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Marine Macroalgae Biodiversity in the Pangandaran Coastal, Indonesia

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ABSTRACT

Macroalgae are critical to marine ecosystems and possess significant economic and ecological value. The present study investigated the biodiversity and distribution of marine macroalgae in the ecotourism coastal of Pangandaran, Indonesia. Marine macroalgae investigation was conducted using survey method with a quadrant transect from low to high tide in the intertidal zone of Madasari, Karapyak, and Pasir Putih. We documented 59 species across three macroalgal classes: Rhodophyta, Chlorophyta, and Ochrophyta, with Chlorophyta being the most dominant. Environmental parameters, including temperature, nitrate, and phosphate levels, were measured and analyzed using Multidimensional Scaling (MDS) to identify their influence on macroalgae distribution. The results showed that Madasari exhibited the highest species richness and density, with alien species *Ulva lactuca* and *U. flexuosa* dominating across all sites. Human activities, substrate type, and nutrient levels were identified as key factors affecting macroalgal diversity and abundance. These findings provide valuable insights for sustainable management of ecotourism and conservation efforts in coastal ecosystems.

INTRODUCTION

The coastal zone is a distinctive environment characterized by intricate interactions among physical, chemical, biological, socio-economic, and cultural variables. One spot in coastal areas that have rich biodiversity is the intertidal zone. The intertidal zone, located only a few meters between high and low tides, is the smallest spot in the world's oceans. The intertidal zone is home to a variety of biodiversity including macroalgae.

Macroalgae is a crucial biological resource for marine ecosystems **(Chang & Tseng, 2010)**. They mostly inhabit substrates such as rocks, sandstone, sandy soil, wood, and mollusk shells. Macroalgae may enhance aquatic production, serve as a food source

(Prathep, 2005), offer habitat for other creatures, mitigate heavy metal contaminants, and perhaps function as biomonitors for pollutants **(Dawes, 1998)**. Moreover, macroalgae play a crucial role in intertidal ecosystems, serving as habitats for echinoderms, crustaceans, mollusca, and coral fish **(Marianingsih *et al.*, 2013)**. They also act as primary producers, carbonate providers, and stabilizers of foundational substrates that bolster the integrity of coral reefs **(Anggadiredja *et al.*, 2009)**. Macroalgae are also economically valuable as a source of sustenance, industrial resources, laboratory supplies, pharmaceuticals, and antibiotic production.

The intertidal of Pangandaran, located on the southern coast of Java Island, is a popular tourist destination. It boasts a coastline spanning 91km, characterized by steep crags and a mix of rocky and sandy substrates **(Sahidin *et al.*, 2018; Nurhayati *et al.*, 2019)**. Marine organisms primarily inhabit the coastal areas with rocky substrates and corals, exhibiting a great diversity of both animals and plants **(Sahidin *et al.*, 2019)** including marine macroalgae. Environmental factors, such as temperature, salinity, dissolved oxygen, and pH, influence the distribution, proliferation, and growth of macroalgae in intertidal zones **(Lapu, 2013)**. Furthermore, increasing human activities such as industrial operations, agriculture, urbanization, fisheries, and tourism have led to an increase in anthropogenic nutrient loads to the shallow coast, causing disturbance to ecosystems that are susceptible to change. Researchers have found that nutrient enrichment enhances the biomass, survival, diversity, and density of vulnerable macroalgae.

Intertidal shores are susceptible to external interference, both naturally occurring and due to anthropogenic disturbances **(Sahidin *et al.*, 2019a; Wardiatno *et al.*, 2017)**. This can lead to a decrease in the biodiversity of marine macroalgae. Anthropogenic factors that can reduce diversity and macroalgae populations include water pollution **(Wardiatno *et al.*, 2017)**, tourism **(Zehadi, 2008)**, fishing **(Marter, 2013)**, and food sales **(Tuaputty *et al.*, 2024)**. One of the tourist activities that can reduce the population of marine algae is the habit of collecting objects. Unfortunately, the report of biodiversity of marine macroalga in Pangandaran coastal is limited. Therefore, it is crucial to update the data on marine macroalgae to reflect the current state of biodiversity and conservation in Indonesia.

