Seasonal changes on macroalgae community structure on the South Coast of Yogyakarta, Indonesia

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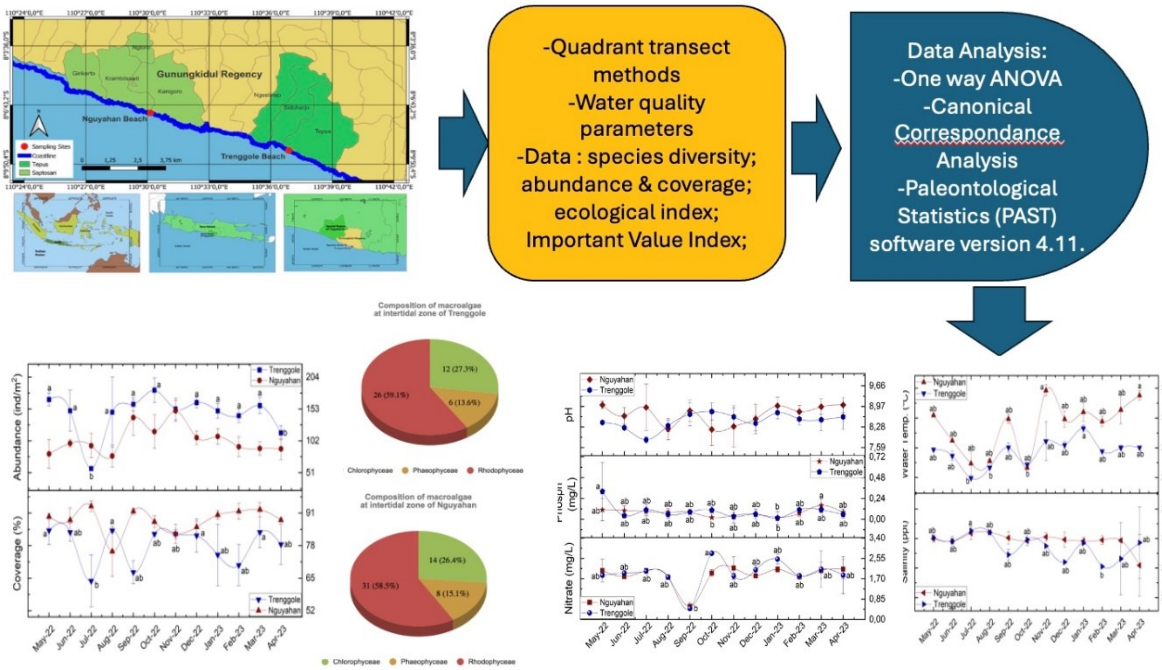
GRAPHICAL ABSTRACT



ABSTRACT

The environmental conditions significantly influence the dynamics of macroalgae community structure and distribution. This study investigates the effects of seasonal changes on the macroalgae community structure and distribution along the South Coast of Yogyakarta. The study was conducted over twelve months in two intertidal zones, Trenggole and Nguyahan, using the transect method with plots. Monthly rainfall data and water quality parameters were collected as supporting data. The data were analyzed using ANOVA, and the relationship between water quality and community structure was determined using Canonical Component Analysis (CCA). The results indicated a moderate diversity index (1.05-2.71) and a low dominance index (0.02-0.37). The average abundance at Trenggole (145.74 ind. m^{-2}) was higher than at Nguyahan (103.72 ind. m^{-2}). The percentage coverage at Trenggole (67.71%) was lower than at Nguyahan (88.14%). Seaweed abundance and percentage cover were relatively higher during the wet season than in the dry season. The diversity of macroalgae tended to be higher in the rainy season than in the dry season. Seasonal changes significantly affected macroalgae abundance and coverage at Trenggole, whereas at Nguyahan, the distance from the shoreline showed significant differences. Temperature, salinity, and pH were the most influential factors affecting the macroalgae community structure. Additionally, coastal characteristics, distance from the shoreline, and substrate types played a pivotal role in shaping the macroalgae community structure. Rhodophyceae species were the most dominant, followed by Chlorophyceae and Phaeophyceae, on the South Coast of Yogyakarta.

Keywords: seasonal changes, coverage, density, diversity, shoreline, Rhodophyceae

1. Introduction

Macroalgae are integral components of intertidal ecosystems, alongside seagrass and coral reef ecosystems. They play a pivotal role in providing essential ecosystem services, such as serving as habitats for various biota, functioning as primary producers in food webs, participating in nutrient cycling, and contributing to carbon sequestration. According to Jung *et al*. (2019), areas with high macroalgae diversity support greater zoobenthic and fish diversity. Additionally, tropical macroalgae contribute to the blue carbon ecosystem (Kwan *et al*., 2022). The diversity of macroalgae holds significant potential for human and animal consumption, the production of seaweed-based products, and the provision of ecological services (Radulovich *et al*., 2015; Stiger-Pouvreau and Zubia, 2020; Olsson *et al*., 2020).

Seasonal changes, environmental parameters, shoreline characteristics, and substrate types can all influence the distribution and community structure of macroalgae, subsequently affecting their ecological functions within ecosystems. The South Coast of Yogyakarta, characterized by a substrate of dead coral substrate and white sand, provides a suitable habitat for various macroalgae species. The type of substrate has been reported to affect benthic macroalgae communities (Tsiamis *et al*., 2020). In this region, the macroalgae ecosystem continues to thrive naturally, with distribution, abundance, species composition, and ecological indices influenced by both natural and anthropogenic factors, as well as biotic and abiotic factors.

Several studies have shown that the dynamics of biomass, population, and productivity of macroalgae are influenced by variations in climate and season, temperature, rainfall, and sunlight (Sanz *et al*., 2023; Jansen *et al*., 2022). Environmental stress levels, including those induced by tourism activities, can also affect the growth and population of macroalgae (Gaspar *et al*., 2017; Mayakun and Prathep, 2005). Furthermore, competition among species can impact macroalgae abundance (Yoshida and Shimabukuro, 2017), and anthropogenic factors, such as the introduction of species into intertidal areas, can alter macroalgae composition and diversity (Raffo *et al*., 2014; Mantri *et al*., 2020). Baseline data on the community structure and abundance of macroalgae in intertidal zones are essential for monitoring the impacts of climate change (Piñeiro-Corbeira *et al*. 2023). Several studies stated that the diversity of macroalgae on the south coast of Gunungkidul is categorized as having low to moderate diversity (Riswanti and Santosa 2017; Sodiq and Arisandi 2020). However, no research has been conducted on the seasonal changes in macroalgae community structure on the South Coast of Yogyakarta. Therefore, this study is necessary to establish a database that will support coastal area management and ensure the sustainability of the ecological and economic functions of macroalgae resources in this region.

2. Materials and methods

2.1. Study location and time of research

The study was conducted on the South Coast of Yogyakarta, Indonesia, focusing on two intertidal zones: Trenggole and Nguyahan. These locations were selected as they are representative of the coastal conditions in the southern region of Yogyakarta, as shown in Figure 1. The research was conducted from May 2022 until April 2023.

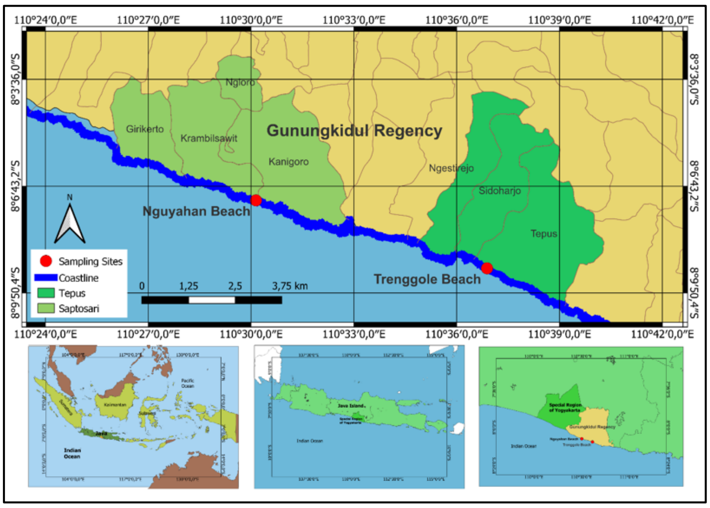


Figure 1. Study sites on the South Coast of Yogyakarta, Indonesia

2.2. Methods

Sampling of macroalgae

The ecological index of seaweed in the intertidal zone of Trenggole and Nguyahan was estimated through several steps, including location determination using the quadrant transect method with 1 × 1 m plots divided into 16 grids. Data were collected at 9 points, consisting of 3 stations, with each station containing 3 substation points. Line transects were drawn at 10 m, 20 m, and 30 m from the shoreline for data collection.

