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The Impact of Spatio-temporal Variation on Seawater Quality and its Effect on the Domination of *Sargassum polycystum* on Small Islands in Western Indonesian Waters

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Abstract

Sargassum sp. is one of the most diverse genera of brown seaweed and widely found in Indonesian waters. This study aimed to provide the latest information on the role of spatial-temporal variation on water quality in macroalgal assemblages in three different locations in the western part of Indonesian waters, which are Tidung, Sebesi, and Bintan Islands. This research was conducted in two different seasons in 2019. Multivariate analysis is used to determine the relationship between environmental characteristics and macroalgae diversity. The results showed that the parameters of nitrate, ammonia, and salinity differed significantly between islands ($p < 0.05$). Besides that, seasons significantly affected the dissolve oxygen (DO), temperature, salinity, selenium (Se), and iron (Fe) ($p < 0.05$). Variation in the concentrations of DO, nitrate, and ammonium nitrogen, and iron (Fe), are the characteristics of Bintan Island. Tidung Island is characterized by variations in salinity and the presence of element zinc (Zn). Sebesi Island shows identical variations in temperature, DO, copper (Cu), and manganese (Mn). It found that *Sargassum polycystum* was the most important species in all locations and seasons and was significantly dominant in Sebesi and Bintan waters. It can be inferred that the high concentration of barium, copper, manganese, DO, and nitrate in the seawater could lead to the dominance of this species. The results demonstrate that spatio-temporal variations in the research locations had significantly influenced the diversity of macroalgal assemblages in the western part of Indonesian waters.

Keywords: Macroalgae; *Sargassum polycystum*; Small Island; Spatio-temporal variations

1. Introduction

Sargassum sp. is one of the most diverse types of brown seaweed (Phaeophyta) globally and plays a vital role in a marine ecosystem. According to Guiry dan Guiry (2020), there are currently 358 species that have been officially accepted as the *Sargassum* clan species from 537 names listed. In Indonesian waters, 58 species have been reported, but only 12 species are used commonly (Kadi 2005; Puspita *et al.,* 2020). Essential roles of *Sargassum* seaweed include shelter, foraging, and as a suitable habitat for the breeding of another biota (Olabarria *et al.,* 2018; Sheng *et al.,* 2018). The *Sargassum* can also be economically utilized as a source of hydrocolloids, antioxidants, antimicrobials, and additives for various food products (Roohinejad *et al.,* 2016) as well as bioactive compounds contained therein can be widely used (Reboleira *et al.,* 2018).

The enormous potential of seaweed, especially the *Sargassum* type, has not been optimally utilized due to fluctuations in biomass amount. The distribution varies according to location and is influenced by habitat characteristics including substrate type, depth, current and wave, pH, temperature, season, and availability of nutrients, both macro and micronutrients (Connan and Stengel 2011; Kang *et al.,* 2011; Zhao *et al.,* 2016; Hoang *et al.,* 2016; Baweja *et al.,* 2016; Kim *et al.,* 2017; Bi *et al.,* 2018; Bui *et al.,* 2018; Sheng *et al.,* 2018; Amper *et al.,* 2020).

Seaweed biomass in a marine ecosystem is not the same due to the availability of different nutrients. *Sargassum* is generally associated with the availability of various nutrients in waters such as nitrate and phosphate (Noorjahan *et al.,* 2019) and the presence of micronutrients including iron (Fe), iodine (I), manganese (Mn), and magnesium (Mg) (Misurcova *et al.,* 2011; Rodrigues *et al.,* 2015; Circuncisão *et al.,* 2018). Variations in the types and numbers of macroalgae that grow in an area are highly dependent on natural competitors and predators' presence; this is also supported by adaptive environmental conditions with variations in temperature, pH, salinity, DO, currents, and waves within safe limits (Wernberg *et al.* 2013; Ar Gall and Le Duff, 2014).

The Indonesian coastal waters of small islands have a potential seaweed, including *Sargassum* Sp. which can be found in the coastal waters of Lombok (Setyawidati *et al.,* 2018), Binuangen-Banten (Dharmayanti *et al.,* 2019), Bitung-North Sulawesi (Wouthuyzen *et al.,* 2016), and Jakarta bay and Seribu Islands (Draisma *et al.,* 2018). However, research on the temporal variation of the specific ecological characteristics of *Sargassum* species in the small island coast is still limited, even though the potential for its utilization has been widely publicized.