MATERIALS AND METHODS

Study area and macroalgae collection

This study was conducted by the survey method in three Pangandaran intertidal zones: Karapyak ($7^0$41’44” S, $108^0$45’37” E), Pasir Putih ($7^0$42’23” S, $108^0$39’09” E), and Madasari ($7^0$47’34” S, $108^0$29’45” E), with three replicates per month in each location (Fig. 1). We used a 1 × 1-meter quadrant and compiled samples manually. Based on accessibility, we examined three quadrants in each location. We meticulously scrutinized every quadrant until we discovered no more macroalgae. We enumerated the samples in each quadrant for density data, thereafter returning them to their habitat and photographing specific species discovered at the Aquatic Resources Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran.

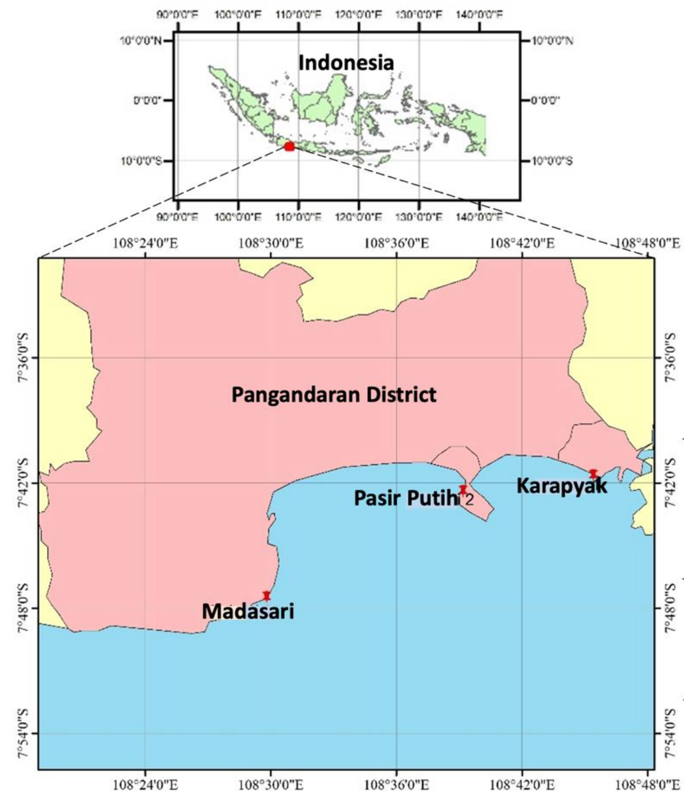

Fig. 1. Map of the sampling locations in Pangandaran Coastal, Indonesia

Environmental data

The water temperature was measured *in situ* using a digital thermometer, dissolved oxygen (DO) with a DO meter, salinity with a refractometer, and pH with a pH meter. While, nitrate and phosphate were estimated during the *ex situ* investigation using spectrophotometer. The environmental factor analysis follows the standard operating procedures prescribed by **APHA (2017)**.

Community structure determination of marine macroalgae

The relative density of marine macroalgae was estimated by the theoretical formula $KR = (ni/\sum n)\ x100\%$, where *KR* represents relative density; *ni* is total individual; and Σn is total species found. While, cover relative was estimated following formula $PR = (Ci/\sum Ci)\ x100\%$, where *PR* represents cover relative; *Ci* is area of cover type I; and $\sum Ci$ is area of cover type of all species. Diversity of marine macroalgae was estimated using Shannon-Weaner formula $H' = -\sum((ni/N) \times Log2(ni/N))$, where H' represents Shannon-Weaner diversity index; *ni/N* is species proportion i from total species; *ni* is total individual each species; and *N* is total individual. In addition, uniformity evenness index was estimated following formula $E = H'/\ln S$, where E represents uniformity evenness index; H' is diversity index; and S is total species found.