Abundance and coverage of macroalgae

Abundance (ind. m^{-2}) is used to calculate the density of individuals or colonies in an ecosystem. Abundance was calculated using the formula by English *et al.* (1997):

$$Abundance = \frac{Number\ of\ individual\ or\ colonies\ \ (n)}{total\ plot\ area\ (A)}$$

Coverage of macroalgae in this study was calculated using the approach by English *et al.* (1997):

$$Coverage = \frac{\text{Number of grids filled with macroalgae}}{\text{Total number of grids in the observation plots}} \times 100\%$$

The total number of observation fields per point was 16, corresponding to a plot size of 1 x 1 m divided into 16 grids.

Determining the species of macroalgae

Macroalgae samples from each plot were placed into labeled plastic bags for identification and documentation. The species were identified morphologically by Guiry and Guiry (2023) on the Algaebase website (www.algaebase.org).

Shannon-Wiener (H') diversity index

The species diversity index of macroalgae was calculated using the Shannon-Wiener diversity index formula (Krebs, 1983) :

$$H' = -\sum_{i=1}^{n} Pi \ \ln Pi$$

where H' is the Shannon-Wiener diversity index, Pi is the proportion of individuals of species i (n_i/N), n_i is the number of individuals of a species i, N is the total number of individuals, and s is the number of species per location.

The diversity index values are interpreted as follows (Krebs, 1983):

- $H' < 1$: low species diversity
- $1 \leq H' \leq 3$: moderate species diversity
- $H' \geq 3$: high species diversity

Evenness Index (E)

The evenness index (E) indicates uniformity and abundance distribution among species. The formula by Krebs (1983) is:

$$\mathrm{E} = \frac{\mathrm{H}'}{\mathrm{H\ max}}$$

where E is the evenness index, *H'* is the diversity index; *Hmax* is the maximum uniformity (Ln S), and *S* is the number of species found.

The evenness index values are interpreted as follows (Krebs, 1983):

- $0 < E \leq 0.4$: the community is in a depressed state
- $0.4 < E \leq 0.6$: the community is in an unstable state
- $0.6 < E \leq 1$: the community is in a stable condition

Dominance Index (C)

The dominance index was calculated using the Simpson dominance index formula by Odum (1993):

$$C = \sum_{i-1}^{s} (Pi)^2 \tag{5}$$

where C is the dominance index, Pi is the proportion of individuals of species i (ni/N), n_i is the number of species i, N is the total number of individuals, and s is the number of species.

The dominance index values are interpreted as follows (Odum, 1993):

- $0 < C \leq 0.50$: low dominance
- $0 < C \leq 0.50$: medium dominance
- $0.75 < C \leq 100$: high dominance

Important Value Index (IVI) of macroalgae

The Important Value Index (IVI) is used to estimate and calculate the role of seaweed species in a community structure. The IVI was calculated using the formula by Brower *et al*. (1998):

$$IVI = Relative\ density + relative\ frequency + relative\ coverage \tag{6}$$

$$Relative\ density = \frac{Density\ of\ a\ particular\ species\ (ni)}{Total\ density\ of\ all\ species\ (\Sigma n)}\ x\ 100\%$$

$$Relative\ frequency = \frac{Frequency\ \ of\ a\ particular\ species\ (ni)}{Total\ frequency\ of\ all\ species\ (\Sigma F)}\ x\ 100\%$$

$$Relative\ coverage = \frac{Area\ of\ cover\ of\ a\ particular\ species\ (Ci)}{Total\ cover\ area\ of\ all\ species\ (\Sigma Ci)}\ x\ 100\%$$

Water quality parameters

Environmental parameters, including water temperature, salinity, and pH, were measured using a water quality checker (Hanna Instruments HI98194). Nitrate and phosphate content were measured using a spectrophotometer (APHA 2017).

2.3. Data Analysis

Data from the monthly calculations of frequency, density, coverage, and important value indices were processed using Microsoft Excel and subsequently analyzed with one-way ANOVA. The purpose of the significant difference analysis was to determine the monthly ecological index differences of macroalgae between Trenggole and Nguyahan Beaches. Additionally, the results of water quality measurements were analyzed to assess significant differences in relation to monthly changes in ecological and environmental indices. Canonical Correspondence Analysis (CCA) was employed to explore the multivariable relationship between water quality and species' ecological data. This analysis was conducted using Paleontological Statistics (PAST) software version 4.11 (Hammer, 2022).

3. Results and Discussion

3.1. Species composition of macroalgae

During the research period, 44 species of macroalgae were identified at Trenggole, while 53 species were found at Nguyahan. The composition of macroalgae communities was dominated by Rhodophyceae (>50%), followed by Chlorophyceae (>25%), and the remainder being Phaeophyceae (Figure 2). These findings align with those from other countries, where species from Rhodophyceae are more abundant than those from Phaeophyceae and Chlorophyceae (Oh *et al*., 2016; Kokabi *et al*., 2016; Dangar *et al*., 2022). Prather (2005) also noted that tropical regions typically exhibit a higher diversity of red seaweeds than temperate regions. However, Chlorophyceae and Phaeophyceae exhibited higher abundance and coverage when compared to Rhodophyceae, mainly in the mid and high-intertidal zones, whereas Rhodophyceae were predominantly found in low-intertidal areas.

The species of macroalgae found at both sites during the study period are listed in Table 1 and illustrated in Figure 2 and 3.

Table 1. The species of macroalgae found on study sites

Species of macroalgae on Trenggole	Species of macroalgae on Nguyahan
Chlorophyceae: 1. Boergesenia forbesii 2. *Bryopsis Rhizophora* M.Howe 1914 3. *Caulerpa racemose* 4. *Chaetomorpha antenna* (Bory) Kutzing 5. *Chaetomorpha crassa* 6. *Chaetomorpha ligustica* 7. *Chaetomorpha ligustica* 8. *Chaetomorpha viellardii* 9. *Ulva sp.* 10. *Ulva fasciata* 11. *Ulva fasciata* 12. *Ulva rigida* **Phaephyceae:** *1.* *Padina australis* 2. *Padina boryana* 3. *Padina boryana* 4. *Sargassum aquifolium* (Turner) C. Agardh 1820 5. *Sargassum polycystum C. Agardh* 6. *Sargassum yinggehaiense Tseng & Lu 2002* **Rhodophyceae:** 1. *Acanthophora spicifera* 2. *Acrocystis nana* Zanardini 3. *Amphiroa fragilisima* 4. *Callophyllis crispata* Okamura 5. *Callophyllis crispata* Okamura 6. *Ceramium japonicum* Okamura 7. *Chondrus crispus* 8. *Gelidiella acerosa* 9. *Gelidiella fanii* 10. *Gelidium indonesianum* 11. *Gigartina polycarpa* 12. *Gracilaria arcuate* 13. *Gracilaria corticata* J. Agardh 14. *Gracilaria edulis* 15. *Gracilaria multipartite* 16. *Gracilaria Salicornia* 17. *Gracilaria verrucose* 18. *Gracilaria vieillardii* 19. *Halymenia maculate* 20. *Halymenia floresi* 21. *Hypnea asiatica* 22. *Laurencia brongniartii* 23. *Laurencia intermedia* 24. *Laurencia papillosa* 25. *Mastocarpus papilatus* 26. *Pterocladiella sp*	**Chlorophyceae:** 1. *Boergesenia forbesii* 2. *Bryopsis Rhizophora* 3. *Caulerpa racemose* 4. *Chaetomorpha antenna* 5. *Chaetomorpha ligustica* 6. *Chaetomorpha linum* 7. *Chaetomorpha viellardii* 8. *Cladophoriopsis javanica* 9. *Enteromorpha compressa* 10. *Enteromorpha flexuosa* 11. *Ulva meridionalis* 12. *Ulva fasciata* 13. *Ulva lactuca* 14. *Ulva sp.* **Phaeophyceae:** 1. *Dictyota ciliolate* 2. *Dictyota sp.* 3. *Padina australis* 4. *Padina minor* 5. *Sargassum aquifolium* 6. *Sargassum polycystum* 7. *Sargassum yinggehaiense* 8. *Turbinaria sp.* **Rhodophyceae:** 1. *Acanthophora spicifera* 2. *Acrocystis nana* 3. *Ahnfeltiopsis fastagiata* 4. *Amphiroa fragilisima* 5. *Callophyllis crispate* 6. *Ceramium sp.* 7. *Chondrophycus sp.* 8. *Chondrus sp* 9. *Gelidiella acerosa* 10. *Gelidiella fanii* 11. *Gelisium pussilum* 12. *Pterocladiella sp.* 13. *Gelidium indonesianum* 14. *Gelidiopsis sp.* 15. *Gelidium japonicum* 16. *Gigartina polycarpa* 17. *Gracilaria arcuate* 18. *Gracilaria corticate* 19. *Gracilaria edulis* 20. *Gracilaria multipartite* 21. *Gracilaria Salicornia* 22. *Gracilaria verrucosa*

