BIODIVERSITAS
Volume 26, Number 7, July 2025
Pages: 3115-3124

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260703

Macroalgal community structure and beta diversity in the coastal waters of East Lombok, Indonesia

ABDULLAH RASYID[1,2], MASTERIA YUNOVILSA PUTRA[2], WINDRI HANDAYANI[3], YASMAN[3,♥]

[1]Doctoral Program of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Prof. Dr. Sudjono D. Pusponegoro, Depok 16424, West Java, Indonesia

[2]Research Center for Vaccine and Drugs, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor KM 46, Cibinong 16911, West Java, Indonesia

[3]Research Group of Omic Science, Physiology, and Chemical Ecology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Prof. Dr. Sudjono D. Pusponegoro, Depok 16424, West Java, Indonesia. Tel.: +62-21-7270163, Fax.: +62-21-78849010, ♥email: yasman.si@sci.ui.ac.id

Manuscript received: 27 April 2025. Revision accepted: 16 June 2025.

Abstract. *Rasyid A, Putra MY, Handayani W, Yasman. 2025. Macroalgal community structure and beta diversity in the coastal waters of East Lombok, Indonesia. Biodiversitas 26: 3115-3124.* Coastal ecosystems in East Lombok, Indonesia, are home to diverse macroalgal communities influenced by local environmental factors. This study investigates macroalgal community structure and beta diversity across three distinct locations: Station 1 (Dasan Ujung Beach), Station 2 (Telong Elong Beach), and Station 3 (Pinky Beach). The survey categorized macroalgae into Chlorophyta, Rhodophyta, and Phaeophyta, and employed Simpson and Sørensen dissimilarity indices alongside the nestedness-resultant component (β_{sne}) to assess community variability. The results show that Station 2, with a complex substrate of coral rubble and calcareous mud, supported a more diverse macroalgal community, including calcifying species like *Halimeda* spp. In contrast, eutrophic conditions at Station 3 promoted the dominance of *Ulva lactuca*, a species indicative of nutrient-rich waters. The beta diversity indices reveal that substrate type and nutrient enrichment play critical roles in shaping macroalgal diversity and community composition, rather than water chemistry alone. These findings suggest that habitat heterogeneity and local anthropogenic pressures significantly influence coastal biodiversity. This study contributes new insights into the ecological drivers of macroalgal distribution in East Lombok and offers a framework for future marine conservation and monitoring.

Keywords: Beta diversity, East Lombok, eutrophication, macroalgal communities, substrate heterogeneity

INTRODUCTION

Macroalgae are diverse, photosynthetic organisms that resemble terrestrial plants but are taxonomically distinct as marine macroalgae. They inhabit a wide range of marine environments, either floating freely in the water column or attached to hard substrates such as rocks, coral, and shells along the coast (Gao and Lin 2018; Cotas et al. 2023). As primary producers, macroalgae play a fundamental role in marine ecosystems by converting sunlight into energy through photosynthesis, thus forming the base of the marine food web. They not only support marine biodiversity but also contribute to oxygen production and nutrient cycling (Abdel-Kareem and Elsaied 2022). Macroalgae are commonly classified into three major groups based on pigmentation and biochemical characteristics: green algae (Chlorophyta), brown algae (Phaeophyceae), and red algae (Rhodophyta), each offering distinct ecological functions and industrial applications (Prasanthi et al. 2020; Cotas et al. 2023).

Globally, approximately 10,500 species of macroalgae have been identified, including around 7,000 species of red algae, 2,000 species of brown algae, and 1,000 species of green algae (Chopin 2018; Prasanthi et al. 2020). Of these, only about 300 species are considered commercially valuable. Furthermore, intensive cultivation efforts have focused on just 11 genera: 3 brown algae (*Saccharina*, *Undaria*, and *Sargassum*), 4 red algae (*Porphyra*, *Eucheuma*, *Kappaphycus*, and *Gracilaria*), and 4 green algae (*Ulva*, *Monostroma*, *Caulerpa*, and *Oedogonium*) (Purcell-Meyerink et al. 2021). Beyond their ecological importance, macroalgae are increasingly recognized for their wealth of bioactive compounds, including antioxidants, antimicrobials, antivirals, anti-inflammatory agents, and anticancer substances. These natural compounds are of growing interest for use in pharmaceuticals, nutraceuticals, functional foods, and cosmetics (Abdel-Kareem and Elsaied 2022; Cotas et al. 2023). Additionally, macroalgae farming contributes to sustainable environmental practices by promoting carbon capture, reducing excess nutrients in coastal waters, and supporting marine habitat restoration, positioning macroalgae as a key component in the development of the blue economy.

Indonesia is the largest country made only of islands, consisting of 13,558 islands, situated within the Coral Triangle (Andréfouët et al. 2022). Indonesia boasts one of the highest levels of marine biodiversity in the world, including a rich diversity of macroalgae (Hutomo and Moosa 2005). The country's vast coastline, warm tropical waters, and varied marine habitats, from coral reefs and mangroves to seagrass beds, create ideal conditions for macroalgae growth. Macroalgae are widely distributed across Indonesia's coastal areas, supporting both ecological functions and the livelihoods of coastal communities engaged in harvesting and aquaculture activities (Rimmer et al. 2021).

Indonesia is home to an estimated 903 species of macroalgae, reflecting its significant marine botanical diversity. Among these, red algae (Rhodophyta) constitute the largest group, with 564 recorded species (Atmadja and Reine 2010). Red macroalgae are particularly important due to their high content of phycocolloids such as agar and carrageenan, which are widely used in food, pharmaceutical, and cosmetic industries. Green algae (Chlorophyta) follow with 201 species, while brown algae (Phaeophyceae) contribute 138 species to Indonesia's macroalgae diversity (Atmadja and Reine 2014). These groups vary not only in color and structure but also in biochemical composition and commercial value.

The high macroalgal diversity in Indonesian waters provides essential ecological services and forms the foundation for sustainable marine resource development, offering significant economic opportunities through biotechnology research and blue economy initiatives that promote food security, environmental resilience, and community welfare. Ecologically, macroalgae play a crucial role in providing habitat, enhancing water quality, and maintaining coastal ecosystem health. They absorb excess nutrients such as nitrogen and phosphorus, reducing eutrophication and enhancing water clarity. Additionally, through photosynthesis, macroalgae produce oxygen, stabilize pH by removing CO_2, and bioaccumulate heavy metals and pollutants, making them key contributors to water purification and overall ecosystem resilience (Kim et al. 2017; Arumugam et al. 2018; Ramesh et al. 2023; Varabih and Nofirman 2023). Economically, macroalgae cultivation is one of the country's key aquaculture sectors, with Indonesia ranking among the world's top producers of commercially valuable macroalgae like *Eucheuma* and *Gracilaria* (Waters et al. 2019).