Analysis

Structure community (density, diversity, uniformity, and covering index) were compared between different locations and macroalgae classes by the Kruskal-Wallis test and followed by a *Post- hoc* Pairwise Mann-Whitney U test. Spatial analysis was applied to determine the distribution and relationship between environmental variable and macroalgae using the multidimensional scaling (MDS) method. All analyses were conducted using RStudio, an open-source software, using codes sourced from **Albert and Rizzo (2012)**, **Chang (2013)** and **Long and Teetor (2019)**.

RESULTS

Environmental variable and composition of macroalgae

Environmental variable of water temperature, salinity, dissolved oxygen and pH were not significantly different between locations (Table 1). In contrast, nitrate and phosphate were at their highest values in Madasari (0.43±0.05 mg/l, 0.19±0.05 mg/l, respectively; $P < 0.05$; Table 1), but Karapyak and Pasir Putih were not significantly different (Table 1).

In the present study, we found 59 species of macroalga in Pangandaran Coastal, divided into 3 classes: Rhodophyta, Chlorophyta, and Ochrophyta (30, 20, and 9 species, respectively; Table 1 & Fig. 3). Number of macroalga was significantly the highest in Madasari following Karapyak, and Pasir Putih (51, 33, and 27, respectively; $P < 0.001$; Table 2). Similarly, diversity index values were significantly the highest in Madasari, following Karapyak dan Pasir Putih ($P < 0.001$). In contrast, relative density was recorded with the highest value at Madasari site (41.5%; $P < 0.001$), though not significant between Pasir Putih and Karapyak (Table 2). While, the covering of macroalga was not significantly different in all locations (Table 2). Globally, the number of Rhodophyta class was higher than Chlorophyta and Ochrophyta in Pangandaran Coastal (Fig. 3). However, the composition, density and covering of macroalgae Chlorophyta were significantly the highest ($P<0.001$) compared to Rhodophyta and Ochrophyta in different locations (Fig. 2A-C). Marine macroalgae was dominating associated with hard coral in Karapyak, Pasir Putih, and Madasari locations (Table 2; Fig. 2D).

The results showed that the macroalgae diversity index in all Karapyak coastal stations was in the high category, namely 3,465 at station 1, 3,991 at station 2, and 4,171 at station 3. In Pasir Putih, high index values were found at station 1 (3,212) and station 3 (3,327), while station 2 was in the medium category with a value of 2,732. In Madasari waters, the diversity index of all stations was in the high category, namely 4,271 at station 1, 4,007 at station 2, and 4,508 at station 3.

Table 1. Environmental variable at Karapyak, Pasir Putih and Madasari sites sampling

Parameter	Sampling sites			*P*- value
	Karapyak	Pasir Putih	Madasari	
Temperature (^{0}C)	29.3 ± 2.1	30.2 ± 1.5	29.6 ± 2.3	n.s.
Salinity (ppt)	35.2 ± 2.3	34.1 ± 1.8	35.3 ± 2.1	n.s.
Dissolved Oxygen (mg/l)	6.2 ± 1.2	5.9 ± 1.8	6.3 ± 2.0	n.s.
pH	7.3 ± 0.5	8.1 ± 0.3	7.5 ± 0.8	n.s.
Nitrat (mg/l)	0.13 ± 0.07^a	0.13 ± 0.03^a	0.43 ± 0.05$^{\mathbf{b}}$	< 0.01
Phosphate (mg/l)	0.14 ± 0.07^a	0.12 ± 0.02^a	0.19 ± 0.05$^{\mathbf{b}}$	< 0.01
Current (m/s)	3.80 ± 0.20	4.80 ± 0.25	4.50 ± 0.30	n.s.

