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THE DIVERSITY OF MACROALGAE SPECIES WITH PROSPECTS FOR MEDICINAL APPLICATIONS IN AQUATIC ENVIRONMENTS

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Abstract. Macroalgae are important marine organisms known to contain polysaccharides such as alginate, agar, and carrageenan, as well as bioactive compounds and pigments with significant pharmaceutical potential. This study aimed to identify and analyze the diversity of macroalgae species that have potential medicinal properties in the coastal waters of Cidatu Beach, Pandeglang Regency, Banten Province, Indonesia. The research employed a transect method with three sampling stations along the intertidal zone. At each station, three transects were established 5 meters apart, and each transect contained five 1×1 m plots separated by 5 meters. A total of 12 macroalgae species were identified, comprising three species of Chlorophyceae (*Ulva intestinalis*, *Ulva reticulata*, *Chaetomorpha crassa*), five species of Phaeophyceae (*Padina australis*, *Turbinaria conoides*, *Turbinaria decurrens*, *Sargassum polycystum*, *Sargassum crassifolium*), and four species of Rhodophyceae (*Gracilaria salicornia*, *Gracilaria coronopifolia*, *Gelidium sp.*, *Amphiroa fragilissima*). The Shannon–Wiener diversity index (H′) of 2.169 indicates a moderate level of species diversity in the study area. Environmental conditions such as temperature (29–30°C), salinity (31–32‰), and pH (7.0) were within the optimal range for macroalgal growth, although light intensity was relatively low (1,939 lux). Based on literature analysis, ten of the recorded species demonstrated potential pharmacological value, exhibiting antibacterial, antifungal, antiviral, antitumor, antihypertensive, and antihemorrhagic properties. Among these, species of *Sargassum*, *Padina*, and *Gracilaria* are particularly noteworthy for their bioactive compounds, including tannins, flavonoids, and polysaccharides. The moderate diversity and high medicinal potential of the identified macroalgae suggest that Cidatu Beach supports a rich yet underutilized marine biota. Further biochemical and pharmacological investigations are recommended to explore their potential as sustainable sources of natural medicinal compounds.

Keywords: Macroalgae diversity; Cidatu Beach; bioactive compounds; medicinal potential; marine ecology

I. INTRODUCTION

Marine macroalgae, commonly known as seaweeds, play a crucial role in coastal ecosystems as primary producers and bioresource reservoirs for the pharmaceutical, cosmetic, and food industries [1]. They are recognized for their rich biochemical composition, including polysaccharides (alginate, carrageenan, agar), proteins, polyphenols, and various secondary metabolites that exhibit diverse biological activities such as antioxidant, antibacterial, antiviral, and anti-inflammatory effects [2], [3]. The growing demand for natural products and eco-friendly therapeutics has intensified global research on macroalgae as alternative sources of bioactive compounds for drug discovery and biomedicine [4]. Indonesia, located within the Coral Triangle, possesses one of the highest marine biodiversity levels in the world, including an extensive diversity of macroalgae species distributed along its tropical coastlines [5]. These macroalgae contribute significantly to local economies through aquaculture, traditional medicine, and natural product industries [6]. However, many of Indonesia's coastal areas remain underexplored in terms of their algal biodiversity and pharmacological potential, particularly in the western regions such as Banten Province [7]. The Cidatu coast in Pandeglang Regency represents one such area with diverse ecological conditions but limited scientific documentation on its macroalgal communities. Macroalgae are taxonomically classified into three major groups: Chlorophyceae (green algae), Phaeophyceae (brown algae), and Rhodophyceae (red algae) [8]. Each group exhibits unique physiological traits and biochemical pathways leading to distinct bioactive profiles. For example, brown algae (Sargassum, Padina, Turbinaria) are known to produce phlorotannins and fucoidans with antioxidant and antitumor effects, while red algae (Gracilaria, Gelidium) are rich in agar and carrageenan with antiviral and immunomodulatory properties [9], [10]. Green algae (*Ulva, Chaetomorpha*) have been reported to contain sulfated polysaccharides and pigments beneficial for antibacterial and anti-inflammatory applications [11]. These biochemical

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differences highlight the ecological and medicinal significance of taxonomic diversity in macroalgal research [12].