Information on marine resources, particularly macroalgae, in the waters of East Lombok, Indonesia, remains limited. Although previous studies have explored macroalgal diversity in other parts of Lombok Island, such as Batu Layar Coast in West Lombok (Kirana et al. 2021) and Sire Beach in North Lombok (Arianti et al. 2024), studies focusing specifically on East Lombok are still scarce. One notable exception is Furqan et al. (2023), who investigated the genetic diversity of macroalgae along the Ekas Coast in East Lombok, yet broader studies on macroalgal community composition and its ecological drivers in this region remain scarce.

Understanding the ecological factors that shape macroalgal community structure is critical for effective coastal ecosystem management. However, the roles of beta diversity components, specifically species turnover and nested-ness, remain underexplored at local spatial scales. Analytical approaches using Sørensen and Simpson dissimilarity indices, combined with nested-ness partitioning, are seldom applied in relation to environmental gradients.

This study aims to address this gap by evaluating the macroalgal community structure and beta diversity across three distinct sites in East Lombok: Dasan Ujung Beach, Telong Elong Beach, and Pinky Beach. Specifically, this research seeks to answer two key questions: (i) How does macroalgal community composition vary among the sites? and (ii) What environmental factors drive these differences? We hypothesize that substrate heterogeneity and seawater parameters are key determinants of beta diversity, shaping both species turnover and nested-ness patterns. The findings are expected to provide baseline ecological data to support conservation and sustainable management of coastal ecosystems in East Lombok.

MATERIALS AND METHODS

Study period and location

The study was conducted during low tide in July 2024 at three selected coastal sites in East Lombok, West Nusa Tenggara, Indonesia: Dasan Ujung Beach (Station 1: 116°27′31.3416″ E, 8°51′3.2004″ S), Telong Elong Beach (Station 2: 116°30′12.6504″ E, 8°48′47.9736″ S), and Pink Beach (Station 3: 116°34′53.4864″ E, 8°51′31.2084″ S) (Figure 1).

Procedures

Transect establishment and quadrat placement

The macroalgae diversity assessment was conducted using the quadrat-transect method, with each transect measuring 100 meters in length (Valero-Rodriguez et al. 2024) and each quadrat measuring 1×1 meter (Wiecek 2023). At each sampling station, three transect lines were laid perpendicular to the shoreline (Wiecek 2023, Arianti et al. 2024), with a distance of 20 meters between each line. Along each transect, 1 m² quadrats were placed at 10-meter intervals (Kirana et al. 2021), starting from 0 meters up to 100 meters.

Macroalgae species and abiotic parameter measurements

Within each quadrat, all visible macroalgae species were recorded, and the number of individuals per species was counted. Representative specimens were collected in labeled plastic bags and brought to the laboratory for further identification and confirmation. In addition to biological data, environmental parameters were also measured (Hasni et al. 2022). Water temperature was recorded using a thermometer, pH was measured with a portable pH meter, and salinity was determined using a refractometer. Observations of the substrate type at each sampling site were also conducted to provide context for habitat conditions.

Species identification

The identification of macroalgae species was conducted using reference guides by Al-Yamani et al. (2014), Lima et al. (2017), Newton (2017), and Handayani et al. (2023). Additionally, the scientific names of the macroalgae were cross-checked with Guiry and Guiry (2022) to ensure alignment with current taxonomic standards.

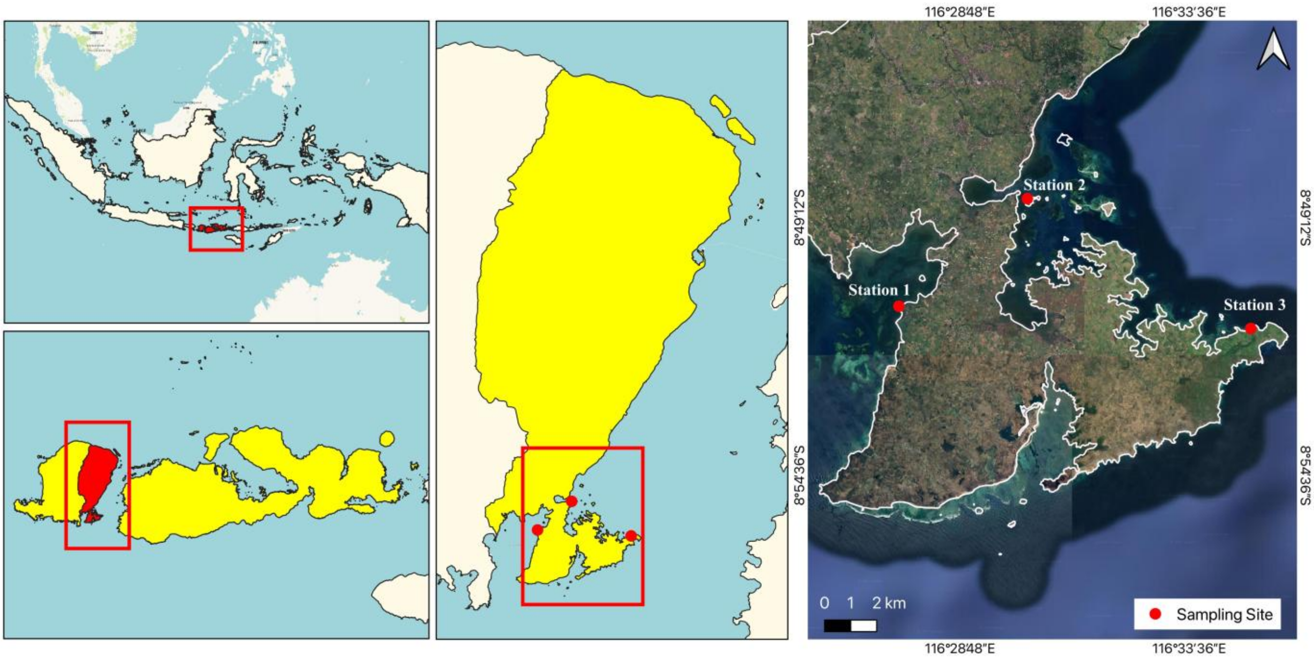

Figure 1. Map of sampling locations in East Lombok, Indonesia, indicating Station 1 (Dasan Ujung Beach), Station 2 (Telong Elong Beach), and Station 3 (Pinky Beach). The inset map displays the Indonesian Archipelago, with a red arrow indicating the position of Lombok Island (Source: Google Maps). Note: The map indicates general sampling areas; detailed coordinates are provided in the paragraph

Data analysis

The obtained data were tabulated. Macroalgae species data analyzed using formula described by Wiraatmaja et al. (2022) to obtain the value of abundance, biodiversity index, species richness index, evenness, and dominance. Beta diversity was assessed using species presence data, without considering abundance. Pairwise comparisons between stations were conducted using three related indices. The Sørensen dissimilarity index (β_{sor}) was used to measure the overall differences in species composition between sites, with values ranging from 0 (identical composition) to 1 (completely different). The Simpson dissimilarity index (β_{sim}) focused specifically on species turnover, or the replacement of species between stations. The nested-ness resultant component (β_{sne}) was calculated by subtracting β_{sim} from β_{sor} ($\beta_{sne} = \beta_{sor} - \beta_{sim}$), representing the portion of beta diversity due to differences in species richness where one community is a subset of another (Fontana et al. 2020). The interpretation of H's values differs, yet typically: $H' \leq 1$: Low diversity; $1 < H' < 3$: Moderate diversity; $H' \geq 3$: High diversity (Spellerberg and Fedor 2003). Evenness ratings span from 0 to 1, with elevated values signifying a more equitable distribution. Categories encompass $0 < E < 0.4$: Low evenness; $0.4 < E \leq 0.6$: Moderate evenness; $E > 0.6$: High evenness (Smith and Wilson 1996). Categories of dominance index encompass $0 < D \leq 0.5$: low dominance; $0.5 < D \leq 0.75$: moderate dominance; $0.75 < D \leq 1$: high dominance (Somerfield et al. 2008). All data were presented descriptively.