Post- hoc Mann-Whitney U tests are denoted by lowercase letter alphabets, n.s. (no significant)

Density and coverity of macroalgae

The comparison among the stations in the waters of Karapyak, Pasir Putih, and Madasari shows significant variations in macroalgae density (Fig. 2). On the coast of Karapyak, the highest density of macroalgae was recorded, influenced by the presence of *Ulva lactuca, U. flexuosa*, and *P. boryana* species that have colony distribution patterns and dense seagrass ecosystems, maintaining a strong balance of nutrients and substrates. In Pasir Putih, the highest density observed, supported by colonizing species and breaking the current. Meanwhile, Madasari had the highest density of macroalgae due to the presence of coral reefs protecting them from currents, with dominant species such as *U. lactuca, P. boryana*, and *Caulerpa taxifolia*.

Madasari coastal was recorded with the highest macroalgae cover of 40.30%, followed by Karapyak and Pasir Putih (39.08%, 34.63%, respectively; Fig. 2B). Madasari substrate was dominated by a sandy coral and large rocks (Table 2). *U. lactuca* and *U. flexuosa* were found with the highest cover in all locations.

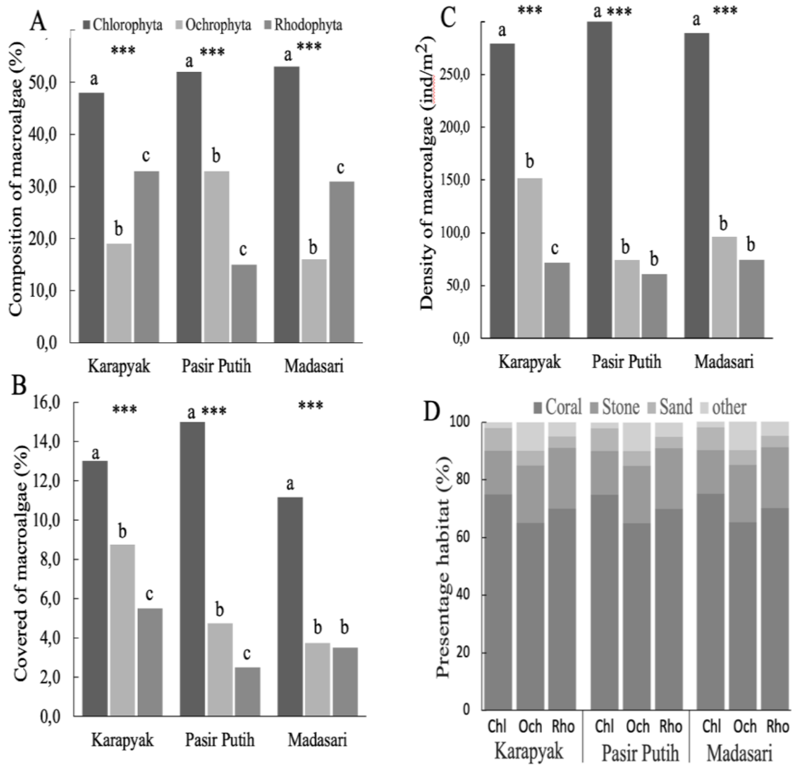

Fig. 2. Community structure showing: **A)** Composition; **B)** Covering; **C)** Density and **D)** Habitat percentages of marine algae across different classes in the Pangandaran coastal *P*-value of Kruskal-Wallis test (*** $P < 0.001$). The *Post- hoc* Mann-Whitney U test; significant differences ($P < 0.05$) are labeled with superscript alphabets: a, b, and c.

