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THE RELATIONSHIP BETWEEN SEASONAL AND ENVIRONMENTAL VARIATIONS WITH MORPHOMETRIC CHARACTERISTICS OF *SARGASSUM POLYCYSTUM* (C. AGARDH. 1824) FROM TIDUNG, SEBESI AND BINTAN ISLANDS WATERS, INDONESIA

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Abstract

Sargassum brown seaweed is one of the most morphologically complex genera due to environmental adaptation. Therefore, the relationship between seasons and different environments condition with the morphometric characters of *Sargassum polycystum* that grows in Tidung, Sebesi, and Bintan Islands waters is determined. Principal Component Analysis (PCA) is used to determine environmental variables' contribution, and discriminant analysis was employed to differentiate variables between research locations. The results showed that there were variations in morphological characteristics between areas. Tidung Island showed an advantage in terms of the blades' size, while Sebesi Island showed dominance in the diameter of the primary stipe, air bladder, and the branching distance from the holdfast. Additionally, we characterized the thallus's length and the seaweed's total length in the Bintan Islands. PCA shows that the main factors of water quality in ammonia, pH, Se, Fe, and Mn are associated with blade variations. On the other hand, there was a correlation between variations in DO and salinity with the branching distance from the holdfast and presence of nitrates, variations in temperature and

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brightness were correlated with holdfast diameter, thallus diameter, and blade size. This study found that the morphometric variation of *S. polycystum* was significantly influenced by the locations (small islands) and seasons.

Introduction

Brown seaweed is one of the three divisions of macroalgae that have high economic value. Most of them are good sources of alginate (FERTAH 2017, SETYAWIDATI et al. 2018) and potentially used as raw material for nutraceutical and medicine due to its high content antioxidant (BORAZJANI et al. 2017, HERMUND 2018). Moreover, seaweeds also have functioned as a shelter for many kinds of biota and outright can provide nutrition for others in the ecosystem (WILLIAMS and FEAGIN 2010). Its abundance in the marine ecosystem also serves as a primary energy producer that potentially consists of ample metabolite compound and formed the food cycle from phytoplankton and zooplankton (SHAFAY et al. 2016).

Sargassum is one genus from brown macroalgae with a rich diversity of species and one of the most complex taxonomically. The number of *Sargassum* species recorded is more than 500 species known worldwide (GUIRY and GUIRY 2020). There are around 50 species found in Indonesian water, while only 12 are well utilized (Puspita et al. 2020). One type of *Sargassum* which has a wide distribution in Indonesian waters is *Sargassum polycystum* C. Agardh. This type is a potential source of alginate (DHARMAYANTI et al. 2019), and the bioactive compound is promising (PERUMAL et al. 2019).

In general, *S. polycystum* grows well in the littoral and sublittoral zones by sticking to rocks, dead coral, or other substrates. Dead and live corals can provide additional habitat for this species (DICKSON dan SEMBILAN 2015). In general, environmental factors such as season can affect the distribution, growth, and reproduction of *S. polycystum* (NOIRAKSAR et al. (2017), temperature, and salinity (ZOU et al. 2018, CHUNG et al. 2007, FULTON et al. 2017) stated that various environmental parameters, both physical and chemical, can affect the presence and distribution of seaweed in marine ecosystems.

The conventional method can determine seaweed morphology from the shape of the thallus parts such as leaf/blade, stipe, vesicle/air bladder, and holdfast. The presence of stolon-like roots in the holdfast section of *S. polycystum* is an important morphological feature to distinguish it from other types (WONG et al. 2004). Moreover, variations in the shape and size of the thallus from the two different habitats can occur due to their interactions with varying conditions of the environment (WIDYARTINI et al. 2017).

Sometimes in distinguishing species between the genus *Sargassum*, the researcher can use the holdfast form and vesicles' presence (CAMACHO et al. 2015). Changes in seaweed morphology can occur as an adaptation to the changes in environmental conditions such as fluctuations in currents, temperature, salinity, and mineral content in waters (BAWEJA et al. 2016).

Indonesia, which is an archipelago and is dominated by small islands, has high potential seaweed resources. The conditions of the waters between islands can differ from one another so that it impacts the morphometric characters of the seaweed that grows as a form of adaptation (MUTA HARAH et al. 2014). Therefore, environmental and seasonal variations might substantially impact changes in the morphology of *S. polycystum* that grows in the Bintan, Sebesi, and Tidung Islands. Furthermore, the purpose of this study was to determine the relationship between the aquatic environmental conditions of various island types and seasonal variation against the morphometric characteristics of *S. polycystum*.

Materials and Methods

Study Area

The research was done from January to December 2019 in three different locations: Bintan, Sebesi, and Tidung Island. Bintan is part of the Riau Islands province, a monadnock island type formed by the metamorphic rock where the bottom of the coastal dominated by mud, sand, and coral fragments substrates (ASRININGRUM 2009). High agricultural activities and rivers influence the coastal area on this island as freshwater and nutrients. This type of island is characterized by water flow directly goes to the coastal area very fast during the wet season, and it will make the seawater turbid. This phenomenon resulted in highly physio-chemical changes in the coastal zone.

Sebesi Island is part of Lampung province where a hilly topography dominates the island's coast with strong currents and waves from Lampung Bay but weak anthropogenic influence (WIRYAWAN et al. 2002). The condition of hydrodynamic strongly influenced by Lampung gulf activity, and most of the nutrient availability depends on the situation of the gulf waters. This island is characterized by freshwater that abundantly available throughout the year. The tidal type is mixed, which happens twice a day.

According to BMKG (Meteorological, Climatology and Geophysical Agency), all of the research locations included in the same seasonal zone that is closed one to the other, namely the Sumatra and Java area. The seasonal differentiation is also according to weather forecast released by the BMKG. The coordinate points of the sites are as follow: Tidung Island is in 5°47’55.7”S 106°30’26.3”E; 5°47’43.0”S 106°28’45.2”E; 5°47’54.8”S 106°30’22.4”E, Sebesi Island is in 5°58’05.3”S 105°30’04.0”E; 5°58’13.6”S 105°28’56.7”E; 5°55’26.0”S 105°29’02.8”E and Bintan Island is in 1°06’30.6”N 104°13’43.7”E; 1°11’57.2”N 104°34’50.4”E; 1°01’07.9”N 104°39’09.1”E. Furthermore, Figure 1 shows the research location in detail. It consisted of three stations on each Island, and the point determination was based on the Global Positioning System (GPS) by employed Garmin ETrex 10. The map used is downloaded from the Indonesian administrative map available in Google and plotted using a QGIS 2.18 application.

