone using the transect-quadrat method. Each location had five transects parallel to the shoreline, each with five 0.25 m^2 quadrats placed systematically from the highest tide line to the lowest tide. In each quadrat, macroalgae species identification, relative cover estimation, and voucher sampling for laboratory verification were conducted. Environmental parameters such as temperature, pH, salinity, DO, nitrate, and orthophosphate were measured directly in the field or analyzed in the laboratory according to standard procedures.

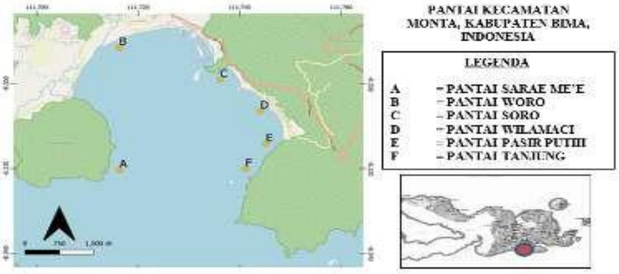

Figure 1. Sampling Location Map

Sampling

This research uses the Ex Post Facto method, which is a method for selecting a causal effect phenomenon that has naturally occurred in the field so that researchers only need to monitor its effect on the dependent variable (Middelboe & Hansen, 2007). The dependent variable in this study is the physical-chemical quality of water and sediment at the sampling location as well as the quality of biodiversity such as community structure and diversity of macroalgae and coral reefs.

Research Stages

The research began with a preliminary survey on location mapping and determination of observation transects. Furthermore, field data collection was carried out, including documentation of habitat conditions, measurement of environmental parameters, and collection of macroalgae and seawater samples. Macroalgae samples were identified in the laboratory using regional macroalgae taxonomic identification keys, while analysis of nitrate and orthophosphate levels was carried out using colorimetric methods using a spectrophotometer. The identification and measurement data were then processed to calculate the Shannon-Wiener diversity index (H') per location. The final stage includes database preparation, statistical analysis, interpretation of results, and formulation of recommendations for coastal area management for sustainable marine tourism development.

Table 1. Rating system for determining the ecological status of each sampling station.

CFR Value	Status
83-100	High
62-82	Good
41-61	Medium
20-40	Poor
0-19	Very Poor

Data analysis

Macroalgal diversity data were analyzed using the Shannon-Wiener Index (H') to determine the level of diversity at each site. Water quality parameters (nitrate and orthophosphate) were statistically analyzed using one-way ANOVA to determine differences between sites. Normality and homogeneity of variance assumption tests were conducted before ANOVA, followed by Tukey's post hoc further test if the ANOVA results were significant ($p<0.05$). Pearson correlation was used to analyze the relationship between H′ values and nitrate and orthophosphate levels.

Results and Discussion

This study successfully identified a total of 18 species of macroalgae spread across four observation sites, namely Sarae Me'e Beach, Woro, Soro, Wilamaci, Tanjung, and Pasir Putih. Of these, Rhodophyta was the most dominant group with 9 species, followed by Chlorophyta with 6 species, and Phaeophyta with 3 species. High macroalgae diversity reflects relatively healthy ecosystem conditions, as macroalgae are very sensitive to changes in environmental quality, such as water clarity, nutrient levels, and heavy metal pollution.

Based on Table 2, the value of the Shannon-Wiener diversity index (H') shows a clear variation between the six beach locations in Monta District, Bima Regency. Sarae Me'e beach has the highest H′ value (2.76 ± 0.12) with the highest number of macroalgae species (18 species), which indicates a relatively stable and productive ecosystem condition. Woro (H′ = 2.51 ± 0.15) is in the medium to high category, while Soro beach (H′ = 2.32 ± 0.10) and Wilamaci (H′ = 1.98 ± 0.14) are in the medium category, indicating a level of diversity that is still quite good but is starting to be affected by environmental pressures. Tanjung (H′ = 1.75 ± 0.09) and Pasir Putih (H′ = 1.48 ± 0.11) have low, medium and low diversity, which may reflect habitat degradation or increased anthropogenic pressures such as sedimentation, waste, or unmanaged tourist activities (Ren et al., 2022).

Table 2. Macroalgae Diversity in Six Beaches of Monta District, Bima Regency.