Table 2. Checklist of marine macroalgae in the ecotourism coastal of Pangandaran, based on population and substrate

No	Species name	Sampling sites			Substrate
		Karapyak	Pasir Putih	Madasari	
1	*Acanthophora spicifera*	++	+	++	K, P
2	*Actinotrichia fragilis*	+			K
3	*Ahnfeltiopsis humilis*			+	K
4	*Boergesenia forbesii*	++	++	+	K, P
5	*Callophyllis laciniata*			++	K
6	*Caulerpa lentillifera*			+	B
7	*Caulerpa racemosa*	++		+++	K, P
8	*Caulerpa sp*			+	K, P
9	*Caulerpa taxifolia*			++	K, P
10	*Chaetomorpha antennina*			+++	K, P
11	*Chaetomorpha crassa*	++	+	++	E
12	*Chaetomorpha Sp.*		+	++	E
13	*Chondracanthus acicularis*			+	K
14	*Chondria macrocarpa*			++	K

15	*Chondrus crispus*	++		+	K
16	*Cladophora catenata*			+	K
17	*Codium harveyi*	++		++	K
18	*Codium reediae*	++	++	++	K
19	*Corallina vancouveriensis*			++	K
20	*Dyctyosphaera caversona*	++	+	+++	K
21	*Eucheuma denticulatum*			++	K
22	*Eucheuma edule*	+++	++	+++	K
23	*Eucheuma serra*		+		K
24	*Eucheuma* sp.	+			K
25	*Galaxaura rugosa*	+		++	K
26	*Galaxaura* sp. *1*			+	K
27	*Galaxaura* sp. *2*			+	K
28	*Gelidiella acerosa*	++	++	++	K
29	*Gelidium latifolium*	++	++	++	K
30	*Gelidium micropterum*			+	K
31	*Gigartina clavifera*			++	K
32	*Gigartina insignis*			++	K
33	*Gracilaria coronopifolia*	++	++	++	K
34	*Gracilaria corticata*	+	+	+++	K
35	*Gracilaria salicornia*	+		+	K
36	*Gracilaria* sp.	++		+	K
37	*Gracilaria spinulosa*		+	+	K
38	*Gracilaria verrucosa*			+	K
39	*Halimeda discoidea*			++	K, P
40	*Halimeda opuntala*		++		K
41	*Halymenia* sp.			+	K
42	*Hypnea cervicornis*	+			K
43	*Laurencia obtusa*			+	K
44	*Melanthalia abscissa*	+	++	++	K, P
45	*Microdictyon umbilicatum*			+	K
46	*Pachymenia dichotoma*			+	K, P
47	*Padina australis*	++	++	+++	K, P
48	*Padina boryana*	++	+++	+++	K
49	*Polysiphonia strictissima*	++	++	++	K, P, E
50	*Rhodymenia palmata*	++		++	K, P
51	*Sargassum aquifolium*	++	++	++	K
52	*Sargassum muticum*	++	++	++	K
53	*Sargassum polycystum*	++	++		K
54	*Sargassum* sp.	++	+	++	K
55	*Turbinaria conoides*	++	++		K
56	*Turbinaria murayana*	+	+		K
57	*Ulva flexousa*	+++	+++	+++	K, B, P, CM
58	*Ulva lactuca*	+++	+++	+++	K, B, P, CM

59	*Valoniopsis pachynema*	++	++	+++	K
	Total species	33[a]	27[a]	51[b]	$p < 0.001$
	Diversity	3.9[a]	3.1[b]	4.3[a]	$p < 0.001$
	Relative density (%)	37.6[a]	36.8[a]	41.5[b]	$p < 0.001$
	Covering (%)	33.3	33.6	33.4	n.s.

Post- hoc Mann-Whitney U tests are denote by lowercase letter alphabets (a,b,c), n.s. (no significant). K: coral, B: stone, P: sand, CM: Mollusca shell, E: Epiphyte, +: 1-50 Individuals, ++: 51-100 Individuals, +++: >100 Individuals.