RESULTS AND DISCUSSION

Macroalgae species composition, frequency, abundance, and density

A total of 15 macroalgae species, representing 11 genera and 10 families, were identified from the quadrat samples collected across the study sites in East Lombok, Indonesia (Table 1). This number is comparable to the findings of Arianti et al. (2024), who also recorded 15 macroalgae species at Sire Beach, North Lombok; however, their study reported fewer genera (9) and families (7). In contrast, Kirana et al. (2021) documented a higher diversity of macroalgae at Batu Layar Coast in West Lombok, with 24 species spanning 20 genera and 14 families. When combined, the total number of species reported in the present study, Kirana et al. (2021), and Arianti et al. (2024) amounts to 45 species, still considerably lower than the macroalgal diversity reported for the Thousand Islands, Jakarta, by Draisma et al. (2018). These comparisons highlight the need for further, more comprehensive surveys to fully explore the macroalgal diversity of Lombok's coastal waters. Notably, several species identified in the present study hold commercial importance across various industries. For example, *Ulva* spp. is widely used in cosmetics, pharmaceuticals, chemicals, food, and bioenergy applications (Dominguez and Loret 2019), while *Caulerpa* spp. are commercially valued in the food and pharmaceutical sectors (Mehra et al. 2019; Zubia et al. 2020). Some species, such as *Sargassum*, *Kappaphycus*, *Gracilaria*, *Ulva*, and *Caulerpa*, are even the focus of intensive cultivation efforts as reported by Purcell-Meyerink et al. (2021).

Table 1. List of macroalgae species recorded across the sampling sites in East Lombok, Indonesia

Division, Class	Family	Species
Chlorophyta		
Ulvophyceae	Caulerpaceae	*Caulerpa lentillifera*
		Caulerpa simpliciuscula
	Halimedaceae	*Halimeda macroloba*
		Halimeda oppuntia
	Ulvaceae	*Ulva lactuca*
		Ulva reticulata
Phaeophyta		
Phaeophyceae	Dictyotaceae	*Dictyota dichotoma* var. *guinea*
		Padina australis
	Sargassaceae	*Sargassum plagiophyllum*
Rhodophyta		
Florideophyceae	Lithophyllaceae	*Amphiroa fragilissima*
	Gracilariaceae	*Gracilaria gracilis*
		Gracilaria salicornia
	Cystocloniaceae	*Hypnea charoides*
	Solieriaceae	*Kappaphycus alvarezii*
	Rhodomelaceae	*Laurencia nidifica*

The macroalgae recorded in this study were classified into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Among these, Chlorophyta and Rhodophyta exhibited the highest species richness, each contributing six species (40%), while Phaeophyta was represented by only three species (20%) (Figure 2). *Ulva lactuca* emerged as the most conspicuous species, particularly at Station 3, with an abundance of 365 individuals, a density of 11.06 ind./m^2, and a frequency of 45.46%. This was followed by *Padina australis*, with a total abundance of 132 individuals, a density of 4.00 ind./m^2, and the highest frequency value of 33.33% at Station 1 and 2. *Halimeda macroloba* ranked third in abundance of 96 individuals, a density of 2.91 ind./m^2, and the highest frequency value of 30.30% at Station 2 (Table 2).

Given that water parameters (pH, salinity, and temperature) were consistent across all three stations, the dominance of Chlorophyta, particularly *Halimeda* species at Station 2 (Telong Elong Beach), appears closely linked to the sandy and coral rubble substrates characteristic of this site (Table 3). According to Johan et al. (2015), sandy substrates are favorable for the establishment of green macroalgae, a finding consistent with Anggadiredja (2017), who noted that many Chlorophyta species are commonly associated with sandy coastal habitats.

The high abundance and frequency of *H. macroloba* and *H. opuntia* at Station 2 further suggest the presence of calcareous substrates beneath the sand and coral rubble layers, as both species are calcareous macroalgae. These algae are essential contributors to carbonate sediment production in tropical marine ecosystems and are known for their resilience to environmental variability, including fluctuating light levels and nutrient availability (Zúñiga-Ríos et al. 2021). The lower diversity of other macroalgal groups at Station 2 may indicate ecological competition or environmental filtering driven by substrate type.

In contrast, at Station 3, the overwhelming dominance of *U. lactuca* suggests the possibility of eutrophic conditions, as this species is known to proliferate in nutrient-enriched environments. The co-occurrence of other green macroalgae such as *Caulerpa simpliciuscula* and *U. reticulata* further supports this ecological inference. Both *Caulerpa* and *Ulva* species are well-adapted to nutrient-rich habitats and may exhibit invasive behavior under elevated nutrient levels (Pacciardi et al. 2011; Chen et al. 2019). In particular, the rapid growth of *U. lactuca* has been widely associated with elevated levels of nitrogen and phosphorus (Hofmann et al. 2024), often linked to anthropogenic sources such as agricultural runoff and sewage discharge (Madjar et al. 2024; Müller-Karulis et al. 2024). However, it should be noted that nutrient concentrations were not directly measured in the present study.

For example, in Ireland, massive blooms of *Ulva* species have been linked to fertilizer runoff from adjacent catchments, leading to ecological impacts such as oxygen depletion and habitat alteration (Wan et al. 2017). Similarly, in Brittany, France, intensive agricultural activities have caused significant blooms of *U. lactuca*, whose decomposition releases harmful gases like methane and hydrogen sulfide, posing health risks to nearby communities (Zhang et al. 2019).

Further evidence indicates that eutrophic conditions substantially enhance the growth rates and photosynthetic performance of *U. prolifera*, a close relative of *U. lactuca*, facilitating the development of large-scale green tides (Cai et al. 2023). Thus, the proliferation of *U. lactuca* at Station 3 serves as a robust bioindicator of nutrient enrichment.

However, it is important to acknowledge that the observed dominance of *U. lactuca* at Station 3, while suggestive of eutrophic conditions (Teichberg et al. 2010), may also be part of natural cyclical bloom phenomena observed in various coastal ecosystems. Studies have documented that green macroalgal blooms, including those of *Ulva* species, can occur periodically due to natural nutrient cycling processes. During such cycles, *Ulva* spp. accumulate significant amounts of inorganic nutrients (primarily nitrogen and phosphorus), reaching peak biomass before collapsing (Dominguez and Loret 2019). This collapse not only releases harmful gases such as methane and hydrogen sulfide, which pose health risks to nearby communities (Zhang et al. 2019), but also returns stored nutrients to the environment, potentially facilitating the recovery of other primary producers like microphytobenthos and seagrasses. However, the limited temporal scope of the present study did not allow for observation of bloom progression or decline, and to our knowledge, there are currently no published reports documenting such cyclical bloom events in Lombok Island. Future long-term studies incorporating seasonal sampling and nutrient monitoring would be essential to distinguish between anthropogenic eutrophication and naturally occurring bloom cycles in this region.