Research on the interaction between seawater quality at different sites and seasons with macroalgae diversity can be the basis for determining the most supportive habitats and allowing the selection of locations for optimal resource use. This study found environmental factors that play the most significant role of macroalgae diversity and importance value index in three different small islands' coastal waters. This study's results are expected to be beneficial for scientists, local communities, and the government in the context of using seaweed sustainably.

2. Materials and Methods

2.1 Research sites

The research has been done in the wet season (March - April 2019) and dry season (August - September 2019). Also, in situ data collection and sampling were carried out at the lowest tide, both for community structure, environmental quality, and water fertility. Type of seasons determined based on weather forecasts on weather forecasts issued by the Meteorology, Climatology and Geophysics Agency (BMKG) of Indonesia. Three islands as research location located in the western part of Indonesian waters. They are Bintan in Riau Island province, Sebesi in Lampung, and Tidung in Seribu Islands as part of Jakarta province. The sampling area of each island is divided into three stations, and each station consists of three points as substations as replications, where the distance of each spot is 50 m. The locations and research stations presented in Figure 1, where the positioning using GPS via Garmin ETrex 10 while the base map is taken from the Indonesian administration map via Google and then plotted using the QGIS 2.18 application. The study sites determined based on island types and seasons were carried out because it suspected that there were differences in environmental conditions that impacted macroalgae diversity. Bintan Island is a monadnock type, which formed from metamorphic sediment and alluvial soil. Water quality variations are influenced by hydrodynamic activity originating from waters of the Riau archipelago and strong anthropogenic pressure from land activities. Sampling sites were in 1°06'30.6"N 104°13'43.7"E, 1°11'57.2"N 104°34'50.4"E, and 1°01'07.9"N 104°39'09.1"E. Sebesi located in 05055'37.43"-05058'44.48" SL and 105027'30.50" - 105030'47.54" WL. It is a volcanic type of island which is formed by volcano mountain activity. The anthropogenic pressures are low, and the physio-chemical parameter is mainly influenced by Lampung bay. The sampling site as research stations were in 5°58'05.3"S 105°30'04.0"E, 5°58'13.6"S 105°28'56.7"E, and 5°55'26.0"S 105°29'02.8"E. Tidung is a coral type of island and has high anthropogenic pressure from tourism activities and high population (4.651 people/km^2). This island has a relatively poor seawater quality due to the limitation of nutrient sources such as a river that brings sediment from the land. The sampling sites were in 5°47'55.7"S 106°30'26.3"E, 5°47'43.0"S 106°28'45.2"E, and 5°48'14.5"S 106°30'31.0"E.

2.2 Ecological Index and Important Value Index

The macroalgae ecological index is calculated based on the number of macroalgae species found in every substation using a 50 × 50 cm quadrant transect. The purposive sampling method is used to determine the sampling spot. The sampling collection was done during the low tide and counting completed directly in the spot, while the photograph was also taken for documentation purposes. The data analysis is finished according to the formula, as described below.

Shannon-Wiener diversity index formula was used to define the seaweed diversity (Bengen, 2000). The equation formula as follows:

$$H' = -\sum_{i-1}^{s} p_i \ln p_i$$

Annotation:

H' = Diversity Index
i = number or proportion of individuals of a species
pi (i/N) = i divided by the total number of individuals (N)
s = number of species per location
H'<1 = the species diversity in a transect is low
1 ≤ H'≤ 3 = the diversity of species in a transect is rather abundant
H'>3 = the diversity of species in a transect is high