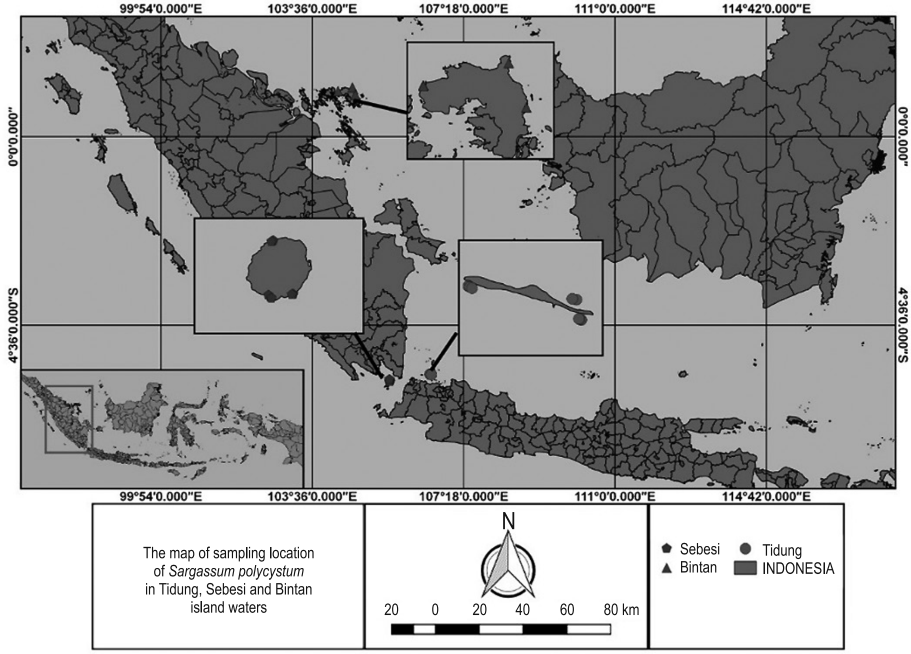

Fig. 1. Three research locations in western part of Indonesian waters

Source: Google named Indonesian administrative map that is available free and that map as a basis to develop the location map by using QGIS app. All of the coordinates points were taken by Garmin GPS

Research Procedure

Samples Collection

We collected the fresh of *S. polycystum* C. Agardh (Phaeophyceae) from the coastal of Tidung, Sebesi, and Bintan Islands waters. The sampling collection was based on a purposive sampling method and divided into three stations on each island. Furthermore, every location consisted of three substations with 50 meters distance of each along the coast.

During the sampling, the water's condition was in low tide, and the depth was about 10–30 cm. The research also considered seasonal variation, which the sampling collections have done in the summer dan wet season. Figure 2 shows the condition of the sampling location in three different islands.

Fig. 2. Research locations: *a* – Tidung; *b* – Sebesi; *c* – Bintan (photo by I Ketut Sumandiarsa)

Environmental Characteristics

The physio-chemical parameters included Nitrate (NO^{3-}), Phosphate (PO_4^{3-}), and ammonia (NH_4^+) as well as temperature, brightness, DO, salinity, and pH. The trace elements of the seawaters assessed, which consist of Barium (Ba), Selenium (Se), Iron (Fe), Manganese (Mn), Copper (Cu), Zink (Zn), and Molybdenum (Mo). There are two ways of determining it, namely in situ using a water quality meter, Combo type 8630, and laboratory assessment with *Ultra Violet-Visible Spectro* (UV-VIS) in the Proling Lab IPB University.

The sample preparation was followed by adding 1 ml of H_2SO_4 to 100 ml seawater sample for water quality parameters and preserving fresh seaweed samples done by adding HNO_3 solution to $pH \leq 2$ for trace element analysis. An Atomic Absorption Spectro-photometry (AAS) Perkin Elmer PinAAcle 900H with Flame technique (Acetylene-Air) with a method of APHA, 23rd Edition (Rice et al. 2017) was employed to determine the trace elements.

Data Analysis

The homogeneity of the data variants tested using heterogeneous insignificant variance values ($p > 0.05$) did not need the data transform. Principal Component Analysis (PCA) carried out the data analysis separately on the environmental characteristics and morphological characters. Euclidean biplots plotted to determine the relative contributions of various variables with variations in the data. The determination of which variables differentiate between study locations (islands) is using discriminant analysis. Discriminant analysis carried out using the SPSS program IBM version 24. PCA performed by using the XLSTAT version 2020.1.3.

Results and Discussion

Sargassum polycystum **Morphometric Characters**

The morphological characteristics of *S. polycystum* on the three islands show distinctive morphometric attributes and features of each island (Table 1). The environmental aspects of the research location and the seasonal variations influence the morphometric variations. There are two seasonal variations in this case, which are wet and dry seasons. Morphometric characteristics, namely the length of the thallus and total length on Bintan Island found to be the longest which are 71.00± 32.78 cm and 77.33±34.01 cm, respectively, and the shortest was in Tidung 32.57 ±15.63 cm and 34.83±14.51 cm, correspondingly, and all of them found in the same season (wet). The most significant size of primary stipe diameter was found in Sebesi (0.46±0.01 cm), whereas the smallest was in Bintan (0.26±0.07 cm), and both of them discovered in the dry season. Based on seasonal variation, the characteristics of primary stipe diameter were not significantly different, but different islands have shown considerably different where the dry season was dominant. The most oversized holdfast diameter in the dry season is part of the Sebesi Island characteristic (2.53±0.45 cm), but it also has shown the smallest during the wet (0.55±0.33 cm). In terms of blade size from the bottom part of the thallus, it has found the longest and the widest was in Tidung during the wet season only (6.40±2.29 cm and 1.57±0.74 cm, respectively). The total length has differed entirely on the island; namely, the shortest found in Tidung, and the longest was in Bintan of about 32.57±15.63cm 77.33±34.01 cm, correspondingly.