Station 1 (Dasan Ujung Beach) is the only site where all recorded species exhibited relatively similar abundance and frequency, indicating a more stable and balanced community structure compared to the other two stations. Although this station had the lowest species richness, it recorded the highest values for both the diversity index and evenness (Table 4). This supports the fundamental ecological concept that diversity indices are not solely influenced by species richness but are also strongly affected by species evenness and dominance patterns (Smith and Wilson 1996; Spellerberg and Fedor 2003; Somerfield et al. 2008).

These patterns highlight how different macroalgal taxa act as bioindicators of specific environmental conditions. While *U. lactuca* and *Caulerpa* species are associated with nutrient enrichment often linked to anthropogenic influences, *Halimeda* species are more indicative of calcareous substrates under less nutrient-rich conditions (McNeil et al. 2021; Zokm et al. 2022). Therefore, variations in substrate composition and anthropogenic pressure are likely key drivers shaping macroalgal distribution in the coastal waters of East Lombok. However, the limitations of the present study highlight the need for further research, particularly involving direct measurements of environmental parameters and the application of more sensitive and advanced analytical methods to capture broader ecological dynamics.

Rhodophyta made a significant contribution to the overall macroalgal diversity, ranking as the second most represented division in this study. Red algae are known for their wide ecological tolerance, inhabiting environments ranging from shallow intertidal zones to deeper subtidal areas (Handayani et al. 2023). The most frequently observed Rhodophyta species was *Amphiroa fragilissima*, particularly abundant at Station 1, where it formed dense clusters in tide pools across intertidal and subtidal zones throughout the year. As noted by Wai (2018), *A. fragilissima* is often associated with other macroalgae such as *Caulerpa*, *Halimeda*, and *Padina*. This association was consistent in the present study for *Padina*, although *Caulerpa* was not observed in close proximity, and *Halimeda* was entirely absent from Station 1. The co-occurrence of *A. fragilissima* and *P. australis* at this site also suggests that environmental conditions, such as moderate wave action, adequate light availability, and suitable substrate type, may be favorable for these species (Islam et al. 2020). Additionally, *A. fragilissima* is known to inhabit seagrass beds (Wai 2018). In this study, it was recorded at Stations 1 and 3, where the substrate was predominantly sandy to slightly muddy sand (Table 3).

In contrast, Phaeophyta (brown macroalgae) were the least abundant group observed. This limited presence may be related to their morphological characteristics; their thalli are typically thin and sheet-like, making them more prone to desiccation. Consequently, brown algae generally prefer deeper subtidal habitats that remain submerged for extended periods (Gómez et al. 2019). They may inhabit depressions or lower intertidal zones that retain water during low tide. The most frequently encountered species from this group was *P. australis*. Along with *Dictyota dichotoma*, these two species were the only ones found consistently across all sampling stations (Table 2).

Diversity, species richness, evenness, and dominance index

Evaluating macroalgal communities through measurements of diversity, species richness, evenness, and dominance is crucial for understanding the ecological health and stability of coastal ecosystems. These ecological indices offer insights into species composition, competitive dynamics, and the degree of environmental stress experienced by marine habitats (Rodriguez et al. 2016). Variations among these indices can reveal important environmental gradients, anthropogenic pressures, and habitat suitability, all of which are critical for effective coastal zone management.

Station 1 exhibited a Diversity Index (H') of 1.45, a Species Richness Index of 0.72, an Evenness Index of 0.90, and a Dominance Index of 0.24 (Table 4). Although the number of species was relatively low (only five species recorded), the very high evenness indicates that individuals were distributed almost equally among the species. The low dominance value suggests no single species overwhelmingly dominated the community, supporting a balanced and stable ecosystem. Such a community structure is typically associated with minimal ecological stress and favorable environmental conditions, including sufficient light penetration, diverse substrate types, and moderate nutrient availability (Leliaert et al. 2014; Asmida et al. 2017; Zainee et al. 2019).

Ecologically, this suggests that Station 1 represents a well-structured macroalgal community, with major contributors like *P. australis* and *A. fragilissima* thriving without suppressing other taxa. The presence of calcified algae such as *A. fragilissima* points to a habitat with moderate wave action and stable environmental parameters (Imchen 2015; Roleda and Hurd 2019).

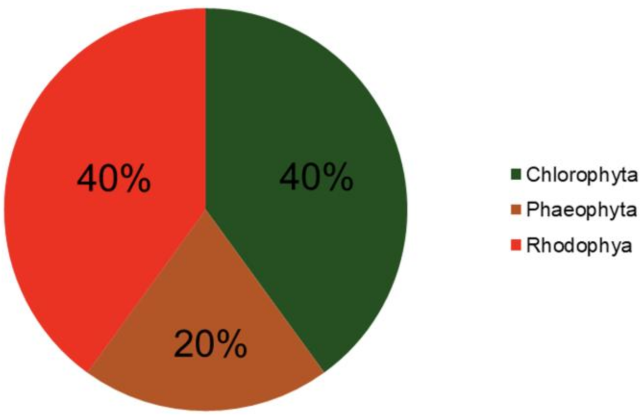

Figure 2. The composition of macroalgae species across the sampling sites in East Lombok, Indonesia

Table 2. Number of individuals, abundance, frequency, and density of macrolagae in East Lombok, Indonesia

Division/Species	Number of individuals			Total quadrats assessed	Abundance (ind.)	Frequency (%)			Density (ind./m^2)
	Station 1	Station 2	Station 3			Station 1	Station 2	Station 3	
Chlorophyta									
Caulerpa lentillifera	52	0	0	33	52	27.27	0	0	1.58
Caulerpa simpliciuscula	0	0	15	33	15	0	0	9.09	0.45
Halimeda macroloba	0	86	10	33	96	0	30.30	18.18	2.91
Halimeda oppuntia	0	64	3	33	67	0	30.30	6.06	2.03
Ulva lactuca	0	0	365	33	365	0	0	45.46	11.06
Ulva reticulata	0	0	2	33	2	0	0	6.06	0.06
Phaeophyta									
Dictyota dichotoma	9	6	1	33	16	6.06	3.03	3.03	0.48
Padina australis	87	43	2	33	132	33.33	33.33	3.03	4.00
Sargassum plagiophyllum	0	1	0	33	1	0	3.03	0	0.03
Rhodophyta									
Amphiroa fragilissima	60	0	2	33	62	21.21	0	3.03	1.88
Gracilaria gracilis	0	0	22	33	22	0	0	12.12	0.67
Gracilaria salicornia	41	9	0	33	50	15.15	9.09	0	1.52
Hypnea charoides	0	0	2	33	2	0	0	3.03	0.06
Kappaphycus alvarezii	0	1	0	33	1	0	3.03	0	0.03
Laurencia nidifica	0	0	9	33	9	0	0	12.12	0.27
Total number of species	5	7	11						
Total number of individuals	254	217	444						