In recent years, numerous studies have documented the pharmacological activities of tropical macroalgae, revealing their potential as sources of natural compounds for treating chronic and infectious diseases [13]. For instance, Sargassum polycystum and Gracilaria salicornia have demonstrated notable antidiabetic and anticancer properties due to their high phenolic and flavonoid content [14]. Moreover, Padina australis extracts have shown antiviral effects against dengue and herpes viruses through inhibition of viral replication [15]. Despite such promising findings, there is limited knowledge about species distribution, abundance, and ecological diversity of medicinally important macroalgae along the Indonesian coasts, especially in less-studied areas like Cidatu Beach. Understanding the diversity and ecological composition of macroalgae is essential for conservation and sustainable utilization. Biodiversity assessments not only contribute to ecological monitoring but also serve as a foundation for bioprospecting—linking taxonomy with bioactivity potential [16]. The evaluation of environmental parameters such as temperature, salinity, pH, and light intensity provides insight into habitat suitability and productivity of macroalgal species [17]. Moreover, recognizing species with medicinal potential can guide future pharmacological research and marine biotechnology innovation in Indonesia [18].

Therefore, this study aims to identify and analyze the diversity of macroalgae species in Cidatu coastal waters and to evaluate their potential as natural medicinal resources. By integrating ecological assessment with literature-based pharmacological analysis, this study seeks to contribute baseline data for future exploration, conservation, and sustainable exploitation of marine bioresources in western Indonesia.

Marine macroalgae exhibit remarkable biodiversity and functional variability across tropical and temperate ecosystems, serving as essential components in primary production, nutrient cycling, and habitat formation [19]. They are broadly categorized into three main divisions—Chlorophyceae (green algae), Phaeophyceae (brown algae), and Rhodophyceae (red algae)—each possessing distinct pigments and cell wall compositions that influence their ecological distribution and physiological roles [20]. The productivity and diversity of macroalgae are strongly influenced by environmental parameters such as temperature, salinity, substrate type, nutrient availability, and light intensity [21]. Macroalgae also serve as critical bioindicators of marine environmental health. Their sensitivity to pollution and eutrophication allows researchers to assess ecological balance and anthropogenic impacts in coastal zones [22]. According to Costa et al. [12], variations in macroalgal diversity can reflect shifts in water quality, hydrodynamic forces, and sediment composition. High species richness typically indicates stable and well-oxygenated environments, whereas dominance by a few tolerant species often signals ecological stress or nutrient enrichment [23]. Hence, studying macroalgal composition not only provides insights into ecosystem dynamics but also supports marine conservation strategies.

Macroalgae produce a wide range of secondary metabolites—such as polyphenols, terpenoids, alkaloids, sterols, and polysaccharides—which play defensive roles against herbivory, UV radiation, and microbial attack [24]. These compounds exhibit diverse pharmacological activities that make macroalgae promising candidates for natural drug discovery. For example, brown algae (Phaeophyceae) are rich in phlorotannins, fucoidans, and laminarins, compounds known for their antioxidant, anti-inflammatory, and anticancer activities [9], [25]. Red algae (Rhodophyceae) contain carrageenan, agar, and mycosporine-like amino acids, which possess antiviral and immunomodulatory properties [10], while green algae (*Chlorophyceae*) provide ulvans and sulfated polysaccharides with strong antibacterial and anticoagulant potential [11]. Recent studies have identified macroalgal metabolites capable of inhibiting key enzymes associated with chronic diseases such as diabetes, hypertension, and cancer. For instance, Sargassum polycystum extracts exhibit α-glucosidase inhibitory activity beneficial for controlling postprandial hyperglycemia [14], while Gracilaria salicornia has shown cytotoxic effects against carcinoma cell lines [26]. Similarly, Padina australis contains bioactive phenolics and flavonoids that disrupt viral replication, offering antiviral potential against dengue and herpes viruses [15]. These findings strengthen the relevance of macroalgal research in developing sustainable marine-based pharmaceuticals.