Relationship between marine macroalga and environmental variable

Spatial distribution analysis by multidimensional scaling (MDS) showed the distribution macroalga in Karapyak, Pasir Putih and Madasari areas' directly influenced by temperature, nitrate, and phosphate. In contrast, pH and dissolved oxygen recorded no influence on the distribution of macroalga (Fig. 4A). However, the distribution of the species of macroalgae exhibited a significant relationship with all environmental parameters, such as dissolved oxygen, pH, nitrate, phosphate, temperature and salinity, with the exception of *U. lactuca* and *U. flexuosa* (Fig. 4B).

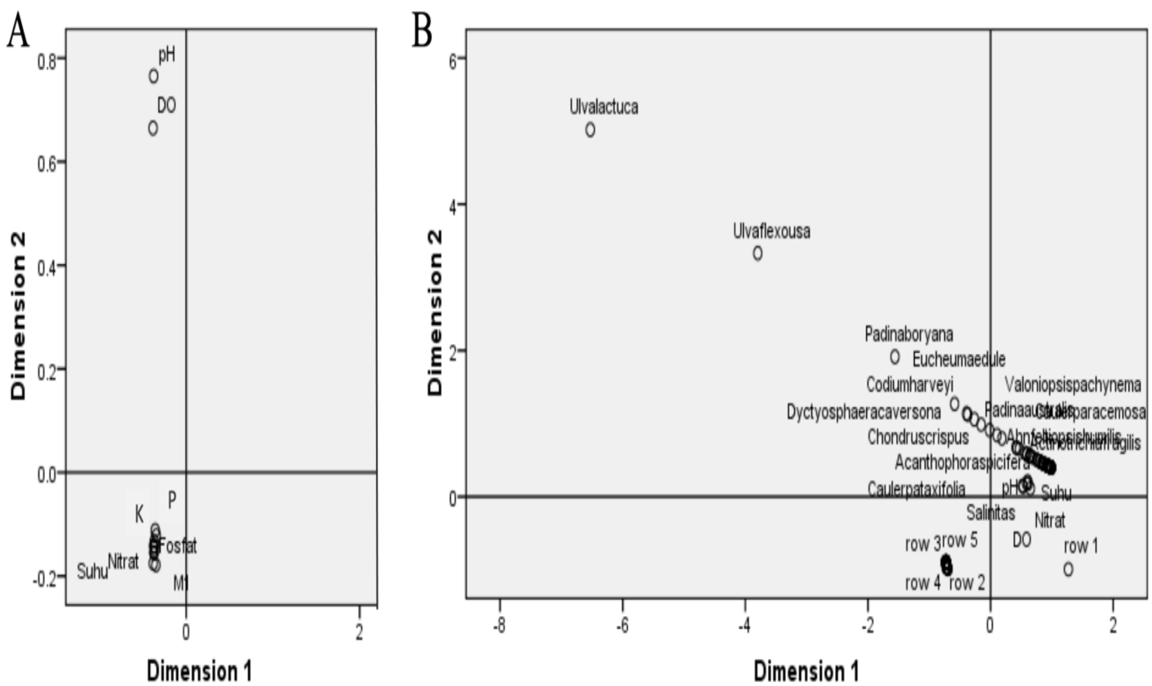

Fig. 4. Relationship between macroalga and environmental variables based on: **A)** Site sampling and **B)** Species of macroalgae

Fig. 3. Macroalgae species found. Chlorophyta: 1) *Boergesenia forbesii*; 2) *Caulerpa lentillifera*; 3) *Caulerpa racemose*; 4) *Caulerpa* sp.; 5) *Caulerpa taxifolia*; 6)