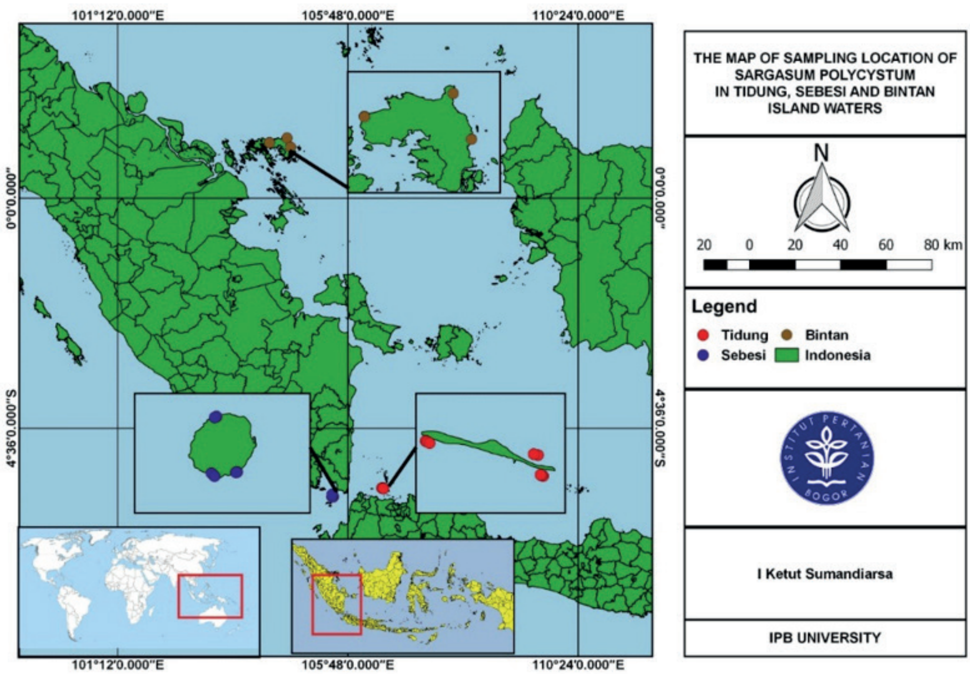

Figure 1. Research location

The uniformity index (equilibrium) (E) was used as an index for the uniformity of abundance or how evenly species are distributed. The formula of the uniformity index as follows:

$$E = \frac{H'}{Hmax}$$

Annotation:
E = Uniformity Index
H' = Diversity Index
Hmax = Maximum diversity (Ln S)
S = number of types

The uniformity index value category (E) shows that a community is in a depressed condition when the value is between 0.00 < e < 0.4, in an unstable condition when the value is between 0.4 < e < 0.6 and in a stable condition when the value is between 0.6 < e < 1.00.

The dominance index at each location is calculated using the Simpson dominance index formula. The formula is as follows:

$$C = \sum_{i-1}^{s} (P_i)^2$$

Annotation:
C = Index of dominance
Pi = ni / N
Ni = number of individuals of type I
S = number of types

Dominance is in the low category when 0.00 < C < 0.50, while the medium category is for value 0.50 < C < 0.75. High dominance is shown at value 0.75 <C < 1.00.

The Importance Value Index (IVI) is used to estimate and calculate the seaweed species' role in a community. The higher the IVI value of a species against other individuals, the higher the community's role. IVI is the sum of frequency, density, and relative coverage. The formula used is as follows:

IVI = FR + KR + PR

Where:
FR = relative frequency
KR = Relative density
PR = Relative coverage

The relative frequency is the ratio between the i type frequency that appears and the frequencies for all types. The formula used is:

$$FR = \frac{Fi}{\sum F} \times 100\%$$

Where:
FR = relative frequency
Fi = the frequency of i
∑F = number of frequencies for all species

The relative density is the ratio between the number of individual species and the total number of individuals of all types. The formula is as follows:

$$KR = \frac{ni}{\sum N} \times 100\%$$

KR = Relative density
Ni = Total Number of individuals of a species
∑N = Total Number of individuals of all species

The relative Coverage is a comparison between individual i-type closures and the total closure of all species. The formula used is as follows:

$$PR = \frac{Ci}{\sum Ci} \times 100\%$$

PR = Relative coverage
Ci = Coverage area by the i-species
∑Ci = Total area of cover for all species

2.3 Waters Quality of the Seaweed Habitat

Water quality measurements on three different islands focused on several parameters, including temperature, DO, salinity, pH, turbidity or brightness, currents, and trace elements of water and seaweed. The tools used are the combo type 8,630 of water quality checker and multi-parametric analysis tools, which can include parameters that have been determined by using tools and carried out in situ. Water fertility parameters that are part of the study include nitrate, orthophosphate, and ammonium nitrogen.

The instrument used in determining the fertility of the waters is the Ultra Violet-Visible (UV-VIS) spectrometer. The trace element analysis was done using the Atomic Absorption Spectro-photometry (AAS) Perkin Elmer PinAAcle 900H with Flame technique (Acetylene-Air) with APHA (American Public Health) method Association) (Rice *et al.,* 2017) in the IPB Proling laboratory. Preservation of the trace elements, which are barium (Ba), selenium (Se), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and molybdenum (Mo) from water samples was carried out using a solution of H_2SO_4 to pH ≤ 2.