Marine natural products (MNPs) derived from macroalgae have gained substantial attention in recent years for their biomedical and biotechnological applications. As noted by Villanueva et al. [16], macroalgae contribute significantly to the global discovery pipeline of marine-derived pharmaceuticals due to their structural chemical diversity and ecological adaptability. Bioassay-guided studies have revealed that macroalgal extracts possess antibacterial, antifungal, and antiviral effects effective against antibiotic-resistant pathogens [27]. Furthermore, macroalgal polysaccharides such as alginate, carrageenan, and agar are widely used as biocompatible polymers in drug delivery systems and wound dressings due to their gel-forming and antioxidant properties [2], [4]. The versatility of macroalgae as both a source of primary metabolites for industry and secondary metabolites for medicine makes them invaluable to the blue economy framework [18]. However, many regions in the Indo-Pacific, including Indonesia, remain underexplored despite their high macroalgal diversity and favorable environmental conditions for bioprospecting [7], [13].

Indonesia's extensive coastline hosts over 8,500 species of marine algae, yet only a fraction has been studied for its biochemical and pharmacological properties [5], [6]. Prior studies have focused predominantly on macroalgae from eastern Indonesia, including Bali, Sulawesi, and Maluku, where species such as Eucheuma cottonii and Kappaphycus alvarezii are commercially cultivated for carrageenan production [19]. Research in western Indonesia, particularly in Banten and West Java, remains limited despite evidence of diverse algal habitats [7]. Widyastuti et al. [7] reported that the Banten coastline supports various species of Sargassum, Padina, Gracilaria, and Ulva, which are ecologically significant for coastal stability and carbon sequestration. Yet, the pharmacological potential of these species remains poorly characterized. Exploring these macroalgal resources, especially in less-documented locations such as Cidatu Beach, is crucial for developing a comprehensive inventory of Indonesia's marine bioresources and their potential medicinal applications [28].

While the biological and pharmacological potential of macroalgae has been widely acknowledged, few studies have simultaneously integrated ecological diversity assessments with medicinal potential analysis in Indonesia. Most available research focuses on either taxonomic identification or bioactivity screening, lacking a holistic perspective on the relationship between ecological diversity and biochemical potential [17], [25]. Moreover, environmental factors influencing macroalgal distribution in Banten's coastal ecosystems have not been systematically documented. Addressing these gaps, this study integrates biodiversity assessment with literature-based pharmacological evaluation to establish a foundational understanding of macroalgal resources at Cidatu Beach, Pandeglang. The conceptual framework assumes that environmental conditions shape macroalgal diversity, which in turn influences the distribution of bioactive compounds. By adopting this integrative approach, the study aims to contribute to marine ecology, natural product discovery, and sustainable resource management.

II. RESEARCH METHODS

This study employed a descriptive quantitative approach to assess the diversity and potential medicinal value of macroalgae species found in the coastal waters of Cidatu Beach, Pandeglang Regency, Banten Province, Indonesia. Sampling was conducted during low tide along the intertidal zone using the line transect-quadrat method following standard marine ecological protocols [29]. Three sampling stations were established along the coastline to represent varying substrate types and tidal conditions. At each station, three transect lines were placed parallel to the shoreline at a distance of 5 meters apart. Along each transect, five 1 × 1 m quadrats were positioned at 5-meter intervals, yielding a total of 45 observation plots. All macroalgal specimens found within each quadrat were collected manually, placed in labeled plastic bags, and preserved in 4% formalin for laboratory analysis. Environmental parameters—including water temperature, salinity, pH, and light intensity—were measured in situ using portable instruments such as a thermometer, refractometer, and digital lux meter to assess habitat suitability [30].

In the laboratory, macroalgae samples were rinsed with seawater to remove sediments and epiphytes, then identified morphologically based on external features such as thallus color, texture, branching pattern, and reproductive structures using standard taxonomic keys [20]. Species identification was performed with reference to the AlgaeBase database and regional identification guides for Indonesian seaweeds [28]. The relative abundance of each species was calculated, and community structure indices—including species richness (S), Shannon–Wiener diversity index (H′), and evenness (E)—were determined using the equations proposed by Shannon and Weaver (1963). Diversity categories were interpreted as low (H′ < 1), moderate (1 ⩽ H′ ⩽ 3), or high (H′ > 3) [31]. A literature-based pharmacological analysis was then conducted to compile scientific evidence regarding the medicinal properties of the identified species. This integrative method allowed for correlating ecological diversity with potential bioactive applications, aligning with current bioprospecting and marine biotechnology frameworks.