	23. *Gracilaria vieillardii* 24. *Halymenia maculate* 25. *Hypnea sp.* 26. *Hypnea nidulans* 27. *Hypnea pannosa* 28. *Laurencia brongniartii* 29. *Laurencia intermedia* 30. *Laurencia obtuse* 31. *Laurencia papillosa* 32. *Palisada concreta* 33. *Rhodymenia palmata*

Description: Classification reference: Algaebase (2023)

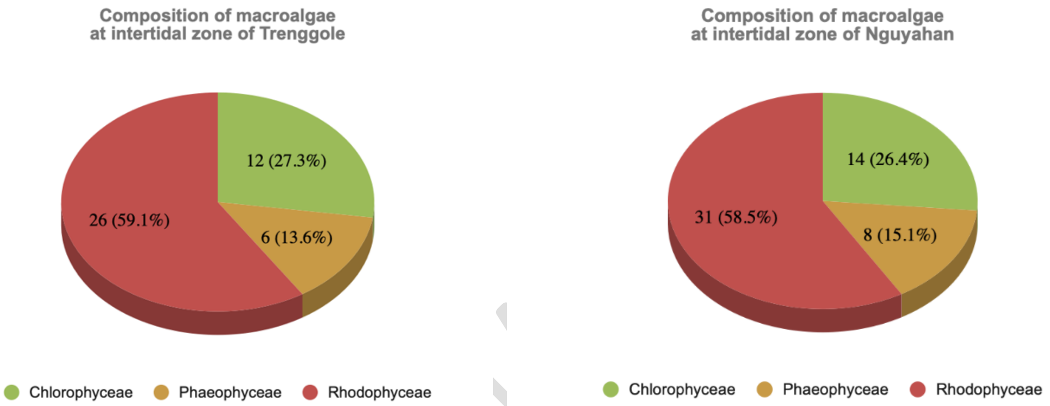
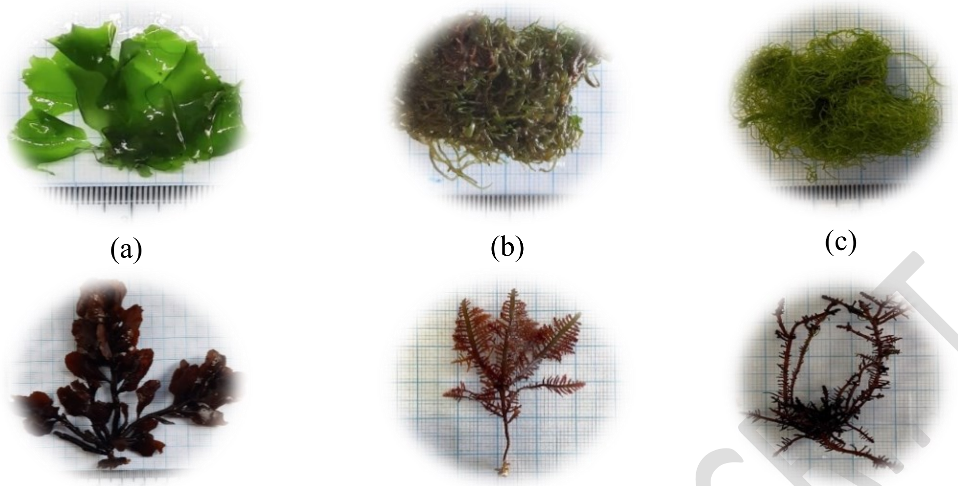


Figure 2. Macroalgae composition in the South Coast of Yogyakarta

Species such as *Ulva lactuca*, *Chaetomorpha linum*, *Chaetomorpha viellardii*, *Sargassum polycystum*, *Pterocladiella* sp., and *Gelidiella acerossa* were the most common across both study sites (Figure 3). This is likely due to the relatively similar environmental conditions at both beaches, despite slight differences in beach characteristics. The fertile conditions at both locations allow species with a broad tolerance to environmental changes to grow optimally and abundantly (Hoang *et al*., 2016; Zou *et al*., 2017). *Ulva* sp. and *Sargassum* sp. are widespread and occur throughout the seasons in the intertidal areas of Argentina Patagonia (Raffo *et al*., 2014), Korea (Oh *et al*., 2016; Ahn *et al*., 2017), Thailand (Mayakun and Prathep, 2005), and the northern coast of Persian Gulf (Dadolahi-Sohrab *et al*., 2012). This widespread occurrence is likely due to the high tolerance and adaptability of Ulva and Sargassum to environmental changes, which contributes to their extensive distribution. Ulva is particularly adaptable to environmental changes and can efficiently absorb nutrients, resulting in a high growth rate and productivity (Adharini *et al*., 2021; Toth *et al*., 2020). Meanwhile, Sargassum demonstrates resilience in the environment due to its high tolerance to epiphytic disturbances, fouling, and threats from herbivorous fish (Radulovich *et al*., 2015).



(a) (b) (c)

(d) (e) (f)

Figure 3. The most common species of macroalgae found at the study sites, (a) *Ulva lactuca*, (b) *Chaetomorpha linum*, (c) *Chaetomorpha viellardii*, (d) *Sargassum polycystum*, (e) *Pterocladiella* sp.; (f) *Gelidiella acerossa*

3.2. Dynamics of Coverage and abundance of macroalgae

The abundance and coverage of macroalgae at the study sites showed seasonal variation. However, macroalgae abundance at Trenggole was higher than at Nguyahan, while macroalgae coverage at Nguyahan tended to be greater than at Trenggole (Figure 4).