Table 3. Water parameters across all sampling stations in East Lombok, Indonesia

Location	Temperature (°C)	pH	Salinity (%)	Substrate
Station 1	30	7	34	Sand, muddy sand
Station 2	30	7	34	Sand, calcareous mud, coral rubble
Station 3	30	7	34	Sand, slightly muddy sand

Table 4. Ecological indices of macroalgal community in East Lombok, Indonesia

Ecological indices of macroalgae community	Values		
	Station 1	Station 2	Station 3
Diversity index (H′)	1.45	1.20	0.73
Species richness (R)	0.72	1.11	1.64
Evenness (E)	0.90	0.61	0.31
Dominance (C)	0.24	0.29	0.68

In contrast, Station 2 displayed a diversity index of 1.20, slightly lower than Station 1, despite hosting seven species (higher species count). The species richness index was 1.11, while the evenness index was moderate at 0.61, and the Dominance Index stood at 0.29 (Table 4). Here, the macroalgal assemblage was more species-rich than Station 1, but less even, with *H. macroloba* (abundance: 86 individuals, density: 2.91 ind./m^2, frequency: 30.30%) and *H. opuntia* (abundance: 64 individuals, density: 2.03 ind./m^2, frequency: 30.30%) being the dominant species (Table 2). Thispoints to a moderately specialized community, where environmental conditions selectively favor calcifying green algae.

The moderate evenness and higher dominance relative to Station 1 indicate stronger competition among species, but still suggest that the habitat supports more than just the dominant taxa. The environmental setting at Station 2 likely features calcareous substrates such as coral rubble and stable, clear waters, conditions that favor calcification processes in macroalgae (Teichberg et al. 2013). Although some dominance by *Halimeda* species was observed, the overall structure still reflects a relatively healthy but more specialized ecosystem compared to Station 1.

Meanwhile, Station 3 showed the most distinctive pattern, with a Diversity Index of just 0.73, a Species Richness Index of 1.64 (the highest among all stations), a very low Evenness Index of 0.31, and a high Dominance Index of 0.68. Despite recording 11 species (the highest richness), biodiversity was the lowest because one opportunistic species, *U. lactuca*, overwhelmingly dominated the community (abundance: 365 individuals, density: 11.06 ind./m^2, frequency: 45.46%).

Such high dominance and low evenness imply a severely imbalanced community, where environmental stress, particularly eutrophication, favors the proliferation of fast-growing species (Green-Gavrielidis et al. 2018). The ecological conditions at Station 3 are therefore likely degraded, characterized by high nutrient loading possibly originating from domestic runoff, agricultural activities, or aquaculture effluents (Cai et al. 2023). This pattern is consistent with other studies showing that eutrophic environments promote green algal blooms, reducing overall diversity and destabilizing established community structures (Teichberg et al. 2013; Green-Gavrielidis et al. 2018).

Although some environmental parameters such as pH, salinity, and temperature were measured and found to be relatively constant across sites, a key limitation of the present study is the absence of direct measurements of nutrient concentrations in the water column. The observed dominance of opportunistic species such as *U. lactuca* at Station 3 may suggest nutrient enrichment; however, this inference is based solely on established ecological associations (Teichberg et al. 2010) rather than empirical evidence. Without quantitative data on nutrient levels, it remains difficult to definitively attribute macroalgal community patterns to eutrophication or to distinguish the specific environmental drivers at play. This limitation hinders a comprehensive understanding of how abiotic factors (particularly nutrient availability, light penetration, and hydrodynamics) influence macroalgal distribution and diversity. To improve ecological interpretations and better identify the mechanisms shaping macroalgal community structure, future research should incorporate detailed physicochemical water quality analyses alongside biological assessments.

In addition, the comparison among the stations underscores that diversity indices are shaped not only by species richness but also by evenness and dominance. Although Station 3 had the highest number of species, its low evenness and high dominance resulted in poor diversity, highlighting that a high species count alone is not a reliable indicator of ecosystem health. In contrast, Station 1, with fewer species but high evenness and low dominance, exhibited the highest ecological stability and health. Station 2 occupied an intermediate position, showing moderate richness, evenness, and dominance, suggesting a habitat transitioning between stability and specialized community structure. Thus, comprehensive assessment of biodiversity must integrate multiple indices rather than relying solely on species counts, as it provides deeper insights into the ecological status and resilience of coastal macroalgal communities.

Beta diversity

The calculation of the Simpson and Sørensen dissimilarity indices among the three locations in East Lombok offers valuable insights into the macroalgal community structure, allowing the partitioning of beta diversity into species turnover and nested-ness components. Species turnover reflects the replacement of taxa between sites, while nested-ness (βsne) accounts for differences in species richness due to species loss or gain without replacement (Fontana et al. 2020).

To further disentangle these patterns, the nested-ness resultant component (β_{sne}) was computed for each pairwise station comparison. The β_{sne} values observed in this study (Table 5) were generally low relative to species turnover, indicating that differences in macroalgal communities among the three sites are largely driven by species replacement rather than simple richness gradients. This suggests that local environmental conditions, particularly substrate heterogeneity and eutrophication, play a more critical role in shaping community structure than species loss alone.

Table 5. Pairwise dissimilarity indices (Simpson and Sørensen) and nested-ness resultant component (β_{sne}) for macroalgal communities across three stations in East Lombok, Indonesia

Comparison	Sørensen dissimilarity (β_{sor})	Simpson dissimilarity (β_{sim})	Nested-ness resultant component (β_{sne})
Station 1 vs 2	0.50	0.40	0.10
Station 2 vs 3	0.56	0.43	0.13
Station 1 vs 3	0.63	0.40	0.23

For example, while the presence of shared species (*D. dichotoma*, *P. australis*, and *Gracilaria salicornia*) suggests a baseline similarity between Station 1 and Station 2, notable species turnover is evident. *C. lentillifera* and *A. fragilissima* were found exclusively at Station 1, whereas *Sargassum plagiophyllum*, *Kappaphycus alvarezii*, and calcifying species such as *H. macroloba* and *H. opuntia* were unique to Station 2. These distinctions are closely associated with substrate characteristics: Station 2 is dominated by coral rubble and calcareous mud, which provide favorable conditions for calcifying macroalgae, while Station 1 exhibits more homogeneous sediment composition. Similarly, the pronounced turnover between Station 2 and Station 3 is marked by the dominance of fast-growing, eutrophic-tolerant species at Station 3, such as *U. lactuca*, *U. reticulata*, *C. simpliciuscula*, and *Gracilaria gracilis*, (Pacciardi et al. 2011; Pedersen and Johnsen 2017; Green-Gavrielidis et al. 2018; Chen et al. 2019), which were entirely absent from Station 2. This pattern further supports our assumption that nutrient enrichment and disturbance tolerance are key factors shaping the macroalgal community composition at Station 3.