Table 1

Morphometric characteristics of *S. polycystum* from different islands

Morphometric [cm]	Tidung Island		Sebesi Island		Bintan Island	
	wet	dry	wet	dry	wet	dry
TL	32.57±15.63	50±25	43.17±18.24	44.33±11.15	71.00±32.78	43.33±6.03
TotL	34.83±14.51	55.33±25	49.67±20.64	48.33±9.71	77.33±34.01	45.33±6.49
DPS	0.35±0.04	0.36±0.11	0.40±0.085	0.46±0.01	0.36±0.03	0.26±0.07
HD	0.66±0.32	0.80±0.2	0.55±0.33	2.53±0.45	1.23±0.05	0.97±0.15
LBL	6.40±2.29	1.80±1.1	4.25±0.40	5.43±1.2	3.00±0.4	4.07±1.6
LBW	1.57±0.74	1.37±0.8	1.33±0.59	0.77±0.2	1.10±0.2	1.53±0.35
MBL	3.40±0.87	4.73±0.7	4.00±1.48	2.80±0.36	3.20±0.3	3.60±1.2
MBW	1.23±0.51	1.03±0.06	1.03±0.25	2.00±1.73	0.83±0.21	0.77±0.15
UBL	3.13±1.79	3.32±0.87	2.87±0.81	2.50±1.25	2.07±0.23	2.07±0.66
UBW	1.20±0.79	0.72±0.19	1.07±0.25	0.60±0.26	0.70±0.2	0.47±0.12
TD	0.27±0.05	0.40±0.13	0.30±0.10	2.60±0.62	0.37±0.03	0.25±0.04
DAB	0.30±0.13	0.21±0.09	0.42±0.13	0.21±0.03	0.31±0.03	0.28±0.03
DFBH1	1.90±0.10	3.17±0.88	2.00±0.9	2.63±0.77	2.23±1.3	2.17±1.6
DFBH 2	3.93±1.62	9.37±5.84	3.13±1.29	13.10±2.62	4.30±1.51	4.50±1.67

Explanation: thallus length (TL), total length (TotL), diameter of primary stipe (DPS), holdfast diameter (HD), lower blade length (LBL), lower blade width (LBW), middle blade length (MBL), middle blade width (MBW), upper blade length (UBL), upper blade width (UBW), thallus diameter (TD), diameter of air bladder (DAB), the distance of the first branch from holdfast (DFBH1), the distance of the second branch from holdfast (DFBH2)

Table 1 shows the variation of *S. polycystum* morphometric characters based on different islands and seasons in the form of the size of thallus parts. Sebesi Island showed the shortest middle blade length, about 2.80±0.36 cm. At the same time, it is the widest of the central blade width (2.00±1.73 cm) during the dry season. Regarding the size of the central blade, the longest was 4.73±0.7 cm, found in Tidung during the dry season, but the shortest was in Bintan throughout the wet (3.20±0.3 cm). It found the tiny upper blade's length and width in Bintan during the dry season of about 2.07±0.66 cm and 0.47±0.12 cm, respectively. On the other hand, the longest and the widest was in the different seasons, namely 3.32±0.87 cm in the dry and 1.20±0.79 cm in the wet season but in the same location, which was in Tidung Island.

Seasonal variations and different locations influenced the dimension of the thallus diameter. It can prove from the finding of the largest thallus diameter in Sebesi with a size of 2.60±0.62 cm and the smallest in Bintan, which is around 0.25 ±0.04 cm in the same period, namely the dry season.

In contrast, the air bladder diameter was only affected by the season. It is indicated by finding the most extensive size during the wet season, which around 0.42±0.13 cm and the smallest occurs in the dry season (0.21±0.03 cm). It found both of the characters only in Sebesi Island. Furthermore, it found the farthest and closest of the first branch's distance from holdfast together in the same location, namely Tidung, which were about 3.17±0.88 cm and 1.9±0.10 cm dry wet season, respectively. The second branch was 13.10±2.62 cm as the furthest in the dry season and was 3.13±1.29 cm in the wet season but only from one location, which was Sebesi.

The macroalgae show a rich variation in size, shape, and structure (BAWEJA et al. 2016). *Sargassum* has a specific part, mainly consist of a vesicle or air bladder and blade with different adaptive functions as a floating device (MEI et al. 2019). (MEI et al. 2019). Noiraksar dan AJISAKA (2008) reported that *S. polycystum* has secondary holdfast, and some of them spread up or without any thorn in the primary branches. Besides, WONG et al. (2004) stated that secondary holdfast changed into stolon or root-like as the only feature distinguishes this species from *S. baccularia.* SOE-HTUN et al. (2012) described that this species' growth influenced by season and optimally grow in intertidal and subtidal zones by sticking to a solid substrate. May-LIN DAN CHING-LEE (2013) reported that *S. polycystum* that grow in Teluk Kemang, Malaysia showed the maximum average thallus length was in the dry season of about 228 mm and also in the Thailand waters with average size reach up to < 2.000 mm as maximum (Noiraksa et al. 2006). RAO DAN RAO (2002) also described that the growth of *S. polycystum* thallus is varied in different times and seasons in the Visakhapatnam India, with an average length of up to 15.9 cm. The diverse location is also significantly affecting the variation of size and shape of blade and vesicle from the *S. polycystum* grow in the central Java waters (WIDYARTINI et al. 2017).

The research shows the percentage of total length and thallus length of *S. polycystum* reach the utmost condition during the dry season. The primary thallus has several primary branches, the so-called primary lateral. Generally, this species consists of the flat and discoid holdfast. It's also complemented by fine root-like at the bottom of its thallus. The stipe is a roundly cylindrical and commonly has a short distance between the first branch to the holdfast, and it's brown to dark-brown color. Blade/leaf is flat brown to light-brown color with dots in the middle, oval lancet-shape with a tapered tip, and blunt edges. The air bladder or vesicle commonly attached to the blade's bottom has a function to float in the water during immersing. It is a round-shape slightly oval and dark brown. Figure 3 shows the morphological characteristics of *S. polycystum*.