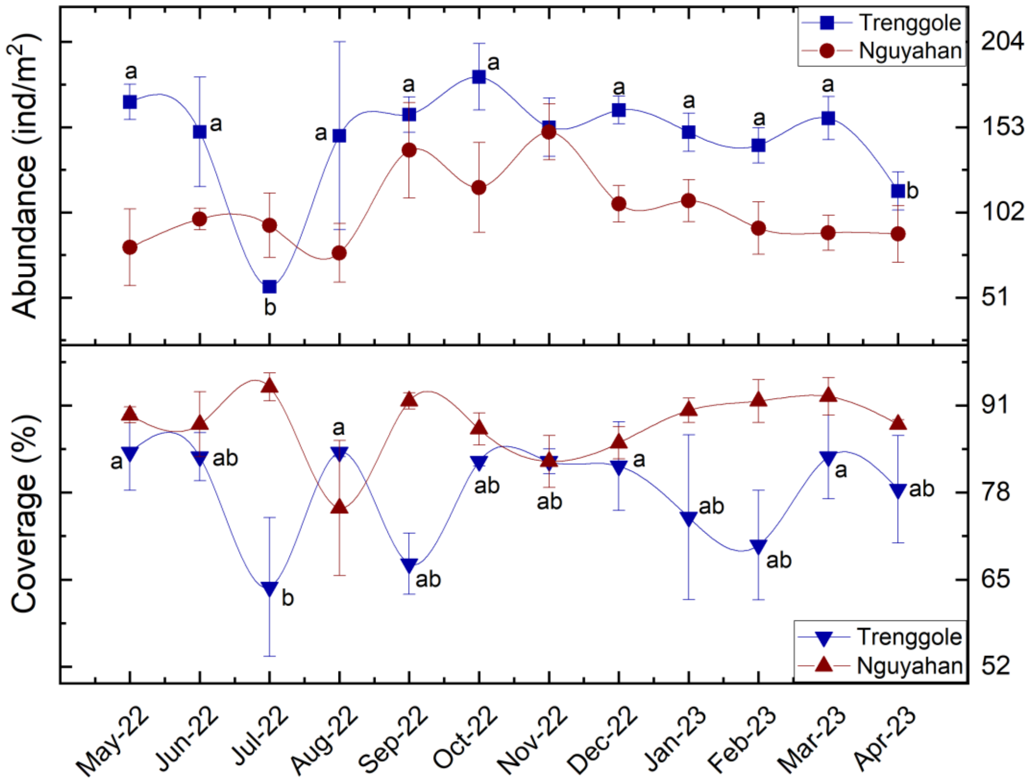


Figure 4. Seasonal changes of macroalgae coverage and abundance in Treggole (TRL) and Nguyahan (NGU)

The abundance and coverage of macroalgae at Trenggole underwent significant seasonal changes. Abundance showed considerable fluctuations, with an average of 145.74 ind. m^{-2}, peaking in October 2022. Similarly, the coverage of the macroalgae community in this location fluctuated throughout the study, reaching its highest value of 67.71% in August 2022. Spatially, the abundance and coverage of seaweed communities at different observation distances showed no significant differences. The highest abundance of seaweed was recorded 20 meters from the shoreline, with an average of 180.42 ind. m^{-2}, while the highest coverage was observed 10 meters from the shoreline, with an average of 80.90% (Figure 5).

In contrast, the abundance and coverage of macroalgae communities at Nguyahan showed insignificant temporal fluctuations but exhibited significant differences based on distance from the shoreline. Seaweed abundance and coverage were relatively higher during the wet season compared to the dry season. The average abundance at Nguyahan was 103.72 ind. m^{-2}, with the highest abundance recorded in November 2022. Meanwhile, macroalgae coverage reached an average of 88.14%, peaking in July

2022. Prather (2005) noted that factors such as season, wave exposure, shore elevation, and species interactions influence seaweed percentage cover. Seasonal macroalgae growth also depends on their ability to tolerate drought and varying environmental conditions (Adharini *et al*., 2016).

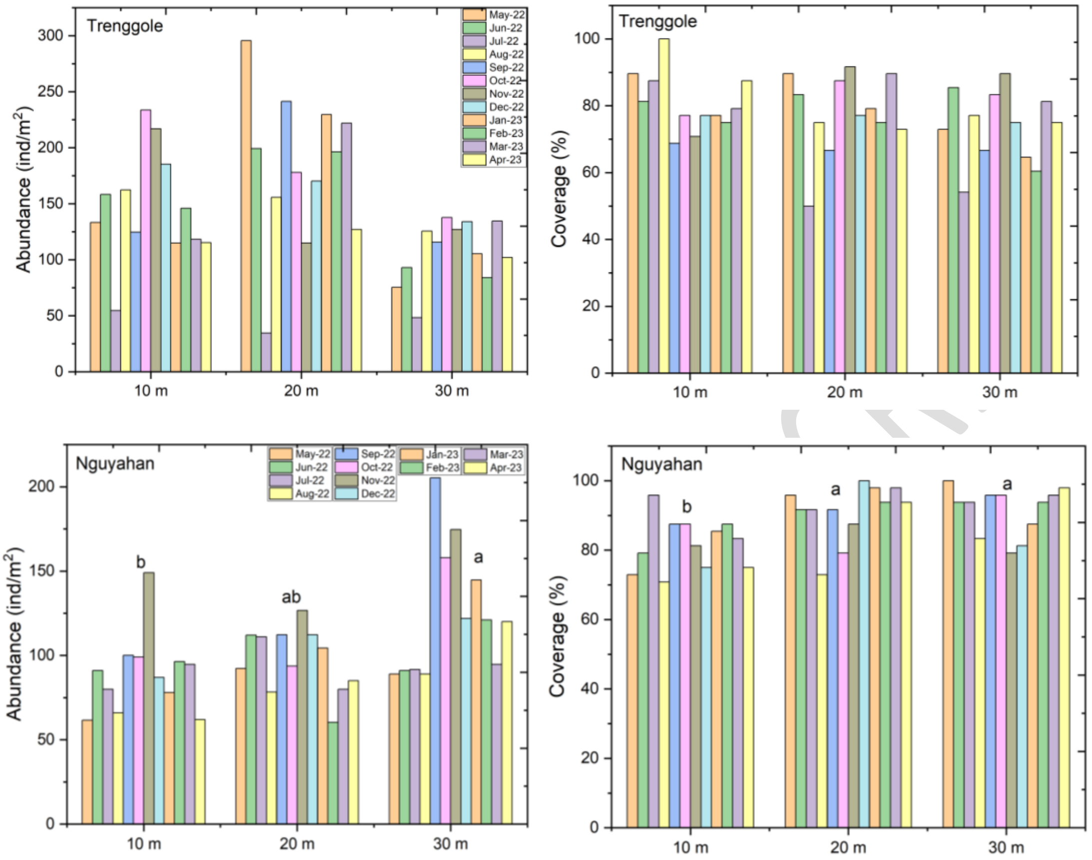


Figure 5. The dynamics of abundance and coverage of macroalga by temporal and distance from the shoreline.

The highest abundance and coverage of macroalgae were found 30 meters from the shoreline (Figure 5). These findings are supported by Raffo *et al.* (2014), who stated that both season and distance or depth from the intertidal zone strongly influence the species composition of macroalgae. In general, the lower the intertidal zone, the greater the species diversity compared to the higher intertidal zone (Kokabi *et al*., 2016). In both Trenggole and Nguyahan, Chlorophyceae were found in the shallowest waters of the coastal intertidal zone, at distances of approximately 10 meters from the shoreline. The presence of Chlorophyta species in these shallow waters may be attributed to the sand substrate and coral rubble along the intertidal zone (Handayani *et al*., 2023). Phaeophyceae, on the other hand, were observed growing firmly attached to coral or rocky substrates at distances of around 20 meters from the shoreline. Xu *et al*. (2016) reported that attachment strength is generally greater in shallow waters than in deeper areas. In this study, many Rhodophyceae were found growing submerged in deeper basins (lagoons) approximately 30 meters from the shoreline. Rhodophyceae can thrive in deeper waters due to their auxiliary photosynthetic pigments, which enable them to absorb sunlight for photosynthesis. This contrasts slightly with conditions on the tropical west coast of Africa, where Phaeophyceae are more commonly found in the upper intertidal zone, Rhodophyceae in the middle intertidal, and Chlorophyceae are less frequently encountered (Piñeiro-Corbeira *et al*., 2023).

3.3. Important Value Index (IVI)

The important value index (IVI) of macroalgae in the intertidal zones of Trenggole and Nguyahan exhibited dynamic variation throughout the year (Table 2).