The comparison between Station 1 and Station 3 mirrors this trend: despite sharing three species, Station 3 again harbors a greater number of opportunistic taxa absent from Station 1. This reinforces the idea that environmental differences, particularly nutrient availability, and substrate type, are key drivers of community differentiation.

The consistently low β_{sne} values across comparisons suggest that nested-ness plays a limited role in shaping beta diversity in this system. However, even a modest degree of nested-ness has ecological and conservation significance. In this context, low nested-ness implies that macroalgal communities are highly specialized and spatially distinct rather than forming subsets of one another. This means that conserving a single site will not capture the full diversity of macroalgal taxa in the region; each location contributes uniquely to the overall biodiversity. From a conservation perspective, this highlights the importance of protecting multiple habitats with varying environmental characteristics to preserve the full spectrum of macroalgal diversity.

In terms of ecosystem functioning, low nested-ness also implies reduced redundancy across sites. Functional traits associated with key taxa (e.g., calcifies at Station 2 or eutrophic-tolerant species at Station 3) may not be present at other sites, increasing the vulnerability of ecosystem functions to local disturbances. Thus, the combination of high turnover and low nested-ness underscores the ecological importance of maintaining habitat heterogeneity and mitigating localized anthropogenic pressures, such as nutrient loading or substrate alteration.

Overall, our findings suggest that beta diversity in East Lombok's coastal waters is primarily governed by species turnover, driven by environmental heterogeneity. The limited contribution of nested-ness reinforces the need for site-specific conservation strategies that reflect the spatial uniqueness of macroalgal communities. Understanding these dynamics is crucial for developing effective coastal management and monitoring frameworks that account for biodiversity at both local and regional scales.

The variation in dissimilarity indices reflects significant beta diversity across the study sites, highlighting that coastal community structure is shaped by a combination of local environmental variables and broader ecological processes. Beta diversity indices such as Simpson and Sørensen dissimilarity emphasize the ecological complexity of coastal habitats and underscore the importance of habitat heterogeneity in maintaining macroalgal biodiversity (Rodriguez et al. 2016).

Thus, while the Sørensen and Simpson indices quantify the overall dissimilarity between stations, the nested-ness component provides deeper insight into the role of species richness in shaping these patterns. The observed differences in substrate types, along with their influence on the macroalgal communities, underscore the complex interplay of abiotic factors driving community structure and function. These findings contribute to a broader understanding of how environmental variability, including substrate complexity and anthropogenic disturbances, shapes coastal ecosystem biodiversity and stability (Asmida et al. 2017; Roleda and Hurd 2019).

In conclusion, this study demonstrates that substrate heterogeneity and local environmental conditions strongly influence macroalgal community composition and beta diversity in East Lombok's coastal waters. The analysis revealed that species turnover, rather than nested-ness, was the dominant driver of beta diversity, indicating pronounced shifts in species composition across sites. Notably, opportunistic taxa such as *U. lactuca* were associated with eutrophic conditions, while calcifying macroalgae were linked to calcareous substrates. These findings highlight the importance of preserving habitat complexity and managing nutrient inputs as essential strategies for conserving macroalgal biodiversity and maintaining ecosystem resilience.

ACKNOWLEDGEMENTS

This research was financially supported by the Hibah Riset PUTI Q1 Universitas Indonesia, Indonesia, grant awarded to Dr.rer.nat. Yasman, M.Sc., for the year 2025 (Grant No. NKB-113/UN2.RST/HKP.05.00/2025). The authors gratefully acknowledge Tri Handayani at the Oceanography Research Center, National Research and Innovation Agency (BRIN), Indonesia, for her assistance in further verifying the identification of macroalgal species.

REFERENCES

Abdel-Kareem MSM, Elsaied AAF. 2022. Chapter 2-Global seaweed diversity. In: El-Sheekh M, Abomohra AE (eds). Handbook of Algal Biofuels. Elsevier, Netherlands. DOI: 10.1016/B978-0-12-823764-9.00001-7.

Al-Yamani FY, Polikarpov I, Al-Ghunaim A, Mikhaylove T. 2014. Field Guide of Marine Macroalgae (Chlorophyta, Rhodophyta, Phaeophyceae) of Kuwait (1st Ed). Kuwait Institute for Scientific Research, Safat.

Andréfouët S, Paul M, Farhan AR. 2022. Indonesia's 13558 islands: A new census from space and a first step towards a one map for Small Islands Policy. Mar Policy 135: 104848. DOI: 10.1016/j.marpol.2021.104848.

Anggadiredja JT. 2017. Seaweed diversity and conservation on the Warambadi Seashore of Sumba Island: Substrata and seasonal phenomenon. Jurnal Teknologi Lingkungan 18 (2): 182-191. DOI: 10.29122/jtl.v18i2.2032.

Arianti A, Pazila BDAP, Ramdhiani A, Kurniawan A, Kholidah BM, Royani BN, Pratiwi BDS, Candri DA, Ghazali M. 2024. Diversity of macroalgae in Sire Beach, North Lombok. Jurnal Biologi Tropis 24 (2b): 315-326. DOI: 10.29303/jbt.v24i2b.8140. [Indonesian]

Arumugam N, Chelliapan S, Kamyab H, Thirugnana S, Othman N, Nasri N. 2018. Treatment of wastewater using seaweed: A review. Intl J Environ Res Public Health 15 (12): 2851. DOI: 10.3390/ijerph15122851.

Asmida I, Akmal ABN, Ahmad I, Diyana MS. 2017. Biodiversity of macroalgae in blue lagoon, the Straits of Malacca, Malaysia and some aspects of changes in species composition. Sains Malays 46 (1): 1-7. DOI: 10.17576/jsm-2017-4601-01.

Atmadja WS, Reine PV. 2010. Checklist of the Seaweed Species Biodiversity of Indonesia with Their Distribution and Classification: Red Algae (Rhodophyceae). Naturalis Biodiversity Centre, Indonesian Institute of Sciences (LIPI), Jakarta. [Indonesian]

Atmadja WS, Reine PV. 2014. Checklist of the Seaweed Species Biodiversity of Indonesia with Their Distribution and Classification: Green Algae (Chlorophyta) and Brown Algae (Phaeophyceae, Ochrophyta). Naturalis Biodiversity Centre, Indonesian Institute of Sciences (LIPI), Jakarta. [Indonesian]

Cai JC, Ni J, Chen Z, Wu S, Wu R, He C, Wang J, Liu Y, Zhou W, Xu J. 2023. Effects of ocean acidification and eutrophication on the growth and photosynthetic performances of a green tide alga *Ulva prolifera*. Front Mar Sci 10: 1145048. DOI: 10.3389/fmars.2023.1145048.

Chen X, Sun Y, Liu H, Liu S, Qin Y, Li P. 2019. Advanced in cultivation, wastewater treatment application, bioactive compounds of *Caulerpa lentilifera* and their biotechnological application. PeerJ 7: e6118. DOI: 10.7717/peerju.6118.