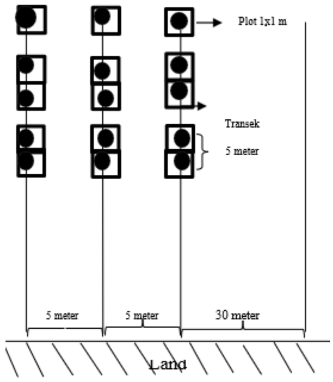

Figure 1. Sampling Technique Method Transect

III. RESULTS AND DISCUSSION

Species Composition and Taxonomic Diversity

A total of 12 macroalgae species were identified from the coastal waters of Cidatu Beach, Pandeglang Regency, consisting of 3 species of Chlorophyceae (green algae), 5 species of Phaeophyceae (brown algae), and 4 species of Rhodophyceae (red algae). The identified species included *Ulva intestinalis, Ulva reticulata, Chaetomorpha crassa (Chlorophyceae); Padina australis, Turbinaria conoides, Turbinaria decurrens, Sargassum polycystum, Sargassum crassifolium (Phaeophyceae); and Gracilaria salicornia, Gracilaria coronopifolia, Gelidium sp., and Amphiroa fragilissima (Rhodophyceae*).

The Shannon–Wiener diversity index (H′ = 2.169) indicates a moderate level of diversity in the study area, suggesting that the environmental conditions are relatively stable and capable of supporting diverse macroalgal communities. According to Shannon and Weaver [31], diversity values between 1 and 3 reflect balanced ecological conditions without dominance by a single species. Similar findings were reported by Suryaningrum et al. [30] in western Java, where coastal areas with mixed substrates and moderate hydrodynamics showed comparable diversity indices (H′ ≈

2.1 – 2.3). The presence of multiple genera from three algal divisions demonstrates the adaptability of Cidatu's intertidal environment to species with different light, substrate, and nutrient preferences [32].

Environmental Parameters and Habitat Suitability

The physical and chemical parameters recorded during the study were within the optimal range for macroalgal growth: temperature 29–30°C, salinity 31–32‰, pH 7.0, and light intensity 1,939 lux. These values correspond to the preferred ranges reported in previous studies [21], [30]. Temperature is a critical determinant of macroalgal productivity and pigment synthesis; values near 30°C favor tropical algal metabolism, particularly for Sargassum and Padina species [33].

The moderate salinity range observed supports both stenohaline and euryhaline macroalgae, enhancing species coexistence. Meanwhile, a slightly acidic pH of 7.0 remains within tolerable limits for cell wall ion exchange and nutrient absorption [19]. The relatively low light intensity may be attributed to turbidity caused by suspended particles and industrial runoff, which could limit the distribution of Chlorophyceae that require higher photosynthetically active radiation (PAR) [34]. Despite this, the persistence of red and brown algae suggests their adaptive efficiency under lower light conditions, supported by accessory pigments such as phycoerythrin and fucoxanthin that enhance light absorption at greater depths [35].

Distribution Pattern and Community Structure

Species from Phaeophyceae—particularly Sargassum polycystum and Padina australis—dominated the community structure, contributing the highest relative abundance across all stations. This dominance may be linked to the coarse-sand substrate and moderate water movement characteristic of the Cidatu coastline, conditions known to favor the attachment of large thalli with robust holdfasts [36]. Sargassum species, with their complex morphology and vesicles, also provide microhabitats for invertebrates, thereby enhancing local biodiversity. In contrast, Chlorophyceae species such as Ulva and Chaetomorpha were more abundant in the upper intertidal zone where sunlight penetration and nutrient influx from terrestrial sources are higher. The distribution pattern corresponds with ecological zonation observed in similar tropical coastlines, where green algae dominate shallow areas, while brown and red algae thrive in mid- to lower-intertidal zones [24]. This stratification suggests niche differentiation driven by light availability, substrate texture, and desiccation tolerance.