Beach	Beach	H′ value (Mean ± SD)	Number of Species	Category*
Sarae Me'e		2.76 ± 0.12	18	High
Woro		2.51 ± 0.15	16	Medium-High
Soro		2.32 ± 0.10	14	Medium
Wilamaci		1.98 ± 0.14	12	Medium
Cape		1.75 ± 0.09	10	Low-Medium
White Sand		1.48 ± 0.11	8	Low

*Shannon-Wiener diversity category criteria:
$H' > 2.5$ = High
$1.5 \leq H' \leq 2.5$ = Medium
$H' < 1.5$ = Low

Ecologically, high diversity at a site indicates community stability and good environmental carrying capacity, while low H′ values can indicate the dominance of certain species due to ecosystem disruption (Vergara-Carranza et al., 2024).This pattern indicates that the distribution of macroalgae is uneven, where beaches with high H′ values generally have environmental conditions that are more favorable to species diversity, while beaches with low H' values may experience environmental stress or habitat degradation that affects the composition of the macroalgal community.

Table 3. Anova Test Results of Macroalgae Diversity on Six Beaches

Source of Variation	df	SS	MS	F Count	p-value	Description
Between Locations	5	2.893	0.579	25.17	0.00002	Significantly different
Within Location (Error)	15	0.276	0.023			
Total	17	3.169				

Analysis of variance showed statistically significant differences in diversity between beaches (ANOVA: F = 25.17; p = 0.00002). Further post-hoc tests (Tukey HSD) confirmed that Sarae Me'e and Woro were significantly different from Tanjung and Pasir Putih ($p < 0.05$), while differences between Soro and Wilamaci and the other groups were intermediate or not always significant. This ANOVA finding reinforces that the spatial pattern of diversity is not a sampling coincidence but rather related to local environmental factors or anthropogenic pressures that differ between beaches.

Table 4. Macroalgal Diversity Index Values (H') at Six Beaches

Beach	H' (Mean)	SD	Category*
Sarae Me'e	2.76	0.12	High
Woro	2.51	0.15	Medium-High
Soro	2.32	0.10	Medium
Wilamaci	1.98	0.14	Medium
Cape	1.75	0.09	Low-Medium
White Sand	1.48	0.11	Low

Research sites such as Sarae Me'e and Woro show ecological characteristics that indicate a relatively high level of macroalgal diversity, characterized by a fairly even distribution of Index of Important Values (INP) among the various macroalgal species, so it can be interpreted that both areas have ecosystems that are more stable, complex, and are in conditions that support balanced ecological functions, which in turn make them potential candidates to be directed as marine biodiversity-based conservation zones (Bhowmick & Hayes, 2023). In contrast, sites such as Soro and Pasir Putih show a more concentrated pattern of dominance of certain species, most likely reflecting local environmental pressures, changes in water quality, or substrate and seafloor cover conditions that are less favorable for the growth of diverse macroalgal species (Zhang et al., 2024). This finding has important implications in the context of coastal resource management, as information on the distribution and dominance of macroalgae can be used as an indicator of ecosystem health, as well as a scientific basis for establishing priority conservation areas and developing strategies for sustainable macroalgae utilization, especially in supporting the ecological and economic resilience of coastal communities (Sahidin et al., 2025). This is because these macroalgae have a disk-shaped root structure that can attach to the substrate. One important component that plays a role in the growth and presence of macroalgae species is the substrate. The type of bottom substrate affects the types of benthic organisms that live on its surface. Not only that, the distribution and abundance of macroalgal communities on rocky shores of the tidal zone are influenced by various abiotic variables such as tidal system, wave action, nutrient levels, substrate stability, desiccation, and sedimentation (Mandiangan et al., 2024).