Chopin T. 2018. Seaweed aquaculture from the global, mostly Asian, picture to the opportunity and constraints of the Canadian scene. Bull Aquac Assoc Can 2017 (1): 8.

Cotas J, Gomes L, Pacheco D, Preira L. 2023. Ecosystem services provided by seaweeds. Hydrobiology 2 (1): 75-96. DOI: 10.3390/hydrobiology2010006.

Dominguez H, Loret EP. 2019. *Ulva lactuca*, A source of troubles and potential riches. Mar Drugs 17 (6): 357. DOI: 10.3390/md17060357.

Draisma SGA, Prud'homme RWF, Herandarudewi SMC, Hoeksema BW. 2018. Macroalgal diversity along an inshore-offshore environmental gradient in the Jakarta Bay-Thousand Islands reef complex Indonesia. Estuar Coast Shelf Sci 200: 258-269. DOI: 10.1016/j.ecss.2017.11.010.

Fontana V, Guariento E, Hilpold A, Niedrist G, Steinwandter M, Spitale D, Nascimbene J, Tappeiner U, Seeber J. 2020. Species richness and beta diversity patterns of multiple taxa along an elevational gradient in pastured grasslands in the european Alps. Sci Rep 10: 12516. DOI: 10.1038/s41598-020-69569-9.

Furqan BRN, Yamin IS, Umami SS. 2023. The genetic diversity of macroalgae on the Ekas Coast of East Lombok based on chromatogram data from PCR amplification. Biota 16 (1): 1-10. DOI: 10.20414/jb.v16i1.417. [Indonesian]

Gao Y, Lin G. 2018. Algal diversity and their importance in ecological processes in typical mangrove ecosystems. Biodivers Sci 26 (11): 1223-1235. DOI: 10.17520/biods.2018080.

Gómez I, Navarro NP, Huovinen P. 2019. Bio-optical and physiological patterns in Antarctic seaweeds: A functional trait based approach to characterize vertical zonation. Prog Oceanogr 174: 17-27. DOI: 10.1016/j.pocean.2018.03.013.

Green-Gavrielidis LA, MacKechnie F, Thornber CS, Gomez-Chiarri M. 2018. Bloom-forming macroalgae (*Ulva* spp.) inhibit the growth of co-occurring macroalgae and decrease eastern oyster larval survival. Mar Ecol Prog Ser 595: 27-37. DOI: 10.3354/meps12556.

Guiry MD, Guiry GM. 2022. Algae Base. World-Wide Electronic Publication, National University of Ireland, Galway.

Handayani S, Widhiono I, Widyartini DS. 2023. Macroalgae diversity in the Pari Island Cluster, Seribu Islands District, Jakarta, Indonesia. Biodiversitas 24 (3): 1659-1667. DOI: 10.13057/biodiv/d240339.

Hasni M, Boundir Y, Sabri H, Bahammou N, Cheggour M, Cherifi O, Yacoubi B. 2022. The use of seaweeds and abiotic parameters for the biomonitoring of Moroccan coastal areas: Case study of Safi City. Desalin Water Treat 260: 309-320. DOI: 10.5004/dwt.2022.28422.

Hofmann LC, Strauss S, Shpigel M, Guttman L, Stengel DB, Rebours C, Gjorgovska N, Turan G, Balina K, Zammit G, Adams JMM, Ahsan U, Bartolo AG, Bolton JJ, Domingues R, Dürrani Ö, Eroldogan OT, Freitas A, Golberg A, Kremer KI, Marques F, Milia M, Steinhagen S, Sucu E, Vargas-Murga L, Zemah-Shamir S, Zemah-Shamir Z, Malendez-Martinez AJ. 2024. The green seaweed *Ulva*: Tomorrow's "wheat of the sea" in foods, feeds, nutrition, and biomaterials. Crit Rev Food Sci Nutr 1-36. DOI: 10.1080/10408398.2024.2370489.

Hutomo M, Moosa MK. 2005. Indonesian marine and coastal biodiversity: Present status. Indian J Mar Sci 34 (1): 88-97.

Imchen T. 2015. Substrate deposit effect on the characteristic of an intertidal macroalgal community. Indian J Geo-Mar Sci 44 (3): 333-338.

Islam MM, Hoq ME, Ali MZ, Hasan SJ, Sharif ASM, Buyan MS. 2020. Diversity and occurrence of seaweeds form the south-eastern coast of Bangladesh. Indian J Geo-Mar Sci 49 (8): 1379-1388.

Johan O, Erlania E, Radiarta IN. 2015. Correlation between water base substrate and the presence of natural seaweed in Ujung Genteng Waters, Sukabumi, West Java. J Aquac Res 10 (4): 609. DOI: 10.15578/jra.10.4.2015.609-618.

Kim JK, Yarish C, Hwang EK, Park M, Kim Y. 2017. Seaweed aquaculture: Cultivation technologies, challenges and its ecosystem services. Algae 32 (1): 1-13. DOI: 10.4490/algae.2017.32.3.3.

Kirana IAP, Kurniawan NSH, Abidin AS, Nikmatullah A, Sunarwidhi AL, Jupri A, Hernawan A, Widyastuti S, Sunarpi H, Prasedya ES. 2021. Identification and abundance of macroalgae at Batu Layar Coast, West Lombok, Indonesia. IOP Conf Ser Earth Environ Sci 913: 012057. DOI: 10.1088/1755-1315/913/1/012057.

Leliaert F, Verbruggen H, Vanormelingen P, Steen F, López-Bautista JM, Zuccarello GC, De Clerck O. 2014. DNA-based species delimitation in algae. Eur J Phycol 49 (2): 179-196. DOI: 10.1080/09670262.2014.904524.

Madjar RM, Scăețeanu GV, Sandu MA. 2024. Nutrient water pollution from unsustainable patterns of agricultural systems, effects and measures of integrated farming. Water 16 (21): 3146. DOI: 10.3390/w16213146.

McNeil M, Nothdurft L, Erler D, Hua Q, Webster JM. 2021. Variations in mid- to late holocene nitrogen supply to northern great barrier reef *Halimeda* macroalgal bioherms. Palaeceanogr Paleiclimatol 36 (2): e2020PA003871. DOI: 10.1029/2020PA003871.

Mehra R, Bast SBF, Singh S. 2019. Marine macroalga *Caulerpa*: Role of its metabolites in modulating cancer signaling. Mol Biol Rep 46 (3): 3545-3555. DOI: 10.1007/s11033-019-04743-5.

Müller-Karulis B, McCrackin ML, Dessirier B, Gustafsson BG, Humborg C. 2024. Legacy nutrients in the Baltic Sea drainage basin: How past practices affect eutrophication management. J Environ Manag 370: 122478. DOI: 10.1016/j.jenvman.2024.122478.

Pacciardi L, Biasi AMD, Piazzi L. 2011. Effects of *Caulerpa racemosa* invasion on soft-bottom assemblages in the Western Mediterranean Sea. Biol Invasions 13: 2677-2690. DOI: 10.1007/s10530-011-9938-5.