Table 2. Important Value Index (IVI) of macroalgae in the intertidal zone of Trenggole and Nguyahan

Species of macroalgae	Sites	Relative frequency (%)	Relative density (%)	Relative coverage (%)	IVI (%)
Ulva lactuca	Trenggole	17,98	35,65	37,42	91,04
	Nguyahan	7,78	10,52	10,52	28,81
C. linum	Trenggole	8,90	10,95	9,69	29,54
C. viellardii	Nguyahan	11,14	24,93	24,93	60,99
S. polycystum	Trenggole	10,70	12,45	14,15	37,30
	Nguyahan	1,31	0,35	0,35	2,01
Pterocladiella sp.	Trenggole	5,90	8,21	9,12	23,23
	Nguyahan	3,25	7,88	7,88	19,01
Acrocytis nana	Trenggole	5,62	6,17	6,17	17,96
G. acerosa	Nguyahan	8,26	9,13	9,13	26,52
Others	Trenggole	50,90	26,57	23,45	100,93
	Nguyahan	68,28	47,19	47,19	162,65

The macroalgae species that played the most significant role in the seaweed community at Trenggole during the study was *Ulva lactuca*, followed by *Sargassum polycystum*, *Acrocytis nana*, and *Pterocladiella* sp. In contrast, at Nguyahan Beach, *Chaetomorpha Viellardii* had the most significant role, followed by *Ulva lactuca*, *Pterocladiella* sp., and *Gelidiella acerosa*. According to Khudin *et al.* (2019), the higher a species's IVI, the greater its role in the community.

Diversity, evenness, and dominance index of macroalgae

Seasonal changes in macroalgae diversity at the study site indicated moderate levels of diversity (Figure 6) and low levels of dominance (Figure 8), while the evenness index showed fluctuations throughout the study period (Figure 7).

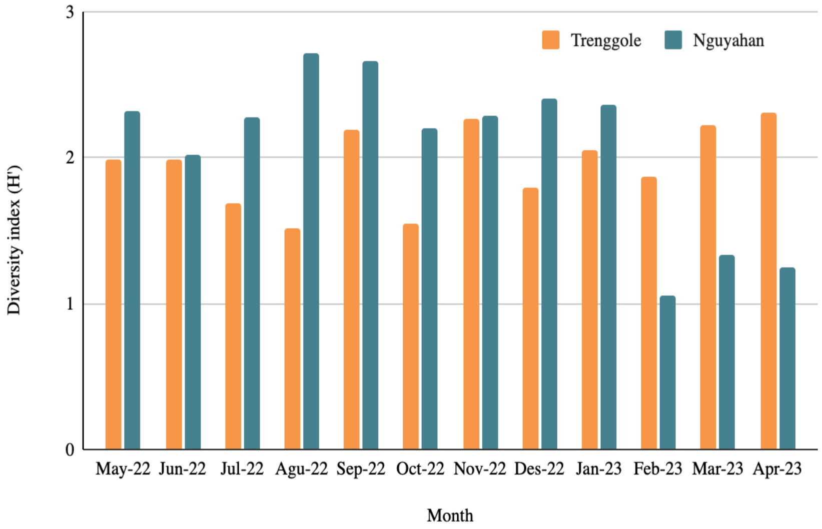


Figure 6. Seasonal changes of macroalgae diversity index (H') on study sites

The macroalgae diversity index in Trenggole averaged 1.95, while the diversity index (H) in Nguyahan averaged 2.07, indicating moderate diversity in both intertidal zones. However, the diversity index in Nguyahan was slightly higher than in Trenggole. This could be due to Nguyahan having more basins, a longer and more exposed coastline, and a stable intertidal zone with abundant dead coral substrate, making it a suitable habitat for a variety of macroalgae species. Intertidal zones with numerous deep basins provide ideal habitats for red algae species that require greater depth, while a long shoreline minimizes intraspecific and interspecific competition for substrate attachment. Nguyahan, with its exposed rocky coastline and dead coral substrate, offers a favorable environment for various macroalgae, as some species require a rigid substrate to anchor their holdfasts. Wells *et al*. (2007) noted that beaches with rock ridge substrates have the highest macroalgae diversity, followed by rock boulders, steep rocks, pebbles, and gravel.

Erniati *et al*. (2023) highlighted that seaweed community diversity is influenced by internal factors such as competition for space and nutrients, as well as external factors like environmental pollution, exploitation of fishery resources, and low biological productivity. Seaweed diversity was higher during the rainy season (September 2022 – January 2023) than in the dry season (Figure 6). In contrast, Prather (2005) reported that in Phuket, Thailand, seaweed diversity was higher during the dry season, when wave activity was calmer.

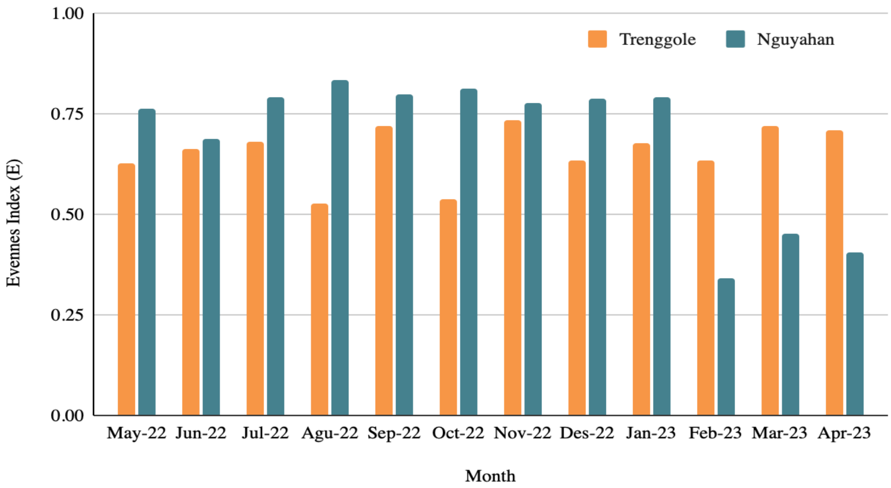


Figure 7. Seasonal changes of macroalgae Evenness index (E) in the study site

The evenness index (E) of macroalgae at Nguyahan averaged 0.69, indicating stable macroalgae conditions from May 2022 to January 2023. Meanwhile, the evenness index at Trenggole averaged 0.65 (Figure 7). However, in August and October 2022, macroalgae in Trenggole exhibited unstable conditions in terms of uniformity. A lower evenness index suggests that the community experienced dominance by certain species that were more resilient to environmental changes.

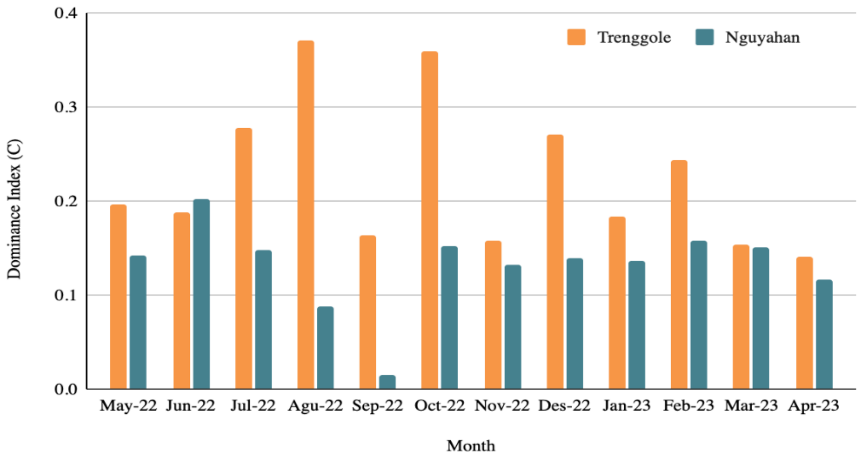
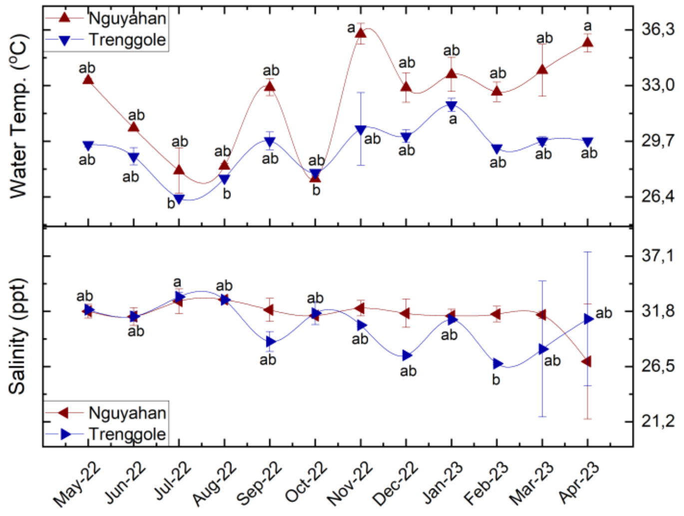


Figure 8. Seasonal changes of macroalgae dominance index (C) in the study site

The average dominance index in Trenggole was 0.23, while in Nguyahan, it averaged 0.13, indicating low macroalgae dominance across the study sites (Figure 8). The dominance index in Trenggole was higher due to its lower diversity and evenness compared to Nguyahan. In general, the higher the diversity and evenness indices, the lower the dominance index, which in turn supports the stability and resilience of an ecosystem against disturbances.