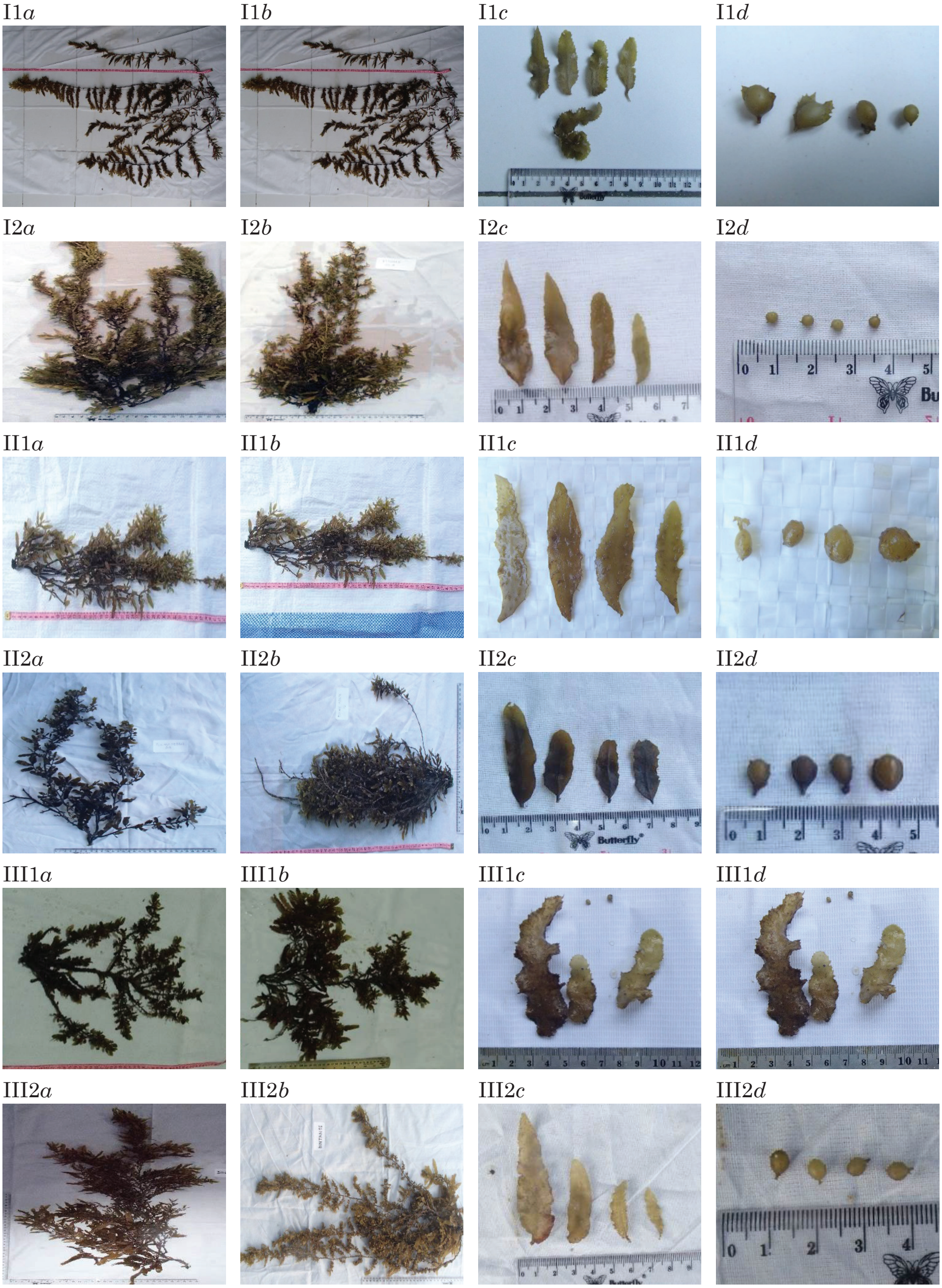

Fig. 3. *Sargassum polycystum* features from 3 different locations and two seasons (photo by I Ketut Sumandiarsa)

Explanation: I – Tidung; II – Sebesi; III – Bintan; 1 – wet season; 2 – dry season; *a* – total length; *b* – thallus length; *c* – lower, middle and upper blade, *d* – air bladder

Moreover, macroalgae can be found easily in shallow water and sticking in rigid substrates such as death coral, coral fragments, stone, and rocky substrate. Furthermore, WONG et al. (2004) stated that the character *of S. polycystum* is the form of the muricate primary stipe; the leaves are oblanceolate with dentate margins. Furthermore, the discoid-shaped holdfast is equipped with dioecious round vesicles. DAN PAYRI (2009) reported that the *Sargassum* population's dispersal could lead to limited genetic differentiation among morphologically different species. The strong holdfast and varying diameter are part of algae's macro adaptation to the constant circulation of seawater carrying nutrients causing mechanical stress. These differences also lead to morphological variations of the branches, leaves, and *Sargassum* vesicles depending on age and habitat (BAWEJA et al. 2016). A research finding by (LIU et al. 2018) concluded that the variation of locations and seasons significantly influences the reproduction part disparity of *Sargassum horneri*.

Trace Elements Content

Figure 4 shows the trace element (TE) content of *S. polycystum* in the three study sites. It found that differences in locations and seasons influence the TE content. Based on the wet season, the Mn content dominates Tidung Island, Sebesi Island, and Bintan Island. On the contrary, the three locations show the fact that Se was the lowest in the wet season, and Molybdenum (Mo) was not detectable in all islands and seasons. The wet season dominated by Mn content in all research locations, and Se content showed the opposite in those sites.

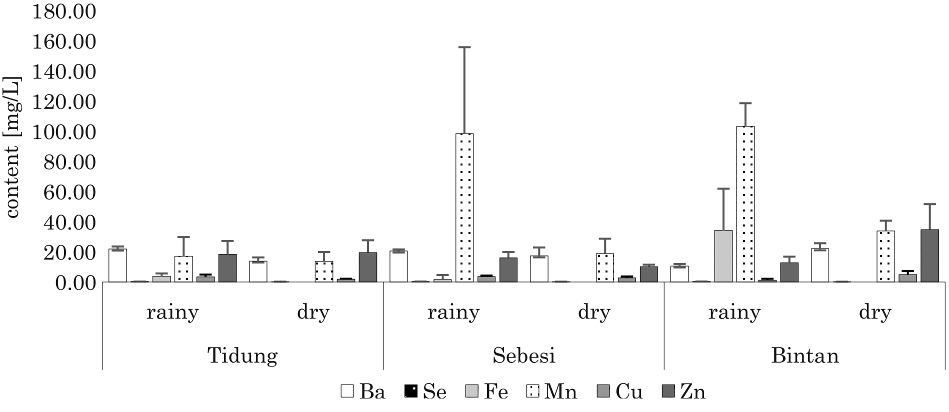

Fig. 4. Trace element composition in different island and season

Regarding the dry season, the content of iron (Fe) was the lowest in all islands (Figure 4). Overall, it can figure out the content of TE from the highest to the lowest in Tidung Island is as the pattern of Ba > Zn> Mn > Cu > Fe > Se during the wet and Zn > Ba > Mn > Cu > Se > Fe in the dry season. On the other hand, Sebesi Island has pattern as Mn > Zn > Fe > Ba > Cu >Se >Fe and Mn > Ba > Zn > Se > Fe during the wet and dry seasons, respectively. A different pattern found in Bintan in the two seasons as well, which are Mn > Fe > Zn > Ba > Cu > Se in the wet and Mn > Zn > Ba > Se > Cu > Fe in the dry.