2.4 Data analysis

Kruskal-Wallis and multivariate discriminant analysis were used to determine the differences in the coastal waters' characteristics and seaweed biota diversity at each location and season. After that, water quality data was transformed into logarithm and seaweed diversity in the square root for multivariate analysis. Characteristics of water and seaweed characteristics at the study site were analyzed using multivariate discriminant analysis. The relationship between multi-variable water characteristics was spatially-temporally using multivariate canonical correspondence analysis. All statistical tests were performed with PAST Statistical Software *V4.02* (Hammer, 2020).

3. Results and discussion

3.1 Spatial and temporal distribution of macroalgae in the waters of Tidung, Sebesi, and Bintan

Based on the five seaweed species' research results from the type of brown macroalgae (Phaeophyta), namely *Sargassum polycystum, Sargassum binderi, Padina australis*, and *Turbinaria* Sp. and green species (Chlorophyta), namely Caulerpa sp. The most common species found is *Sargassum polycystum*, which is found abundantly in all islands' coastal waters during all seasons. The abundancy is likely influenced by this species' characteristics that have a wide tolerance for changes in environmental conditions (Zou *et al.,* 2018). This species' abundance of environmental characteristics and substrates supports the optimization of these species' growth, namely coral substrates and coral fragments (Erlania dan Radiarta, 2015; Hoang *et al.,* 2016). In addition to the substrate, nutrient components carried by currents and waves from the bottom of the water and erosion from the land provide suitable habitat dynamics energy to support optimal macroalgae (Tecchiato *et al.,* 2015). Seaweed species from the three study sites are presented in Table 1, and the Ecological Index can be seen in Table 2.

Based on the analysis of the ecological index, it can be seen that all stations have a low diversity index characterized by the small number of individual macroalgae that were found. The diversity index of inter-island diversity is stable on Tidung Island, unstable on Bintan Island, and depressed on Sebesi Island. Simultaneously, the dominance index tends to be moderate on Tidung Island and high on the other two islands.

Table 1. Seaweed species from the three study sites

Class	Order	Family	Genus	Species
Phaeophyceae	Dictyotales	Dictyotaceae	Padina	*Padina australis*
	Fucales	Sargassaceae	Sargassum	*Sargassum polycystum*
				Sargassum binderi
			Turbinaria	*Turbinaria* sp.
Ulvophyceae	Bryopsidales	Caulerpaceae	Caulerpa	*Caulerpa* sp.

Table 2. Ecological index of the three different Islands

Location	Season	Diversity index (H')	uniformity (E)	dominance (C)
Tidung	Wet	Low	Stable	Medium
	Dry	Low	Stable	Medium
Sebesi	Wet	Low	Unstable	Medium
	Dry	Low	Depressed	High
Bintan	Wet	Low	Unstable	Medium
	Dry	Low	Depressed	Medium

Anotation: H’ < 1=Low; $1 <$H’< 3=Medium; H’ < 3=High;
$0.00 < E < 0.4$= Depressed; $0.4 < E < 0.6$= Unstable; $0.6 < E < 1.00$= Stable;
$0.00 < C < 0.50$=Low; $0.50 < C < 0.75$= Medium; $0.75 < C < 1$= High

The diversity index, on average, shows low value. However, when viewed from the number of individuals, there are more individuals on Tidung Island because diversity is positively correlated with substrate types (Erlania and Radiarta, 2015). Substrates dominated by sand and mud are generally overgrown by various biota, including brown macroalgae (Johan *et al.,* 2015). Also, there is competition, and there are predators so that only certain types can survive. Strong waves and currents also affect the distribution of spores. The spores are carried by the currents and maybe more widely spread (Bi *et al.,* 2018).

The uniformity index on Tidung Island looks stable, which means that no individual species dominate, and more individuals can grow. It is supported by the substrate that varies at the research location. Sargassum species can thrive on muddy substrates with a combination of coral fragments (Aaron-Amper *et al.,* 2020). The same is right at the three observation stations on Bintan Island because the substrate in the area varies from mud, sand, and rock. Physical-chemical factors and nutrient availability are sufficient (Suthar *et al.,* 2019).

The dominance index is seen on all islands and is dominated by brown macroalgae. A slight variation in macroalgae generally overgrows an area with extreme environmental conditions because these conditions require rapid adaptation where the amount of nutrients fluctuates. Research (Ar Gall dan Le Duff, 2014; Lalegerie *et al.,* 2019) stated that the distribution of seaweed in an intertidal zone is influenced by hydrodynamic systems that cause variations in temperature, nutrients, grazer fauna distribution and competition between macroalgae. *Sargassum’s* dominancy is also supported by seasonal variations, rainfall, and nutrient availability, which significantly influences the distribution of this species (Hoang *et al.,* 2016).