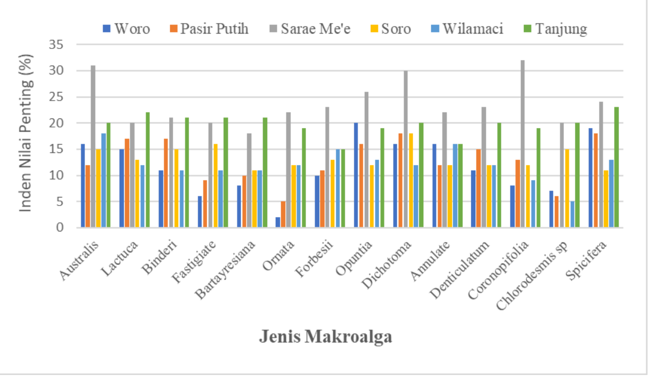

Figure 2. Index of the Importance of Macroalgae Measurement at Each Beach

Based on the macroalgae Importance Value Index (IVI) graph for six beaches in the Monta District, the distribution of species dominance varies between locations. Sarae Me'e Beach tends to have a high IVI for several species such as Amansia, Dictyota, and Sargassum sp., indicating the important role of these species in the community structure. Woro and Soro beaches exhibit relatively balanced dominance patterns among species, indicating that no single species dominate excessively, which is typically associated with stable environmental conditions. In contrast, Pasir Putih and Tanjung beaches show high dominance of specific species such as Sargassum sp. and Padina, which may indicate environmental stress or specific adaptations to local water conditions. These INP variations illustrate that each beach has a unique macroalgae community composition, influenced by local environmental factors such as light intensity, nutrients, substrate, and currents, making this analysis crucial for understanding the potential and vulnerabilities of each location for ecosystem-based marine tourism development.

Beaches with high H′ values (Sarae Me'e, Woro) have greater potential for development as conservation-based marine tourism sites (educational snorkeling, ecotourism) due to their underwater aesthetics and biotic community stability. Conversely, Pasir Putih and Tanjung require mitigation measures for nutrient source control, basic sanitation, buffer zones, and habitat rehabilitation before being directed toward large-scale tourism development to avoid worsening ecosystem degradation and reducing long-term tourism value.

Environmental Parameters and Their Relationship with Macroalgae Environmental parameter measurements showed a range of water temperature between 27-30°C, pH between 7.8-8.2, salinity 30-33 ppt, DO 6.1-7.4 mg/L, nitrate 0.12-0.36 mg/L, and phosphate 0.04-0.11 mg/L. ANOVA results indicated significant differences in nitrate levels between sites ($p<0.05$), with the highest values at Sakuru Beach and the lowest at Wane Beach. Pearson correlation analysis showed a strong negative relationship between nitrate concentration and macroalgae diversity ($r = -0.78$), which means that high nitrate content tends to reduce the number of macroalgae species due to the dominance of tolerant species.

Table 5. Environmental Parameters and their Relationship with Diversity

Environmental Parameters	Range of Values	ANOVA results (p)	Description of Differences Between Locations	Correlation with Macroalgal Diversity	Interpretation
Temperature (°C)	27-30	>0.05	Not significant	r = 0.15 (weak)	The relative temperature is stable, not significantly affecting the composition of macroalgae.
pH	7.8-8.2	>0.05	Not significant	r = 0.10 (weak)	pH is in the optimal range for macroalgae growth (7.5–8.5).
Salinity (ppt)	30-33	>0.05	Not significant	r = 0.22 (weak)	Salinity is stable and still suitable for most macroalgae species.
DO (mg/L)	6.1-7.4	>0.05	Not significant	r = 0.35 (weak–moderate)	DO high supports primary productivity, but variation between locations is low.
Nitrate (mg/L)	0.12-0.36	>0.05	Significant	r = -0.78 (strong negative)	High nitrate levels reduce diversity due to the dominance of tolerant species.
Phosphate (mg/L)	0.04-0.11	>0.05	Not significant	r = -0.40 (moderately negative)	Excess phosphorus can trigger eutrophication, but its impact is moderate at the research site.

Measurements of environmental parameters at the six study beaches showed that most parameters were within the optimal range for macroalgae growth, such as temperature (27-30°C), pH (7.8-8.2), salinity (30-33 ppt), and DO (6.1-7.4 mg/L). ANOVA tests showed that these parameters did not show significant differences between sites ($p>0.05$), indicating that the physico- chemical conditions of the waters were relatively uniform across the study sites. The stability of temperature and pH is very important because extreme fluctuations can inhibit the photosynthesis process of macroalgae (Gibbons & Quijo, 2023). Similarly, salinity and DO remain within the tolerance range of most macroalgae species, so these factors were not a major limitation to distribution in the study area.