Chaetomorpha antennina; 7) *Chaetemorpha crassa*; 8) *Chaetomorpha* sp.; 9) *Cladophora catenate*; 10) *Codium harveyi*; 11) *Codium reediae*; 12) *Gelidium latifolium*; 13) *Gelidium micropterum*; 14) *Halimeda discoidea*; 15) *Halimeda opuntala*; 16) *Halymenia* sp.; 17) *Microdictyon umbilicatum*; 18) *Ulva flexousa*; 19) *Ulva lactuca*; 20) *Valoniopsis pachynema*. **Ochrophyta:** 1) *Pachymenia dichotoma*; 2) *padina australis*; 3) *Padina boryana*; 4) *Sargassum aquifolium*; 5) *Sargassum muticum*; 6) *Sargassum polycystum*; 7) *Sargassum* sp.; 8) *Turbinaria conoides*; 9) *Turbinaria murayana*. **Rhodophyta:** 1) *Acanthophora spicifera*; 2) *Actinotrichia fragilis*; 3) *Ahnfeltiopsis humilis*; 4) *Callophyllis laciniata*; 5) *Chondracanthus acicularis*; 6) *Chondria macrocarpa*; 7) *Chondrus crispus*; 8) *Corallina vancouveriensis*; 9) *Dyctyosphaera caversona*; 10) *Eucheuma denticulatum*; 11) *Eucheuma edule*; 12) *Echeuma serra*; 13) *Eucheuma* sp.; 14) *Galaxaura rugosa*; 15) *Galaxaura* sp.1; 16) *Galaxaura* sp.2; 17) *Gelidiella acerosa*; 18) *Gigartina clavifera*; 19) *Gigartina insignis*; 20) *Gracilaria corticate*; 21) *Gracilaria coronopifolia*; 22) *Gracilaria salicornia*; 23) *Gracilaria* sp.; 24) *Gracilaria spinulosa*; 25) *Gracilaria verrucosa*; 26) *Hypnea cervicornis*; 27) *Laurencia obtusa*; 28) *Melanthalia abscissa*; 29) *Polysiphonia strictissima*; 30) *Rhodymenia palmata*.

DISCUSSION

The present study revealed that the class of Chlorophyta predominates in all locations. We predict that the greatest species richness and density of Chlorophyta owing to the prevalence of hard substrate (Table 2). Rigid substrates and cliffs can obstruct the current, enabling macroalgae to persist more frequently. **Irwandi *et al*. (2017)** similarly discovered that the class Chlorophyta exhibits a propensity for thriving on hard substrates resistant to currents, comprising 69% of all macroalgae on these surfaces. Moreover, previous studies have indicated that the Chlorophyta class, specifically *Caulerpa* sp., *H. macroloba*, *H. opuntia*, and *C. cupressoides*, dominates on Pudung Island, Riau Islands, with substrates consisting of rock, sand, and coral fragments **(Nurkiama *et al*., 2015)**.

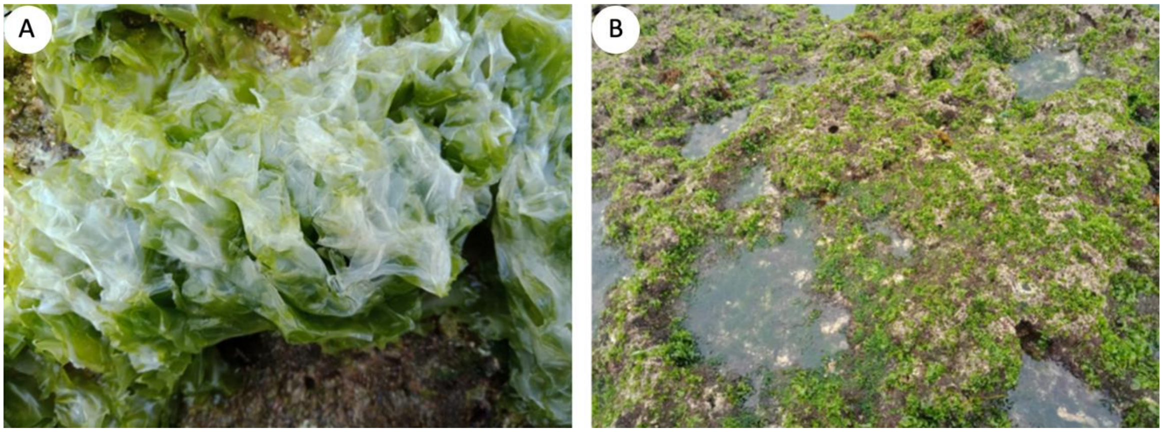

Fig. 5. The temperature shock in the predominant macroalgae, *Ulva lactuca*. **A)** photograph of unhealthy/bleaching macroalgae captured at high temperatures; **B)** macroalgae that regenerates when the temperature declines