The Importance Value Index (IVI) analysis (Table 3) generally shows that seasonal differences result in different IVI values for each individual. Based on the variance analysis, it was found that there was a significant difference ($p < 0.05$) of IVI concerning *S. polycystum,* which grew in the three study sites. The highest score was found on Sebesi island in two different seasons. It is presumably due to the identical beach topography with large waves and close distance to the coast. These results are by the statement of Bi *et al.,* (2018) that the area affected by wave activity will be dominated by only one type of macroalgae where there is a physiological modification in the context of adaptation. The dynamic movement of water due to currents and waves results in nutrient limitations so that only certain types of macroalgae can grow and remain attached to the substrate of the wave blows (Stephani *et al.,* 2014; Lalegerie *et al.,* 2019).

Discriminant analysis is used to determine the relationship between macroalgae diversity with different locations and seasons. Based on the results of discriminant analysis on the diversity of macroalgae in the three islands (Figure 2), it can be seen that the diversity between islands is not significant. However, the high IVI of *S. polycystum* is a feature of Sebesi and Bintan islands. At the same time, *Tubinaria* sp, *Caulerpa* sp., and *Padina australis* can be found on the island of Tidung with a high variation in the number of individuals between seasons and research stations.

Table 3. Importance Value Index (IVI) of macroalgae in three different Islands

Wet season					
Island	*P. australis**	*S. polycystum**	*S. binderi*	*Turbinaria sp.*	*Caulerpa sp.* *
Tidung	48.11 ± 23.5	159.44 ± 31.5	21.81 ± 37.7	16.83 ± 29.1	13.4 ± 23.2
Sebesi	21.66 ± 19.0	180.29 ± 12.6**	25.02 ± 14.4	2.20 ± 3.8	0
Bintan	66.92 ± 16.2	174.54 ± 10.3**	28.19 ± 24.3	4.11 ± 7.1	0
Dry season					
Tidung	53.97 ± 31.5	127.8 ± 21.8	17.2 ± 29.7	0	51.8 ± 47.8
Sebesi	0	192.7 ± 10.4**	15.45 ± 16.7	0	0
Bintan	32.48 ± 33.1	183.5 ± 10.7**	14.93 ± 13.7	0	0

Notes: * Significantly different at significance ($p<0.05$), ** at ($p<0.01$)

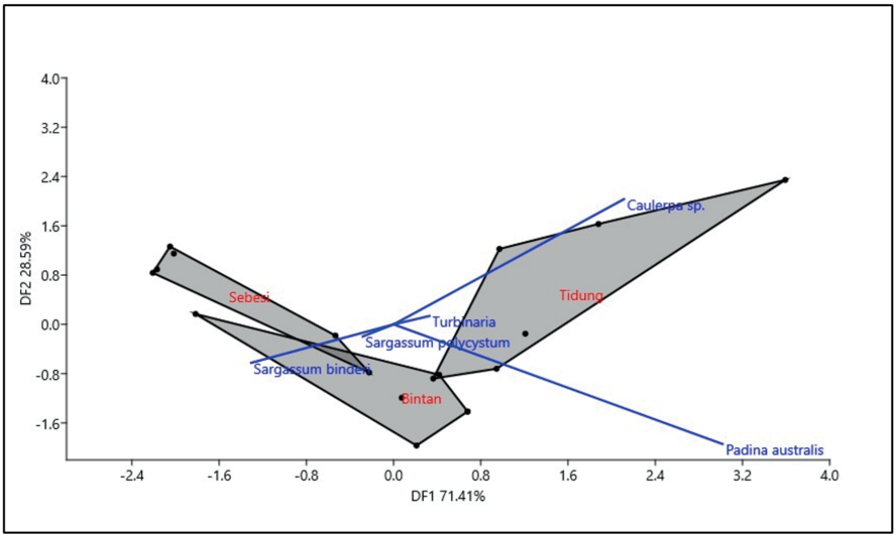

Figure 2. Discriminant diagram of the diversity of seaweed on the islands of Tidung, Sebesi, and Bintan.