Pedersen MF, Johnsen KL. 2017. Nutrient (N and P) dynamics of the invasive macroalga *Gracilaria vermiculophylla*: Nutrient uptake kinetics and nutrient release through decomposition. Mar Biol 164 (8): 172. DOI: 10.1007/s00227-017-3197-7.

Prasanthi N, Prasannakumar C, Annadurai D, Mahendran S. 2020. Identifying seaweeds species of Chlorophyta, Phaeophyta and Rhodophyta using DNA barcodes. BioRxiv 1-29. DOI: 10.1101/2020.08.30.274456.

Purcell-Meyerink D, Packer MA, Whecler TT, Hayes M. 2021. Aquaculture production of the brown seaweeds *Laminaria digitata* and *Macrocystis pyrifera*: Application in food and pharmaceuticals. Molecules 26 (5): 1306. DOI: 10.3390/molecules26051306.

Ramesh B, Saravanan A, Kumar PS, Yaashikaa PR, Thamarai P, Shaji A, Rangasamy G. 2023. A review on algae biosorption for the removal of hazardous pollutants from wastewater: Limiting factors, prospects and recommendations. Environ Pollut 327: 121572. DOI: 10.1016/j.envpol.2023.121572.

Rimmer MA, Larson S, Lapong I, Purnomo AH, Pong-Masak PR, Swanepoel L, Paul NA. 2021. Seaweed aquaculture in Indonesia contributes to social and economic aspects of livelihoods and community wellbeing. Sustainability 13 (19): 10946. DOI: 10.3390/su131910946.

Rodriguez S, Martin AP, Sousa-Pinto I, Arenas F. 2016. Biodiversity effects on macroalgal productivity: Exploring the roles of richness, evenness and species trails. Mar Ecol Prog Ser 562: 79-91. DOI: 10.3354/mrps11948.

Roleda MY, Hurd CL. 2019. Seaweed nutrient physiology: Application of concepts to aquaculture and bioremediation. Phycol 58 (5): 552-562. DOI: 10.1080/00318884.2019.1622920.

Smith B, Wilson JB. 1996. A consumer's guide to evenness indices. Oikos 76 (1): 70-82. DOI: 10.2307/3545749.

Somerfield PJ, Clarke KR, Warwick RM. 2008. Simpson Index: In: Fath B (eds). Encyclopedia of Ecology. Elsevier, Netherlands. DOI: 10.1016/B978-008045405-4.00133-6.

Spellerberg IF, Fedor PJ. 2003. A tribute to Claude Shannon (1916-2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon-Wiener' index. Glob Ecol Biogeogr 12 (37): 177-179. DOI: 10.1046/j.1466-822x.2003.00015.x.

Teichberg M, Fox SE, Olsen YS, Valiela I, Martinetto P, Iribarne O, Muto EY, Petti MAV, Corbisier TN, Soto-Jiménez M, Páez-Osuna F, Castro P, Freitas H, Zitelli A, Cardinaletti M, Tagliapietra D. 2010. Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with *Ulva* spp. Glob Chang Biol 16 (9): 2624-2637. DOI: 10.1111/j.1365-2486.2009.02108.x. PMCID: PMC3627300.

Teichberg M, Fricke A, Bischof K. 2013. Increased physiological performance of the calcifying green macroalga *Halimeda opuntia* in response to experimental nutrient enrichment on a Caribbean coral reef. Aqua Bot 104: 25-33. DOI: 10.1016/aquabot.2012.09010.

Valero-Rodriguez JM, Dempster T, Wong WW, Lewis JA, Cook PLM, Swearer SE. 2024. Spatio-temporal patterns in the biomass, species composition and nitrogen content of drift macroalgae in an urbanised coastal embayment. J Appl Phycol 36: 2369-2381. DOI: 10.1007/s10811-024-03249-3.

Varabih CA, Nofirman. 2023. The importance of seaweed as bioremediation natural agent. Joane 1 (2): 48-53. DOI: 10.56855/joane.v1i2.343.

Wai MK. 2018. Morphotaxonomy, culture studies and phytogeographical distribution of *Amphiroa fragilissima* (Linnaeus) Lamouroux (Corallinales, Rhodophyta) from Myanmar. J Aquac Mar Biol 7 (3): 142-150. DOI: 10.15406/jamb.2018.07.00201.

Wan AHL, Wilkes RJ, Heesch S, Bermejo R, Johnson MP, Morrison L. 2017. Assessment and characterization of Ireland's green tides (*Ulva* species). Plos One 12 (1): e0169049. DOI: 10.1371/journal.pone.0169049.

Waters T, Lionata H, Wibowo TP, Jones R, Theuerkauf S, Usman S, Amin MI, Ilman M. 2019. Coastal Conservation and Sustainable Livelihoods Through Seaweed Aquaculture in Indonesia: A Guide for Buyers, Conservation Practitioners, and Farmers, Version 1. The Nature Conservancy, Arlington VA, USA and Jakarta, Indonesia.

Wiecek M. 2023. Densities of Understory Macroalgae and Substrate Classification in Southern Hood Canal. [Thesis]. The Evergreen State College, Olympia.

Wiraatmaja MF, Hasanah R, Dwirani NM, Pratiwi AS, Riani FE, Hasnaningtyas S, Nugroho GD, Setyawan AD. 2022 Structure and composition of molluscs (bivalves and gastropods) in the mangrove ecosystem of Pacitan District, East Java, Indonesia. Intl J Bonorowo Wetl 12 (1): 1-11. DOI: 10.13057/bonorowo/w120101.

Zainee NFA, Ahmad I, Taip ME, Ibrahim N, Ismail A. 2019. Habitat preference of seaweeds at a tropical island of southern Malaysia. Songklanakarin J Sci Technol 41 (5): 1171-1177. DOI: 10.14456/sjst-psu.2019.147.

Zhang Y, He P, Li H, Li G, Liu J, Jiao F, Zhang J, Huo Y, Shi X, Su R, Ye N, Liu D, Yu R, Wang Z, Zhou M, Jiao N. 2019. *Ulva prolifera* green-tide outbreaks and their environmental impact in the Yellow Sea, China. Natl Sci Rev 8 (4): 825-838. DOI: 10.1093/nsr/nwz026.

Zokm GME, Ismail MM, Okbah MAE. 2022. Seaweeds as bioindicators of organic micropollutants Polycyclic Hydrocarbons (PAHs) and Organochlorine Pesticides (OCPs). Environ Sci Pollut Res Intl 29 (23): 34738-34748. DOI: 10.1007/s11356-022-18634-z.

Zubia M S, Draisma GA, Morrissey KL, Varela-Álvarez E, Clerck OD. 2020. Concise review of the genus *Caulerpa* J.V. Lamouroux. J Appl Phycol 32 (1): 23-39. DOI: 10.1007/s10811-019-01868-9.

Zúñiga-Ríos D, Vásquez-Elizondo RM, Caamal E, Robiedo D. 2021. Photosynthetic responses of *Halimeda scabra* (Chlorophyta, Bryosidales) to interactive effects of temperature, pH, and nutrients and its carbon pathways. PeerJ 9: e10958. DOI: 10.7717/peerj.10958.