3.4. Seasonal Changes in Water Quality Parameters

The spatio-temporal variations in water quality parameters at the study site are presented in Figure 9.



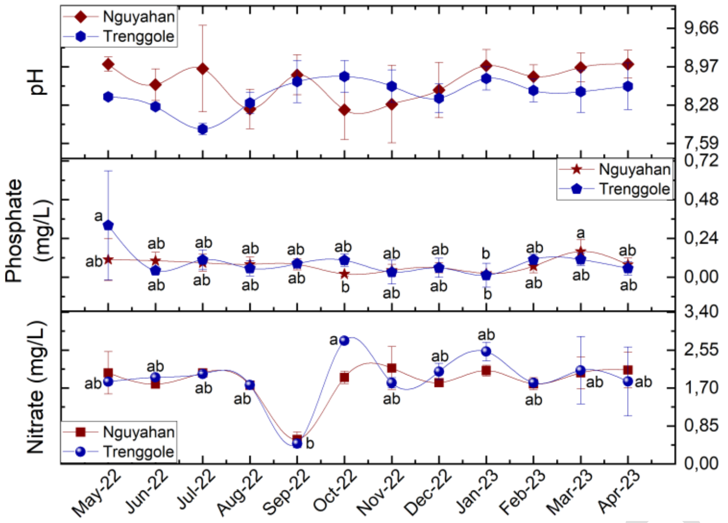


Figure 9. Seasonal changes in precipitation and water quality parameters in the study site

Daily rainfall in the southern coastal area of Yogyakarta fluctuated between 0.10 and 27.60 mm, with an average rainfall of 10.10 mm. According to Sanz *et al*. (2023), months with high solar radiation support macroalgae growth and influence biochemical compounds and phycobiliprotein levels. The monthly variations in water temperature at both sites showed dynamic conditions, though the temperature range remained suitable for sustaining various macroalgae species. In this study, the abundance and coverage of macroalgae is relatively high in the transition of the rainy season to the beginning of the dry season. Tropical seaweed generally grows optimally at the temperature range between 25 and 35°C (Widyartini *et al.*, 2017). Temperature directly influences enzymatic reactions involved in photosynthesis, with higher temperatures increasing the rate of photosynthesis. Water temperature is a significant factor in seaweed growth, as it affects dissolved oxygen levels and photosynthetic processes (Haas *et al.*, 2014).Salinity at both study sites showed significant fluctuations, but it remained within a range that supports macroalgae life. Optimal seaweed growth generally occurs in salinities between 28 and 34 ppt (Madina *et al.*, 2022). Water salinity affects the osmoregulation process, which is essential for the growth and development of macroalgae. Seawater pH in the intertidal zone of Nguyahan ranged from 8.20 to 9.02, while at Trenggole, it ranged from 7.85 to 8.80. These pH levels are conducive to the optimal growth of various seaweed species. The degree of acidity (pH) is linked to hydrogen ion activity in the water. In alkaline conditions, a higher percentage of un-ionized ammonia is present, which can enhance the rate of photosynthesis in macroalgae.

Nitrate levels at Nguyahan fluctuated stably, with an average of 1.8 mg/L, while Trenggole showed more significant fluctuations, averaging 1.91 mg/L. According to Boyd (1982), the tolerance limit for nitrate in algae growth is between 0.1 and 3 ppm, indicating that nitrate levels at both sites are within the optimal range to support seaweed growth. Phosphate levels averaged 0.08 mg/L at Nguyahan and 0.09 mg/L at Trenggole, both of which are sufficient for promoting seaweed growth. Nutrients such as nitrate and phosphate influence the fatty acid, protein, and phenolic content of macroalgae (Toth *et al*., 2020).

3.5. Relationship of Water Quality to Important Value Index (IVI) of macroalgae

Water quality measurements on the South Coast of Yogyakarta during the study revealed dynamic changes that significantly impacted the community structure of macroalgae (Figures 10 and 11).

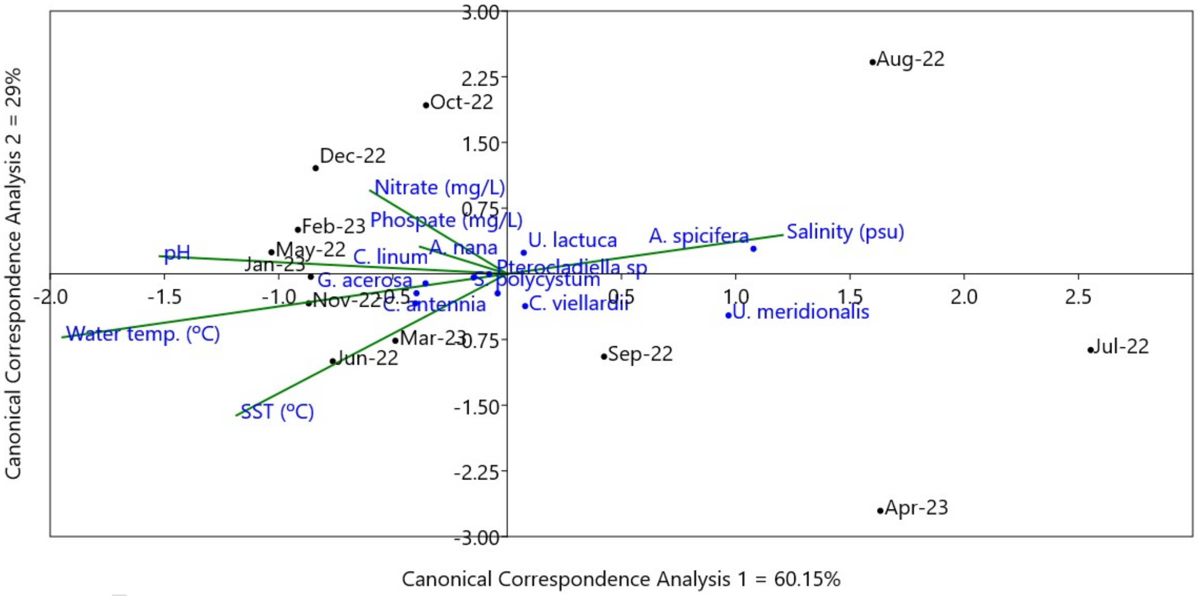


Figure 10. The effect of water quality on macroalgae IVI based on Correspondence Components Analysis (CCA) at Trenggole

The important value index (IVI) of seaweed in the intertidal zone of Trenggole is represented by the ten species with the most critical roles, including *Chaetomorpha* spp., *Ulva* spp., *Sargassum* spp., *Acrocytis nana*, *Gracilaria* spp., *Laurencia* spp., and *Pterocladiella* sp. According to the triplot graph, water temperature had the most substantial influence on the IVI of macroalgae in Trenggole during the study period, while phosphate had the weakest influence. This is likely due to fluctuating water temperatures, particularly between November 2022 and January 2023. Temperature is known to significantly affect macroalgae's survival, morphological forms, and reproductive cycles (Adharini *et al.*, 2016). Additionally, temperature, irradiance, and photoperiod influence the growth rate of macroalgae thalli (Toth et al., 2020; Adharini and Kim, 2016).