It can be inferred that the dominance and high importance value index of *S. polycystum* compared to other species is due to the excellent environmental carrying capacity of the two islands, namely Sebesi and Bintan. It further confirms that the coastal area with a sandy mud substrate has a higher salinity than hard substrates such as corals and coral fragments. Hydrodynamic conditions such as currents, waves, freshwater runoff, wind direction, and speed cause the spreading of nutrients and oxygen depletion so that only certain tolerant macroalgae species can survive (Lalegerie *et al.,* 2019). It happens on the coasts of Sebesi islands that are impacted by big wave situations and the effect of Sunda Strait current, resulting in nutrient limitation so that only *Sargassum* species can grow well and dominate (Zou *et al.,* 2018).

3.2 Environmental Characteristics of the coastal waters of Tidung, Sebesi, and Bintan Island

The three research sites are islands with a different type of topographical and have different anthropogenic pressure. Tidung Island is a reef-formed island with a robust anthropogenic pressure due to the population and well known as a tourism object Khirsnamurti *et al.* (2016). A hilly topography dominates the Sebesi Island coast with strong currents and waves but weak anthropogenic influence (Wiryawan *et al.,* 2002). On the other hand, Bintan Island is a hinterland of the Monadnock type formed from metamorphic rocks where the beach conditions are dominated by mud and sand substrate and a few coral fragments (Asriningrum, 2009).

General environmental characteristics show that Nitrate parameters, pH, temperature, and brightness are evenly distributed in all locations and between seasons. However, Phosphate and ammonium nitrogen content tend to decrease from the wet season to the dry season on all research sites. At the same time, DO and salinity increase in seasons across the islands based on the season (Figure. 2). Based on the micronutrient content (trace elements) in Figure. 3, it can be seen that the change of seasons causes a decrease in the concentration of all tested elements on all research sites, except for barium (Ba), copper (Cu), and zinc (Zn) on Bintan Island. The pattern of seawater trace element content in research locations can be seen in table 4. Based on the results, there are two-element exhibits in all locations and seasons, namely selenium and zinc. In contrast, molybdenum was the only trace element unrevealed. Trace element content in seawater shows variations in the amount based on research location and season.

The results of the study on the environmental characteristics through Kruskal-Wallis significant analysis showed significant differences for several parameters, namely nitrate, ammonium nitrogen, and salinity ($p < 0.05$) between islands of the study location. On the other hand, based on season across the islands, it is found that DO, temperature, salinity, selenium (Se), and iron (Fe) parameters were significant ($p < 0.05$). Other parameters were not significantly different between locations and study seasons. Differences in ecological characteristics between study sites may be caused by differences in wind direction, currents, and rainfall. It is in line with Lalegerie *et al.* (2019) statement that the hydrodynamic system of currents and waves influences other environmental factors such as light penetration, temperature, and nutrient availability. Current movements in the three study sites are generally influenced by wind direction and velocity and tidal patterns. Multiple tidal patterns are found in Sebesi and Bintan islands, while single tidal patterns are found on Tidung Island (Widhi *et al.,* 2012; Yogaswara *et al.,* 2016; Suhana *et al.,* 2018).

Differences in physical-chemical characteristics based on the season may occur due to rainfall, wind speed, and direction, currents, and waves that change each season. These factors can carry and distribute nutrient elements so that their concentration may differ from one to another (Bi *et al.,* 2018). This situation impacts the water's nutrient content, which tends to be higher on Bintan Island during the wet season. This condition is suspected of enriching waters by freshwater runoff from land containing macro and micronutrients due to higher inland activity and natural decomposition processes. The average nutrient concentration and physio-chemical parameters are presented in Table 5.

Based on multivariate analysis of discriminant against water characteristics in the three study sites over two different seasons, it was seen that there were no significant differences between locations in both water quality and micronutrient parameters (trace elements) (Figure 3). However, the concentration of DO, nitrate, ammonia, and the iron element characterizes Bintan's island. On the other hand, Tidung Island is characterized by variations in salinity and the element zinc presence. Sebesi Island itself is identical with variations in temperature, DO, copper, and manganese. Three research sites are included in the adjacent zone (ZOM), namely the Sumatra and Java zones (BKMG, 2019).