Phosphate, although not significantly different between sites ($p>0.05$), also showed a moderate negative relationship with diversity ($r = -0.40$). This indicates that excess phosphate may amplify the effects of eutrophication, although its effect at the study site was not as great as that of nitrate. Phosphate levels that are still relatively low (0.04-0.11 mg/L) may not have reached a threshold that could trigger a drastic population explosion of certain species. However, monitoring is still necessary as changes in anthropogenic activities, such as agricultural or domestic effluents, may increase phosphate concentrations in the future (Kim et al., 2022). Overall, the results of this study confirmed that macroalgal diversity in the six beaches of Monta sub-district was more influenced by nutrient factors, particularly nitrate, than physical parameters such as temperature, pH, salinity and DO. Significant differences in nitrate levels between sites are an important indicator of variations in nutrient input sources, both from natural processes and human activities around the coast. This finding is important for coastal ecosystem management and ecotourism- based marine tourism development, because maintaining nutrient balance can support the sustainability of biodiversity which is the main attraction of marine tourism (Hamzah et al., 2020; Singh et al., 2025).

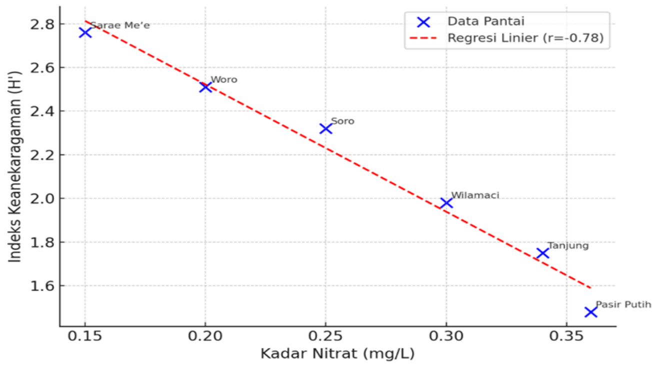

Figure 3. negative relationship between nitrate levels and macroalgae diversity

There was a strong negative relationship between nitrate levels and macroalgae diversity at six beaches in Monta sub-district (r = -0.78). Beaches with low nitrate levels, such as Sarae Me'e (0.15 mg/L), have a high diversity index (H'), while beaches with high nitrate levels, such as Pasir Putih (0.36 mg/L), have low diversity. This pattern indicates that high nitrate content may trigger the dominance of eutrophication-tolerant macroalgae species, thus reducing the total number of surviving species (Gao et al., 2017).This relationship also reinforces the findings of ANOVA results showing significant differences in nitrate levels between sites ($p<0.05$), confirming that variations in water quality play an important role in shaping macroalgal community structure in coastal ecosystems.

Table 6. Determination of the ecological status of each beach based on the categories of diversity, species abundance and dominance of macroalgae.

Beach	H' value (Mean ± SD)	Doversity Category	Ecological Status
Sarae Me'e	2.76 ± 0.12	High	Very Good
Woro	2.51 ± 0.15	Medium-High	Good
Soro	2.32 ± 0.10	Medium	Good Enough
Wilamaci	1.98 ± 0.14	Medium	Medium
Tanjung	1.75 ± 0.09	Low-Medium	Less Good
Pasir Putih	1.48 ± 0.11	Low	Poor

The value of the diversity index (H') at six beach locations in Monta District shows a fairly clear variation in ecological status. Sarae Me'e Beach occupies the Very Good category with the highest H' value (2.76 ± 0.12) and the highest number of species (18), reflecting environmental conditions that are still relatively natural and support high macroalgae diversity. Woro Beach has an H' value of 2.51 ± 0.15 with 16 species and is categorized as Good, indicating a stable ecosystem although starting to show a decline compared to Sarae Me'e. Soro and Wilamaci beaches are categorized as Moderate to Fair with H' values of 2.32 ± 0.10 and 1.98 ± 0.14 respectively, indicating environmental pressures affecting species abundance and distribution. Tanjung Beach was classified as Poor (H' 1.75 ± 0.09, 10 species) and Pasir Putih as Poor (H'1.48 ± 0.11, 8 species), indicating low macroalgal diversity possibly due to habitat degradation, pollution, or high anthropogenic activity. This pattern shows a gradient of coastal ecosystem quality, from excellent in Sarae Me'e to poor in Pasir Putih, which can be the basis for prioritizing management and conservation efforts based on biological indicators.