Meanwhile, phosphate levels remained relatively stable in tropical areas, unlike in temperate regions where increased nutrients often result in higher macroalgae abundance (Kokabi *et al*., 2016). The cumulative eigenvalue represented by axes 1 and 2 in the triplot is 89.15%, indicating that 89.15% of the variation in the IVI of the seaweed community in Trenggole is explained by the six water quality parameters.

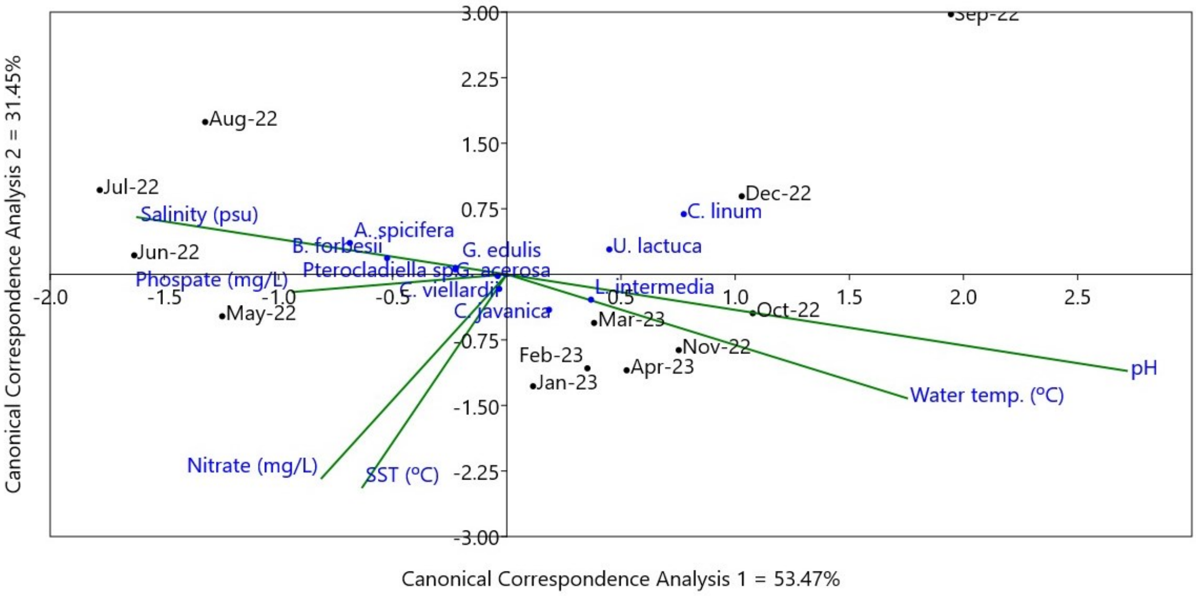


Figure 11. The effect of water quality on macroalgae IVI based on Correspondence Components Analysis (CCA) at Nguyahan

The macroalgae species with the most critical roles (highest IVI) at Nguyahan are represented by the ten most dominant species, including *Boergensenia forbesii*, *Chaetomorpha* spp., *Ulva* spp., *Acanthophora* sp., *Gracillaria* spp., *Laurencia* spp., and *Pterocladiella* sp. According to the triplot graph, pH is the parameter that strongly influences the important value index of seaweed in Nguyahan during the study, followed by temperature and salinity. In contrast, phosphate has the weakest influence, likely due to its relatively stable levels compared to the more fluctuating pH changes, particularly from

July 2022 to October 2022. Similar results were observed on the eastern coast of Qeshm Island, Iran, where pH significantly affected macroalgae communities (Kokabi *et al*., 2016). Seasonal changes contribute to pH fluctuations, with lower pH levels correlating with reduced benthic community diversity (Baggini *et al.*, 2014). The eigenvalue of the triplot, represented by axes 1 and 2, is 84.92. This indicates that 84.92% of the variation in the IVI of the macroalgae community at Nguyahan Beach can be explained by the six water quality parameters.

4. Conclusion

Seasonal changes and environmental conditions significantly influence the community structure of macroalgae. On the South Coast of Yogyakarta, Indonesia, the abundance and diversity of macroalgae increase during the transition of rainy season until beginning of the dry season. The areas 20 to 30 meters from the shoreline exhibit the highest abundance and coverage of macroalgae. Among the environmental factors, seawater temperature, pH, and salinity have the most substantial impact on macroalgae community structure. Rhodophyceae species constitute the largest component of the macroalgae communities in this region.

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References

Adharini R.I. and Kim H.G. (2016), Growth of gametophytes and sporophytes of *Grateloupia subpectinata* (Rhodophyta) in culture, *Ocean Science Journal*, **51(3)**, 477-483. 10.1007/s12601-016-0043-7

Adharini R.I., Kim J., Kandasamy G. and Kim H.G. (2016), Seasonal growth and reproductive status of *Grateloupia subpectinata* (Rhodophyta) on the east coast of Korea, *Fisheries and Aquatic Science*, **19**:13. DOI 10.1186/s41240-016-0013-0.

Adharini R.I., Murwantoko, Probosunu N., Setiawan R.Y. and Satriyo T.B. (2021). The Effectiveness of seaweeds as biofilter for reducing wastewater nutrient and preventing water pollution from hybrid grouper culture. *Jurnal Ilmiah Perikanan dan Kelautan*, **13(2)**,133-143. http://doi.org/10.20473/jipk.v13i2.28105

Ahn J.K., Yoo K.D., Oh J.C., Lee J.I., Yoon H.D. and Kim Y.H. (2017), Species composition and vertical distribution of marine algal communities at the Taean Peninsula of the West Coast of Korea, *Korean Journal of Fisheries & Aquatic Sciences*, **50(1)**, 055–064.

APHA 4500-NO3-B. (2017). The standard method for the examination of water and wastewater. 18th edition. Washington, pp. 252.

Baggini C., Salomidi M., Voutsinas E., Bray L., Krasakopoulou E. and Hall-Spencer J.M. (2014), Seasonality affects macroalgal community response to increases in pCO2, *PLoS ONE*, **9(9)**, e106520. doi:10.1371/journal.pone.0106520.

Brower J.E, Zar J.H. and Von Ende C.N. (1998), Field and laboratory methods for general ecology. Third Edition. USA: Wm. C. Brown Publisher.

Dadolahi-Sohrab A., Garavand-Karimi M., Riahi H. and Pashazanoosi H. (2012), Seasonal variation in biomass and species composition of seaweeds along the northern coasts of the Persian Gulf (Bushehr Province), *Journal of Earth System Science,* **121**, 241–250.

Dangar K., Vyas S., Karangiya R. and Gadhvi K. (2022), A survey of seaweeds in intertidal areas along the Veraval coast of India, *The Iranian Journal of Botany*, **28(2)**, 200-208.

English S., Wilkinson C. and Baker V. (1997), Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townsville.

Erniati, Erlangga, Andika Y. and Muliani. (2023), Seaweed diversity and community structure on the west coast of Aceh, Indonesia, *Biodiversitas*, **24(4)**, 2189 – 2200.

Gaspar R., Pereira L. and Neto J.M. (2017), Intertidal zonation and latitudinal gradients on macroalgal assemblages: Species, functional groups, and thallus morphology approaches, *Ecological Indicators,* **81**, 90–103.

Guiry M.D. and Guiry G.M. (2023), AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. https://www. algaebase.org

Haas A.F., Smith J.E., Thompson M. and Deheyn D.D. (2014), Effect of reduced dissolved oxygen concentrations on physiology and fluorescence of hermatypic corals and benthic algae, *PeerJ **2:e235**,* DOI 10.7717/peers. 235: pp. 1-19

Hammer. (2022), Paleontological Statistics Reference Manual. Natural History Museum University of Oslo, Norwegia.