Table 4. Trace element content in the seawater (mg/L) based on locations and seasons (1= wet, 2= dry); (mean ± SD; n=3)

No.	Parameter	Tidung		Sebesi		Bintan	
		1	2	1	2	1	2
1	Barium	0*	0*	0.01±0.001	0.003±0.01	0*	0.01±0.0
2	Selenium	0.0012±0.0001	0.001±0.00006	0.0013±0.0001	0.0012±0.0001	0.0021±0.0007	0.0015±0.0004
3	Iron	0*	0.22±0.007	0.45±0.08	0.159±0.01	0.117±0.06	0.024±0.04
4	Manganese	0*	0*	0*	0*	0*	0.0057±0.0006
5	Copper	0.0097±0.0001	0.0083±0.0006	0.0113±0.002	0*	0.005±0.001	0.005±0.001
6	Zinc	0.018±0.002	0.014±0.003	0.019±0.004	0.015±0.005	0.0077±0.002	0.01±0.002
7	Molybdenum	0*	0*	0*	0*	0*	0*

Notes: *= under detection limit of the AAS (Fe < 0.050; Mo < 0.005)

Table 5. Physio-chemical variation of the seawater (mean ± SD; n = 9)

Parameters	Tidung		Sebesi		Bintan	
	Wet	Dry	Wet	Dry	Wet	Dry
Nitrate (NO_3^-) (mg/L)	0.23 ± 0.1	0.24 ± 0.2	0.27 ± 0.1	0.26 ± 0.1	0.77 ± 0.3	1.00 ± 0.7
Phosphate (PO_4^{3-}) (mg/L)	0.047 ± 0.01	0.022 ± 0.004	0.004 ± 0.003	0.027 ± 0.003	0.058 ± 0.009	0.008 ± 0.005
Ammonium nitrogen (NH_4^+) (mg/L)	0.09 ± 0.003	0.84 ± 0.05	0.27 ± 0.04	0.06 ± 0.01	2.35 ± 0.3	0.81 ± 0.1
DO (mg/L)	5.61 ± 0.1	6.53 ± 0,8	5.58 ± 0.3	7.53 ± 1.4	5.88 ± 0.5	7.77 ± 0.6
pH	7.40 ± 0.2	7.35 ± 0.3	7.55 ± 0.2	7.26 ± 0.3	7.68 ± 0.1	7.43 ± 0.4
Temperature (°C)	31.6 ± 0.4	27.53 ± 0.1	30.8 ± 1.6	28.67 ± 0.7	30.47 ± 0.9	29.8 ± 3.8
Salinity (‰)	34.67 ± 0.6	35.53 ± 0.4	33.93 ± 1.6	34.33 ± 1.2	32.2 ± 0.9	34.33 ± 1.15
Brightness (%)	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	100 ± 0.0	93.3 ± 11.6

These zones generally have similar wind patterns, seasons, and water currents where winds and tides influence the currents' movement. Rainfall by season shows a different pattern because the type of island of the three study locations is different. Bintan Island, a large island with more rivers flowing into the sea, shows the coastal zone's enrichment during the wet season (Rahmawitri *et al.,* 2016; Irawan 2017). Research (Bi *et al.,* 2018) has shown that the wave size on different islands results in variations and distribution patterns of physics-chemical parameters such as turbidity and salinity. As a consequence, the spatial distribution of seaweed varies per island of the study locations. On the other hand, another study (Chung *et al.,* 2007) show that the waters' nutrient fluctuations and physicochemical parameters may be associated with seasonal and temporal variations. Furthermore, sedimentation in the form of sediment transfer, accumulation, and erosion from the hinterland at a location impacts differences in water fertility level, which is closely related to an area (Tecchiato *et al.,* 2015).

3.3 The relationship between seawater quality and macroalgae diversity

In line with the correspondence analysis results of the relationship between multi-variable water characteristics, *S. polycystum* is strongly impacted by barium, copper, and manganese. Also, variations of DO and nitrate are parameters that determine this type of distribution's dominance. Thus, based on the environment's location and character, *S. polycystum*, as the dominant macroalgae found, can grow both on the coast of Sebesi and Bintan parts during the wet and dry seasons. This finding is in line with various studies which state that factors such as substrate, coastal topography, the interaction of abiotic and biotic parameters have determined the distribution and biomass of Sargassum throughout the world (Ar Gall dan Le Duff, 2014; Zhao *et al.,* 2016; Sheng *et al.,* 2018).

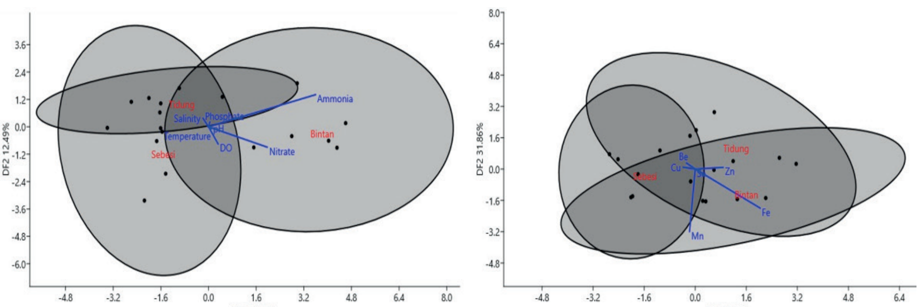

Figure 3. Discriminant diagram of water quality (a) and micronutrients (b) from the seawater of Tidung, Sebesi, and Bintan Islands.