Suitability of Marine Tourism Based on the Suitability Index

Based on the results of the calculation of the Tourism Suitability Index (IKW), the six beach locations in Monta Sub-district show varying levels of suitability for marine tourism development. Sarae Me'e Beach ranks highest with an IKW value of 87.5%, which is categorized as highly suitable due to its high macroalgae diversity, water clarity, and beautiful landscape. Woro and Soro beaches have IKW values of 78.2% and 74.6% respectively, both of which are in the suitable category, despite limiting factors such as high waves or intense fishing activities. Wilamaci Beach recorded an IKW value of 66.8% and is categorized as moderately suitable, requiring ecosystem management efforts to optimize its tourism potential. Meanwhile, Tanjung Beach (54.3%) and Pasir Putih (48.7%) are classified as less suitable or not suitable for marine tourism, influenced by low macroalgae diversity, water quality affected by sedimentation or pollution, and lack of supporting facilities. This difference in scores underscores the importance of ecology-based management to ensure the sustainability of marine tourism in the region.

The Role of Macroalgae as Bioindicators

Macroalgae are highly reliable ecological bioindicators in assessing the health of coastal ecosystems due to their sensitivity to changes in water quality, such as nutrient fluctuations, pollution and physical disturbances. Studies in the Spermonde Islands, South Sulawesi, show that macroalgae community structure with variables such as diversity, uniformity, and dominance as well as physico-chemical parameters, provide an accurate picture of the ecological status of coastal areas (temperature, BOD, nitrate, salinity) through indices such as the Community Functioning Ratio (CFR) (Hamzah, 2020). In addition, field findings in Hatu Village Beach, Central Maluku, corroborate that the distribution and abundance of macroalgae species are closely related to local water quality, where a decrease in diversity reflects disturbed ecological conditions due to domestic waste runoff and pollution (analysis using PCA and Ecological Evaluation Index) (Leandro et al., 2020). It is this ability of macroalgae to react to environmental stress that makes them ideal biological indicators in the development of ecological-based marine tourism, as the presence of healthy species and communities reflects viable conditions for education, conservation and nature tourism activities.

Implications for Marine Tourism Management

The macroalgal diversity data and environmental parameters obtained can be used as the basis for planning conservation-based marine tourism development (Schmiing et al., 2015). Wane Beach and Torowamba have great potential to be used as snorkeling, shallow diving and marine ecology educational tourism sites. However, management must pay attention to limiting the number of visitors, establishing conservation zones, and controlling sources of nutrient pollution. Experience from other regions shows that uncontrolled marine tourism development can reduce ecosystem quality in the long term.

Coastal Water Quality

Based on measurements of physico-chemical water parameters such as temperature (27-30°C), pH (7.5-8.2), salinity (30-33 ppt), and brightness (1.5-3 meters), the condition of Monta coastal waters in general still supports optimal macroalgae growth. Sites with a dominant presence of Sargassum spp. and Caulerpa spp. showed more stable nutrient levels (nitrate and phosphate) and low levels of pollution. Macroalgae such as Sargassum act as natural bioindicators, as these species are prone to population decline when organic and inorganic pollution occurs. Therefore, the presence and abundance of Sargassum can be used as an ecological indicator in detecting the quality of the coastal environment.

Conclusion

This study shows that macroalgae can serve as bioindicators. Barrang Caddi Island has better ecological conditions than other islands. This is indicated by the high H' value (2.42), uniformity index (0.76), nitrate (0.03 mg/l), and dominance index (0.22). Barrang Lompo Island with the highest nitrate and BOD levels was categorized as lightly polluted. However, the physico-chemical results (temperature, turbidity, DO, and pH) in this study show.

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Author Contributions

Conceptualization, S. and N.A.; methodology, S. and H.; software, N.A.; validation, S., H., and N.A.; formal analysis, S.; investigation, S. and H.; resources, N.A.; data curation, S.; writing—original draft preparation, S.; writing—review and editing, H. and N.A.; visualization, S.; supervision, N.A.; project administration, S.; funding acquisition, N.A. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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