Handayani S., Widhiono I. and Widyartini D.W. (2023), Macroalgae diversity and its relationship with environmental conditions in polluted waters of Seribu Islands, Jakarta Bay, Indonesia, *Biodiversitas,* **24(11)**, 6279-6286.

Hoang T.C., Cole A.J., Fotedar R.K., O'Leary M.J., Lomas M.W. and Roy S. (2016), Seasonal changes in water quality and Sargassum biomass in Southwest Australia, *Marine Ecology Progress Series*, **551**, 63–79. https://doi.org/10.3354/meps11735.

Jansen H.M., Berbard M.S., Nederlof M.A.J., van der Meer I.M. and van der Werf A. (2022), Seasonal variation in productivity, chemical composition, and nutrient uptake of *Ulva* spp. (Chlorophyta) strains, *Journal of Applied Phycology*, **34**, 1649-1660. https://doi.org/10.1007/s10811-022-02708-z.

Jung S.W., Oh Y.S., Shimasaki Y., Kang I.J. and Choi C.G. (2019), The macroalgal community at the floristic boundary area between the South and West Seas in Korea, *Journal of Faculty Agriculture, Kyushu University*, **64(1)**, 87-94.

Khudin M., Santosa G. and Riniatsih I. (2019), Ekologi rumput laut di Perairan Tanjung Pudak Kepulauan Karimunjawa, Jawa Tengah, *Journal of Marine Research*, **8 (3)**, 291-298.

Kokabi M., Yousefzadi M., Razaghi M. and Feghhi M.A. (2016), Zonation patterns, composition and diversity of macroalgal communities in the eastern coasts of Qeshm Island, Persian Gulf, Iran, *Marine Biodiversity Records*, **9**, 96. DOI 10.1186/s41200-016-0096-4.

Krebs, J.C. (1983), Ecology. The Experimental Analysis of Distribution and Abundance. Harper and Row Publisher. New York. 694 p.

Kwan V., Fong J., Lionel Ng C.S. and Huang D. (2022), Temporal and spatial dynamics of tropical macroalgal contributions to blue carbon, *Science of Total Environment*, **828**, 154369. https://doi.org/10.1016/j.scitotenv.2022.154369

Madina M St., Syafiuddin S., Samawi M.F., Muhiddin A.H. and Hatta M.H. (2022), Water quality of seaweed cultivation (*Eucheuma cottonii*) location in Old Takalar, Mappakasunggu District, Takalar Regency, *SPERMONDE*, **8(2)**, 28 – 36.

Mantri V.A., Kavale M.G. and Kazi M.A. (2020), Seaweed biodiversity of India: Reviewing current knowledge to identify gaps, challenges, and opportunities, *Diversity*, **12**, 13. doi:10.3390/d12010013

Mayakun J. and Prathep A. (2005), Seasonal variations in diversity and abundance of macroalgae at Samui Island, Surat Thani Province, Thailand, *Songklanarin Journal Science Technol*ogy**, 27(3)**, 653-663.

Oh J.C., Choi H.G., Ki C.D. and Ahn, J.K. (2016), Ecological evaluation of Marine National Parks based on seaweed community index, *Korean Journal of Fisheries & Aquatic Sciences*, **49(3)**, 385–392.

Olsson J., Toth G.B. and Albers E. (2020), Biochemical composition of red, green, and brown seaweeds on the Swedish west coast, *Journal of Applied Phycology*, **32**, 3305-3317. https://doi.org/10.1007/s10811-020-02145-w

Piñeiro-Corbeira C., Arenas F., Dolbeth M. and Vale C.G. (2023), Species composition, distribution, and zonation patterns in the intertidal seaweed assemblages from Santo Antão, Cape Verde, *Regional Studies in Marine Science*, **63**, 102999. https://doi.org/10.1016/j.rsma.2023.102999

Prathep, A. (2005), Spatial and temporal variations in diversity and percentage cover of macroalgae at Sirinart Marine National Park, Phuket Province, Thailand, *ScienceAsia,* 225–233. doi: 10.2306/scienceasia1513-1874.2005.31.225

Radulovich R., Umanzor S., Cabrera R. and Mata R. (2015), Tropical seaweeds for human food, their cultivation, and their effect on biodiversity enrichment, *Aquaculture*, **436**, 40-46. http://dx.doi.org/10.1016/j.aquaculture.2014.10.032

Raffo M.P., Russo V.L. and Schwindt E. (2014), Introduced and native species on rocky shore macroalgal assemblages: Zonation patterns, composition, and diversity, *Aquatic Botany,* **112**, 57-65. http://dx.doi.org/10.1016/j.aquabot.2013.07.011

Riswanti D. and Santosa G.W. 2017. Community structure of seaweed on the west of Krakal Beach Gunungkidul Yogyakarta. Prosiding Seminar Nasional Hasil-Hasil Penelitian Perikanan dan Kelautan VI, FPIK, Universitas Diponegoro.

Sanz V., Torres M.D., Domínguez H., Pinto I.S., Costa I. and Guedes A.C. (2023), Seasonal and spatial compositional variation of the red algae *Mastocarpus stellatus* from the Northern coast of

Portugal, *Journal of Applied Phycology*, **35**, 419-431. https://doi.org/10.1007/s10811-022-02863-3 .

Sodiq A.Q. and Arisandi A. 2020. Identification and macroalgae abundance on the south coast of Gunungkidul. 2020. *Juvenil*, **1(3)**, 325-330. doi.org/10.21107/juvenil.v1i3.8560

Stiger-Pouvreau V. and Zubia M. (2020), Macoalgal diversity for sustainable biotechnological development in French tropical overseas territories, *Botanica Marina*, **63(1)**, 17-41. https://doi.org/10.1515/bot-2019-0032

Tsiamis K., Salomidi M., Gerakaris V., Mogg A.O.M., Porter E.S., Sayer M.D.J. and Küpper F.C. (2020), Macroagal vegetation on a north European artificial reef (Loch et al.): biodiversity, community types and role of abiotic factors, *Journal of Applied Phycology*, **32**, 1353-1363. https://doi.org/10.1007/s10811-019-01918-2 .

Toth G.B., Harrysson H., Wahlström N., Olsson J., Oerbekke A., Steinhagen S., Kinnby A., White J., Albers A., Edlund U., Undeland I. and Pavia H. (2020), Effects of irradiance, temperature, nutrients, and pCO_2 on cultivated Ulva fenestrate's growth and biochemical composition, *Journal of Applied Phycology*, **32**, 3243–3254. https://doi.org/10.1007/s10811-020-02155-8

Wells E., Wilkinson M., Wood P. and Scanlan C. (2007), Using macroalgal species richness and composition on intertidal rocky seashores in assessing ecological quality under the European Water Framework Directive, *Marine Pollution Bulletin*, **55**, 151-161.

Widyartini D.S., Widodo P. and Susanto A.B. (2017), Thallus Variation of *Sargassum polycystum* from Central Java, Indonesia, *Biodiversitas,* **18 (3)**, 1004-1011.

Xu M., Sakamoto S. and Komatsu T. (2016), The attachment strength of the subtidal seaweed *Sargassum horneri* (Turner) C. Agardh varies among development stages and depths, *Journal of Applied Phycology,* **28**, 3679-3687. DOI 10.1007/s10811-016-0869-5

Yoshida G. and Shimabukuro H. (2017).,Seasonal population dynamics of *Sargassum fusiform* (Fucales, Phaeophyta), Suo-Oshima Is., Seto Inland Sea, Japan—development processes of a stand characterized by high density and productivity, *Journal of Applied Phycology*, **29**, 639-648. DOI 10.1007/s10811-016-0951-z

Zou X.X., Xing S.S., Su X., Zhu J., Huang H.Q. and Bao S.X. (2017), The effects of temperature, salinity, and irradiance upon *Sargassum polycystum C. Agardh* (Phaeophyceae) growth, *Journal of Applied Phycology,* **30(2)**, 1207–1215. https://doi.org/10.1007/s10811-017-1282-4