Overall, the highest content of trace elements found in all locations was Mn with 103.29 mg/L, and Mo content was the lowest with no detection by the AAS. Based on seasonal variations, it found that Mn with 103.29±15.21 mg/L as the highest and 0.2 ± 0.01 mg/L of Se was the lowest detected trace element in the wet season. Meanwhile, Fe content as the lowest, and Mn content during the dry season as the highest with average amounts was 0 mg/L and 33.88 ± 6.76 mg/L. In general, these results indicate that the differences in location and season affect the composition of trace element content in the research locations' waters.

Fe's elemental content in the seaweed is more dominant in Bintan Island; however, in the other two islands, it is few, and there is even no detectable element of iron (Fe). Iron contributes to metabolism and promotes enzyme activity. Se content was detected to stand out from the other content. According to FAIRWEATHER-TAIT et al. (2011), this element is notable, where Se has a significant function in maintaining DNA stability and stopping the cell cycle. The Se content in this study was 0.1–0.3 mg/L. This value is still within the safe threshold value of 0.01–2.0 mg/kg, with an overall mean of 0.4 mg/L (FORDYCE 2013).

Moreover, trace elements on the three islands contain Zn, but Bintan waters have the highest. Zn plays a vital role in growth. Cu and Zn are the main components of various enzymes involved in energy metabolism (OSREDKAR dan SUSTAR 2011). MATANJUN et al. (2009) reported that the Zn content in *S. polycystum* was more dominant than Cu.

MATANJUN et al. (2009) also reported that the Fe content in *S. polycystum* was found to be 68.21±0.03 mg 100 g − 1 DW and Se 1.14±0. 03 mg. 100 g − 1 DW. Fe can function as a component of various metabolic processes, oxygen transport, electron transfer, and oxidase activity. On the other hand, Mn elements can serve as cofactors of metalloenzymes (superoxide dismutase, arginase, and pyruvate carboxylase) and associated with amino acids' metabolism, lipids, and carbohydrates. Se also comes with several functions, namely antioxidants, immunity, and hormone metabolism. Se in seawater shows 0.4–0.5 mg/L (CHAU DAN RILEY 1965). MEHDI et al.

(2013) stated that Se found to vary according to soil type and texture, organic matter content, and rainfall. Assimilation by plants influenced by soil physicochemical factors, including redox status, pH, and microbiological activity.

The Characteristics of the Aquatic Environment

Table 2 shows the indicators of water fertility in the three islands, namely the nitrate content of 0.23–1 mg/L, orthophosphate 0.004–0.047 mg/L, and ammonia 0.09–2.35 mg/L. Nitrate content was increased from 0.23–0.77 mg/L during the wet to 0.24–1 mg/L in the dry season.

Table 2

Seawaters quality of *S. polycystum* habitat in Tidung, Sebesi, and Bintan Islands

Location	Season	Nitrate (NO^{3-}) [mg/L]	Orthophosphate (PO_4^{3-}) [mg/L]	Ammonia (NH^{3-}) [mg/L]
Tidung	wet	0.23±0.1	0.047±0.01	0.09±0.003
	dry	0.24±0.2	0.022±0.004	0.84±0.05
Sebesi	wet	0.27±0.1	0.004±0.003	0.27±0.04
	dry	0.26±0.1	0.027±0.003	0.06±0.01
Bintan	wet	0.77±0.3	0.058±0.009	2.35±0.3
	dry	1.00±0.7	0.008±0.005	0.81±0.1

The wet season's orthophosphate content ranges from 0.004–0.058 mg/L, and the dry season is 0.008–0.027 mg/L. The ammonia content in the wet season is 0.09–2.35 mg/L, and the dry season is 0.06–0.84 mg/L, which means the highest ammonia content found in the wet season. Based on the fertility of the waters in terms of the island, it shows that the highest nitrate concentration found on Bintan Island and the lowest is on Tidung Island, the highest orthophosphate content found on Bintan Island and the lowest is on Sebesi Island. Furthermore, the most increased ammonia found on Bintan Island, and the lowest is on Sebesi Island. It can infer that seasonal and location variations influenced the concentration of these waters' quality indicators. Seaweed growth is mainly depending on the availability of essential elements, which are inorganic carbon, nitrogen, and phosphorus in the environment (Roleda and Hurd 2019).

Table 3

The physio-chemical characteristics of Tidung, Sebesi, and Bintan waters

Location	Season	DO [mg/L]	pH	Temperature [^{o}C]	Salinity (PSU)	Brightness [%]
Tidung	wet	5.61±0.1	7.40±0.2	31.6±0.4	34.67±0.6	100±0.0
	dry	6.53±0.8	7.35±0.3	27.53±0.1	35.53±0.4	100±0.0
Sebesi	wet	5.58±0.3	7.55±0.2	30.8±1.6	33.93±1.6	100±0.0
	dry	7.53±1.4	7.26±0.3	28.67±0.7	34.33±1.2	100±0.0
Bintan	wet	5.88±0.5	7.68±0.1	30.47±0.9	32.2±0.9	100±0.0
	dry	7.77±0.6	7.43±0.4	29.8±3.8	34.33±1.15	93.3±11.6

Table 3 shows the water quality of the three islands, which differed by season. The influence of the season on the quality of DO shows a difference; namely, the wet season DO lower than the dry season. As for the overall DO value is 5.61–7.77 mg/L, which indicates it is within normal limits for plant survival. The wet season's pH and temperature conditions are higher than in the dry season, it is 7.26–7.55 and 27.53–31.6^{o}C, respectively. The salinity in the dry season is higher than the wet season in the three islands. Salinity ranges from 32.2–35 PSU in all sites.