Simultaneously, there is a positive effect of micronutrients on growth and vice versa. Selenium has a positive impact where the presence of these micro-nutrients is positively correlated to seaweed growth, while copper can inhibit growth because it can reduce the ability of photosynthesis, causing a decreased food intake (Connan dan Stengel 2011; Costa *et al.,* 2016; Liu *et al.,* 2018). Regional differences in the distribution of micronutrients are caused by at least two factors: anthropogenic factors such as pollutants from rivers, and natural factors such as hydrodynamic conditions (Liu *et al.,* 2016; Siregar *et al.,* 2016). The interaction between macroalgae abundance in the study area with the seawater quality is presented in Figure 4 with eigenvalues of axis 1 is 0.271 or 58.69% and axis 2 is 0.110 or 23.87%. The interaction was based on seasonal and spatial variations.

4. Conclusion

The water characteristics on Tidung, Sebesi, and Bintan are spatially significant but not temporally. Each research location has a particular characteristic, for instance, the variation in salinity and the element zinc as a differentiator on the coast of Tidung Island. Meanwhile, Sebesi Island is identical with temperature variations, DO, copper, and manganese, while DO, nitrate, and ammonium nitrogen concentrations, as well as iron, are the hallmarks of Bintan Island.

Variations in the concentration of nitrate, DO, barium, and copper in seawater determine the growing seaweed diversity. These elements stimulate the dominance and index of the highest importance of *S. polycystum* in the coastal waters of the island of Sebesi. The presence of copper elements and the Sebesi island topography as a volcanic island is thought to be a determinant factor of dominance. Competition between seaweed species is low so that *S. polycystum* seaweed can grow well. Thus, the use of seaweed in the research locations can be proposed without neglecting sustainability, especially the use of *Sargassum polycystum*.

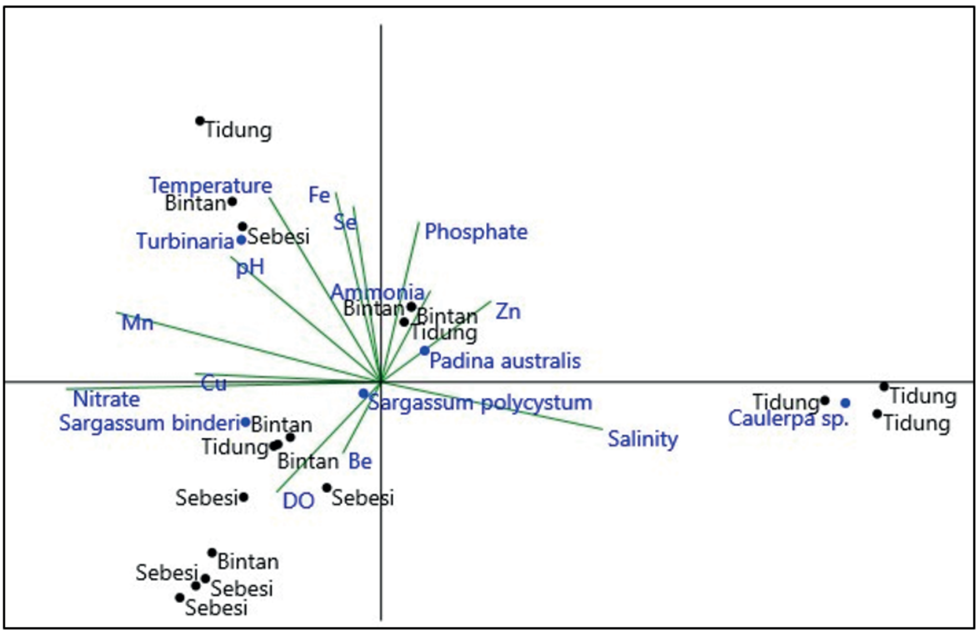

Figure 4. Diagram of the canonical correspondence analysis results of seaweed environmental characteristics and diversity on the coast of Tidung, Sebesi, and Bintan islands.

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