Medicinal Potential of Identified Macroalgae

Literature analysis revealed that 10 of the 12 identified species possess significant pharmacological potential based on prior biochemical studies. Brown algae species such as Sargassum polycystum and Turbinaria conoides are rich in phlorotannins, fucoidans, and terpenoids, which have demonstrated antioxidant, antitumor, and anti-inflammatory activities [9], [14], [26]. Padina australis has been reported to exhibit antiviral properties by inhibiting viral replication in dengue and herpes infections [15]. Red algae such as Gracilaria salicornia and Gelidium sp. contain agar and carrageenan, known for their immunostimulant and antimicrobial effects [10]. These polysaccharides also serve as biocompatible materials for drug delivery and tissue engineering due to their gel-forming ability and low cytotoxicity [25]. Meanwhile, green algae (Ulva reticulata and Chaetomorpha crassa) are sources of ulvans, chlorophylls, and carotenoids with antihypertensive and antibacterial functions [11], [27]. The broad range of pharmacological properties underscores the importance of tropical macroalgae as bioresources for sustainable drug discovery.

Ecological Implications and Conservation Perspectives

The moderate diversity and high medicinal potential of macroalgae in Cidatu Beach highlight the area's ecological importance and bioprospecting value. However, anthropogenic pressures such as industrial runoff, sedimentation, and unregulated harvesting pose threats to macroalgal habitats and biodiversity [7], [30]. The observed environmental stability suggests that conservation interventions should focus on preventive management rather than restoration.

Table 1. Types of Macroalgae Found in Cidatu Waters, Pandeglang Regency

Class	Species name	Station		
		I	II	III
		Σ indv	Σ indv	Σ indv
Chlorophyceae	*Ulva intestinalis*	266	82	214
	Ulva reticulate	179	97	51
	Chaetomorpha crassa	143	66	43
Phaeophyceae	*Padina australis*	129	138	94
	Turbinaria conoides	88	81	105
	Turbinaria decurrens	22	19	24
	Sargassum polycystum	44	194	155
	Sargassum crassifolium	39	157	143
Rhodophyceae	*Gracillaria salicornia*	30	39	27
	Gelidium sp.	28	35	17
	Gracilaria coronopifolia	3	19	7
	Amphiroa fragilissima	257	165	237
Total		1228	1092	1117

Community-based monitoring programs, combined with sustainable harvesting practices, could help maintain macroalgal populations while supporting local livelihoods through eco-friendly industries [37]. Integration of marine biodiversity conservation with blue economy initiatives aligns with global sustainable development goals (SDG 14: Life Below Water) and Indonesia's national marine policy framework [38]. Further biochemical profiling and in vitro pharmacological testing are necessary to validate the therapeutic claims and assess the commercial feasibility of identified species [39]. From a pharmacological perspective, most of the identified species exhibit promising bioactive potential supported by previous studies, particularly in antioxidant, antibacterial, antiviral, and anti-inflammatory applications. Brown algae such as Sargassum polycystum and Padina australis contain phlorotannins and fucoidans, while red algae (Gracilaria salicornia, Gelidium sp.) provide agar and carrageenan compounds with well documented biomedical relevance. These findings reaffirm the ecological–pharmacological linkage between biodiversity and bioprospecting value. To harness these resources sustainably, it is imperative to integrate biodiversity conservation with marine biotechnology and blue economy initiatives.

Strengthening local-based management, promoting eco-friendly seaweed utilization, and encouraging collaborative research between academic institutions, industries, and policymakers are essential to ensuring that macroalgal resources are utilized responsibly and equitably [40]–[42].

IV. CONCLUSION

This study provides a comprehensive assessment of the diversity and medicinal potential of macroalgae species inhabiting the coastal waters of Cidatu Beach, Pandeglang Regency, Banten Province, Indonesia. A total of 12 macroalgae species were identified, comprising representatives of Chlorophyceae, Phaeophyceae, and Rhodophyceae. The moderate Shannon–Wiener diversity index ($H' = 2.169$) indicates a balanced and stable ecosystem capable of supporting diverse macroalgal communities. Environmental parameters such as temperature (29–30°C), salinity (31–32‰), pH (7.0), and light intensity (1,939 lux) were found to be within optimal ranges for macroalgal growth. These conditions collectively support a diverse array of taxa with varying ecological preferences, reflecting the adaptive potential of macroalgae in tropical intertidal habitats. The predominance of Sargassum, Padina, and Gracilaria species underscores the ecological resilience and productivity of this coastal zone.

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