In terms of location in Table 3, we found the highest DO and pH on Bintan Island, and the lowest was on Sebesi Island. The highest and lowest temperatures are on Tidung Island. We found the highest salinity concentration on Tidung Island of about 35.53±0.4 PSU, and the lowest was on Bintan Island in approximately 32.2±0.9 PSU. In general, the brightness shows similarities in season, but only Bintan Island reveals a difference during the dry season. It is due to community activities that affect the level of water transparency. Table 3 shows the temperature conditions of 27.53–31.6^{o}C and salinity of 32.2–35 PSU. This value has the similarity reported by Zou et al. (2018), stated that it found that *S. polycystum* grows well at the temperature of 15–25°C and the salinity of 20–40 PSU. Haas et al. (2014) has stated that increasing seawater temperature can reduce the amount of dissolved oxygen content and cause the photosynthetic process of seaweed.

Figure 5 shows the result of the discriminant analysis of the effect of the island's aquatic conditions on the morphology of *S. polycystum*. F_1 factor 86.07% and F_2 factor 13.93% with a total of 100%. ndBased on the Wilks' Lambda test, it shows a *p*-value of 0.027 with an alpha of 0.05 ($p < 0.05$) meaning that the three islands have different characteristics. The Wilks' Lambda number is close to 0, so there tends to be a difference within the group. F_1 factors consist of LBL, LBW, MBL, UBL, UBW, DFBH1, and DFBH2. F_2 aspect includes TL and TotL.

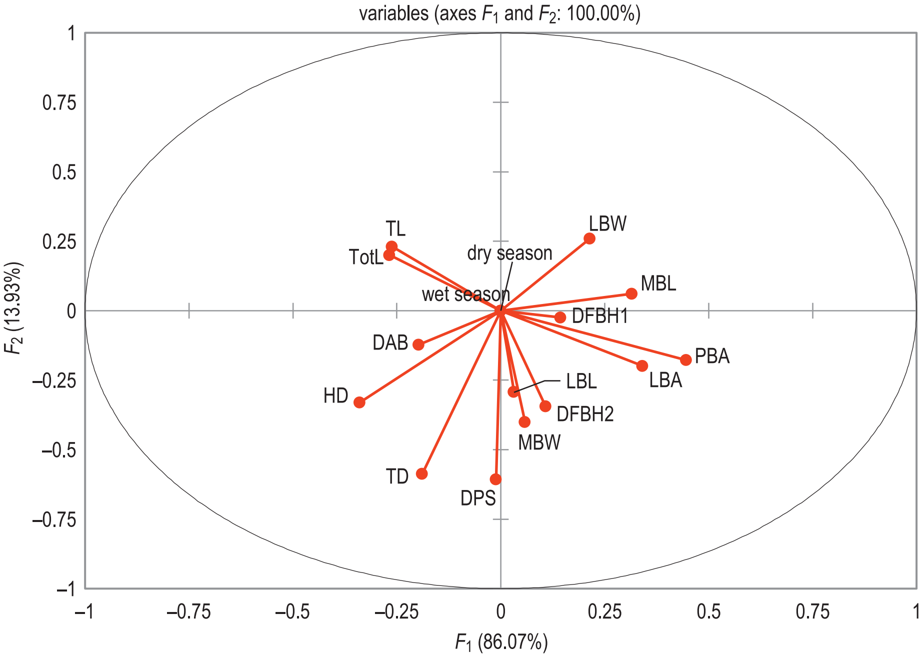

Fig. 5. Morphological characteristics of *S. polycystum* based on different location by using discriminant analysis

Explanation: thallus length (TL); total length (TotL); diameter of primary stipe (DPS); holdfast diameter (HD); lower blade length (LBL); lower blade width (LBW); middle blade length (MBL); middle blade width (MBW); upper blade length (UBL); upper blade width (UBW); thallus diameter (TD); diameter of air bladder (DAB); the distance of the first branch from holdfast (DFBH1); the distance of the second branch from holdfast (DFBH2)

The Relationship Between the Morphology of *S. polycystum* and the Environment Characteristics

The morphological analysis using PCA successfully uncovered the differences in the morphological characteristics of *S. polycystum* as a targeted sample in this study by separating its habitat into three island characteristics (Figure 6). Factors F_1 23.96% and F_2 15.27% with a total of 39.22%. The loading factor (F_1) shows that ammonia and pH have a positive relationship with the content of trace elements Se, Fe, Mn, and morphometric character of the lower blade length and upper blade width. Besides, DO and salinity showed a positive association with the distance of first and second branches to the holdfast (DFBH1 and DFBH2) in *S. polycystum*. The second loading factor (F_2) shows that nitrate, temperature, and brightness correlated with holdfast diameter (HD), central blade length (CBL), upper blade length (UBL), and thallus diameter (TD), but negatively correlated with the distribution of trace elements of Zn in *S. polycystum* habitat. It means that the higher the water temperature causes HD, CBL, UBL, and TD is getting bigger.

The analysis results based on (Figure 6) show that brightness is the main requirement for the growth and development of *S. polycystum* in the coastal area. The brightness level causes *S. polycystum* to have the ability to absorb CO_2 and produce O_2 in seawater for photosynthesis (KOMATSU DAN KAWAI 1986, KOMATSU 1989). According to BAWEJA et al. (2016), seaweed distribution depends on physical factors like temperature, quality, and quantity of light, dynamic tidal activity, winds, and storms. It is also correlated with chemical elements such as salinity, pH, nutrients, and pollution. Biological factors involve following herbivores, microbes, epiphytes, endophytes, symbionts, parasites, and diseases.