Interestingly, the composition and cover of macroalgae individuals decreased during the hottest temperature and increased again during the early rainy seasons, when the temperature was lower (Fig. 5). High temperatures may induce the talus to have a light yellowish or white hue, indicating an unhealthy state. Extreme temperatures can impair enzymes and can disrupt biochemical processes in macroalgae talus, hindering their development **(Arfah & Patty, 2016)**. **Palallo (2013)** stated that high temperature fluctuations can lead to macroalgae mortality, reproductive abnormalities, and stunted development. In contrast, low temperatures inhibit biochemical activity in the talus, and the elevated temperatures impair the enzymes.

We also found that high nutrient levels, fisheries activity, and tourist activities all influence the high macroalgal cover. Macroalgae grow optimally in the tidal zone associated with sediments, a factor that influences their growth. Macroalgae ecosystems are also vulnerable to human activities and heavy ship traffic **(Litaay, 2014)**. Community activities in these waters tend to affect macroalgae diversity **(Langoy *et al*., 2011)**. For instance, the characteristics of sandy substrates, dead shells, and less human activity in Madasari and Karapyak coastal lead to the highest relative macroalgae cover, while Pasir Putih experiences high tourist activity.

Researchers assert that the homogeneous aquatic substrate of corals and sand, which generally sustains a greater variety of algal species compared to regions with sand or mud substrates, is responsible for the increased biodiversity **(Atmadja, 1999)**. The variety of macroalgae species in these waterways indicates that the water conditions remain relatively healthy. Waters characterized by favorable circumstances, elevated production, and stable ecosystems typically have high macroalgae diversity indices. The uniformity stability indicates that the quantities of each macroalgal type are almost equivalent, as evidenced by the low dominance value. The diversity of macroalgae indicates that they may thrive optimally owing to stable aquatic conditions and favorable environmental circumstances. **Connel (1974)** and **Arfah (2016)** asserted that stable aquatic environments maintain a balanced population of all species, but unstable waters often exhibit one or more dominating species.

Environmental factors such as substrate, DO (dissolved oxygen), pH, salinity, nitrate concentration, and phosphate influence the distribution of macroalgae species at each observation station. According to **Littler and Littler (1984)**, the right substrate is one of the key components in supporting macroalgae growth because it provides a surface for macroalgae to attach and develop. The DO factor is also very important because, according to **Connell (1975)**, sufficient dissolved oxygen supports the metabolism and photosynthesis of macroalgae, allowing optimal growth. In addition, appropriate pH and salinity support osmotic balance in macroalgae, as proposed by **Dawes (1998)**, so stable environmental conditions are more likely. According to **Lapointe (1997)**, the concentration of nutrients like nitrates and phosphates also significantly influences the primary productivity of macroalgae, as nitrogen and phosphorus are essential elements. If nitrate and phosphate concentrations are at optimal levels, macroalgae can grow more fertilely and evenly across the observation sites

CONCLUSION

Fifty-nine species of marine macroalgae in Pangandaran Coastal were documented; they were identified as Rhodophyta, Chlorophyta, and Ochrophyta, with a majority of Chlorophyta at each site. Madasari has a greater prevalence and coverage of macroalgae compared to other sites. The alien macroalgae *Ulva lactuca* and *U. flexuosa* dominate the Pangandaran Coastal. The habitat type, temperature, nutrient availability, and tourism traffic are critical factors influencing the distribution and abundance of macroalgae in the intertidal zone of Pangandaran shoreline.

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