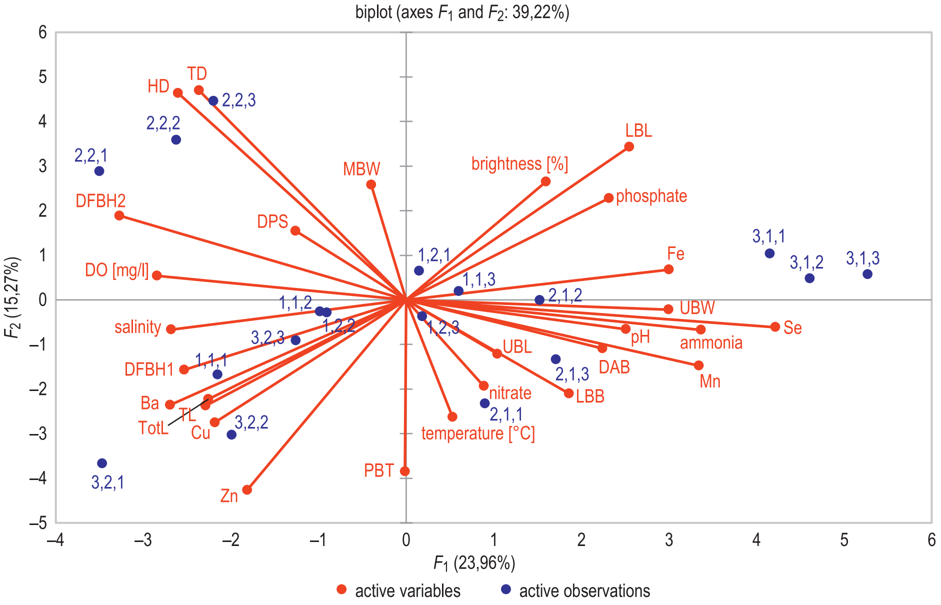

Fig. 6. The relationship between morphological characteristics of *S. polycystum* and environmental conditions

In general, seaweed growth requires an area with sufficient nutrients and light for growth and salinity and temperature (CAMPBELL et al. 2019). Seaweed biomass fluctuation associated with various biotic (competition, herbivory) and abiotic (light, temperature, wave, nutrition) factors (FULTON et al. 2017). HWANG et al. (2004) reported that the maximum growth temperature of *S. polycystum* was at 15–25°C in the south Taiwan waters. The growth of seaweed responds to the ever-changing physical biotic and abiotic factors (ROLEDA and HURD 2019). Seasonal changes and variations in abiotic factors and temperature, salinity, pH, nutrients, and water movement are also driving *Sargassum*'s annual growth cycle.

According to CHUNG et al. (2007), the temperature has a high impact on marine morphology and geographic distribution of wild seaweed. Furthermore, AGRAWAL (2009) added that weather has a role in regulating reproduction. On the other hand, studies conducted on coral reefs in Southern Taiwan indicated that water temperature impacted abundance for *S. siliquosum* but negatively correlated with *S. polycystum*. The increasing temperature could reduce *S. polycystum* cover (±9.62% coverage) in that region. So, seasonal dynamics, species, temperature limits, and nutrient utilization strategies can all influence *S. polycystum* growth and abundance.

PCA shows that the temperature correlates with holdfast diameter (HD), middle blade length (MBL), upper blade length (UBL), and thallus diameter (TD). It implies that the higher the water temperature causes HD, MBL, UBL, and TD to be bigger or more extended and vice versa. In general, the growth of *S. polycystum* is divided into three periods, namely accretion, reproduction, and degeneration in a year. The typical growth cycle in *Sargassum* species is characterized by a slow accretion phase, a fast-growth phase, and a reproductive phase followed by aging (ANG 2006). RAO AND RAO (2002) reported that the growth pattern of *S. polycystum* was influenced by season and correlated with temperature. The environmental conditions required for seaweed species' growth may vary (KERRISON et al. 2015). *Sargassum* species are controlled by water temperature and related to the wet season because the water temperature is one of the most important factors influencing the Sargassum species' phenological pattern (ANG 2006). Temperature also tends to affect this species' distribution pattern by limiting its growth (KANTACHUMPOO et al. 2014), and the optimal water temperature for the optimal development of tropical *Sargassum* species is 20–25°C (PHANG et al. 2016).

Figure 6 also shows the positive correlation between ammonia and pH, which positively correlates with the trace elements content Se, Fe, Mn, and morphometric PBB and LBA in *S. polycystum*. Thus, this element affects the dissolved oxygen content in seawater, and consequently, the pH distribution through the carbonate equilibrium in seawater changes the absorption and release of CO2 (KOMATSU et al. 1996). The fluctuations of nitrate content in waters due to seasonal changes can affect the distribution and morphology of *S. polycystum*, as reported by MAY-LIN DAN CHING-LEE (2013) and ANDRÉFOUËT et al. (2017).

Sfriso dan Facca (2013) stated that *Sargassum* shows the advantages of broader distribution and forms of dense populations on the side of ledges, rocks, and rigid substrates. Widyartini et al. (2017) reported that environmental factors that influence the talus's variation in vesicle length are salinity and pH. Meanwhile, temperature, salinity, and pH affect the colour of the vesicles, while nitrate and phosphate affect the width of the blade/leaves and the upper and lower surfaces. Phosphate also affects leaf margins and vesicle diameter. Sfriso dan Facca (2013) also stated that *Sargassum* commonly reached a peak growth of 2.32 cm per day. Species growth is mainly regulated by water temperature, nutrient concentration, especially nitrogen and water turbidity. Nitrate is a compound that contains nitrogen and can dissolve in water. The presence of nitrate content in seawater affects seaweed features such as the formation of a delicate root-like part in its holdfast (Connor dan West 1991). On the other hand, the decreased growth decreased photosynthetic activity, and decreased enzymes are involved in carbon metabolism (Collén et al. 2004, Xiao et al. 2019). Reidenbach et al. (2017) reported that decreased pH affects carbon and nitrogen metabolism of seaweed, for example, that happens in *Ulva australis*; however, it did not involve growth changes.

DO, and salinity shows a positive association with the distance of the first and the second branches from holdfast (DFBH1 and DFBH2, respectively) in *S. polycystum*. These features are closely related to the growth of *Sargassum*. Li et al. (2019) reported that the salinity of seawater affects the development of *Sargassum*, precisely 6.40% per day with 30 PSU, and saltiness is also affecting the quality of the biomass (Niwa and Harada 2013). Salinity is an important environmental factor that influences seaweed growth and distribution, and the seaweed spread in different areas shows different ranges of tolerance to salinity Karsten 2012). Fredersdorf et al. (2009) also stated that each growth cycle of brown seaweed provides an overview of differences in salinity conditions. Seasonal variations affect the level of seawater quality, which impacts changes in the structure of the *Sargassum* canopy and affects population density (Rivera dan Scrosati 2006, Ateweberhan et al. 2009). Anthropogenic pressure was also significant to influence water quality into less fertile and decrease organism growth in coral reef area including macroalga (Januar et al. 2015).

Conclusions

In general conclusion, the factors including geographic environment and seawater quality and nutrient availability can affect the morphometrics of *S. polycystum*. Ammonia and pH have a positive relationship with the content of trace elements Se, Fe, Mn, and morphometric lower blade length (LBL) and upper blade width (UBW). Besides, DO, and salinity showed a positive correlation with the distance of first and second branches from holdfast (DFBH1 and DFBH2). Meanwhile, the nitrate, temperature, and brightness correlated with Holdfast diameter (HD), middle blade length (MBL), upper blade length (UBL), and the thallus diameter (DT). The optimum environmental temperature conditions for this species grow in the three different locations are 27.530–31.6°C. DO, which exceeds the threshold in the waters, around 5.61–7.77 mg/L, has supported the growth and development of *S. polycystum* and correlated with the larger holdfast diameter (HD) and the upper blade length (UBL), which is getting longer.

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References

AGRAWAL S.C. 2009. *Factors affecting spore germination in algae – Review*. Folia Microbiologica, 54(4): 273–302.

ANDRÉFOUËT S., CLAUDE P., SIMON V.W., OLIVIER L., SEMESE A., GARRY P., HIROYA Y., SOPHIE B. 2017. *The timing and the scale of the proliferation of Sargassum polycystum in Funafuti Atoll, Tuvalu*. Journal of Applied Phycology, 29(6): 3097–3108.

ANG P.O. 2006. *Phenology of Sargassum* spp. *in Tung Ping Chau Marine Park, Hong Kong SAR, China*. Journal of Applied Phycology, 18(3–5): 629–36.

ASRININGRUM W. 2009. *Pengelompokan pulau kecil dan ekosistemnya berbasis geomorfologi di indonesia*. IPB University, Bogor-Indonesia (Ph.D. *thesis)*.

ATEWEBERHAN M.J., HENRICH B., ANNEKE M.B. 2009. *Seasonal changes in size structure of Sargassum and Turbinaria populations (Phaeophyceae) on tropical reef flats in the Southern Red Sea*. Journal of Phycology, 45(1): 69–80.

BAWEJA P.S., KUMAR D.S., LEVINE I. 2016. S*eaweed in health and disease prevention*: *biology of Seaweeds*. Elsevier Inc., doi: 10.1016/B978-0-12-802772-1.00003-8.

BORAZJANI NILOOFAR J., MEHDI T., SANG G.Y., MASOUD R. 2017. *Effects of extraction methods on molecular characteristics, antioxidant properties and immunomodulation of Alginates from Sargassum angustifolium*. International Journal of Biological Macromolecules, 101: 703–11.

Camacho O., Mattio L., Draisma S., Fredericq S., Diaz-Pulido G. 2015. *Morphological and molecular assessment of Sargassum (Fucales, Phaeophyceae) from Caribbean Colombia, including the proposal of Sargassum giganteum* Sp. *nov., Sargassum schnetteri comb. nov. and Sargassum section Cladophyllum sect. nov*. Systematics and Biodiversity, 13(2): 105–30.

Campbell I., Adrian M, Christian S., Luiza N., Jon F., Margareth Ø., Adam D.H., Michele S. 2019. *The environmental risks associated with the development of seaweed farming in Europe. Prioritizing key knowledge gaps*. Frontiers in Marine Science, 6(MAR): 1–22.

Chung I., Ray-Lien H,, Sin-Haw L., Tzure-Meng W., Jing-Ying W., Chung-Sin C., Tse-Min L. 2007. *Nutrients, temperature, and salinity as primary factors influencing the temporal dynamics of macroalgal abundance and assemblage structure on a reef of Du- Lang Bay in Taitung in Southeastern Taiwan*. Bothanical Studies, 48: 419–33.

Collén P.N., Astrid C., Robert D.H., Roberto V., Marianne P. 2004. *Effect of nutrient deprivation and resupply on metabolites and enzymes related to carbon allocation in Gracilaria Tenuistipitata (Rhodophyta).* Journal of Phycology, 40(2): 305–14.

Connor K.A.O., West J.A. 1991. *The effect of light and nutrient conditions on hair cell formation in Spyridia filamentosa (Wulfen) Harvey (Rhodophyta)*. Botanica Marina, 34(4): 359–364.

Dharmayanti N., Jatna S., Abinawanto, Yasman. 2019. *Isolation and Partial characterization of Alginate extracted from Sargassum polycystum collected from three habitats in Banten, Indonesia. Biodiversitas,* 20(6): 1776–85.

Dickson P., Negeri S. 2015. *Morphological Studies of Marine Macroalgae at Sri Rusa Beach, Port Dickson, Negeri sembilan, Malaysia*. Educatum Journal of Science, Mathematics and Technology, 2(1): 24–33.

Fairweather-Tait S.J., Yongping B., Martin R.B., Rachel C., Dianne F., John E.H., Rachel H. 2011. *Selenium in human health and disease: A review*. Antioxidants & Redox Signaling, 14(7): 1337–83.

Fertah M. 2017. *Seaweed polysaccharides. Isolation, biological and biomedical applications: isolation and characterization of Alginate from Seaweed,* Elsevier Inc., pp. 11–26.

Fordyce F.M. 2013. *Selenium deficiency and toxicity in the environment. In: Essentials of medical geology*. Ed. O. Selinus. *Springer, Dordrecht,* doi: 10.1007/978-94-007-4375-5_16.

Fredersdorf J., Ruth M., Susanne B., Christian W., Kai B. 2009. *Interactive effects of radiation, temperature and salinity on different life history stages of the Arctic kelp Alaria esculenta (Phaeophyceae)*. Oecologia, 160(3): 483–92.

Fulton C.J., Martial D., Thomas H.H., Mae M.N., Ben R., Thomas W., Shaun K.W. 2017. *Sea temperature shapes seasonal fluctuations in seaweed biomass within the Ningaloo Coral Reef Ecosystem*. Limnology and Oceanography, 59(1): 156–66.

Guiry M.D, Guiry, G.M. 2020. *AlgaeBase. World-wide electronic publication, National University of Ireland*, Galway. http://www.algaebase.org, access: 17.02.2020.

Haas A.F., Jennifer E.S., Melissa T., Dimitri D.D. 2014. *Effects of reduced dissolved oxygen concentrations on physiology and fluorescence of hermatypic corals and benthic algae*. Peer J. 2014(1): 1–19.

Hermund D.B. 2018. *Antioxidant properties of seaweed-derived substances*. Elsevier Inc.

Hwang R.L., Chuan C.T., Tse M.L. 2004. *Assessment of temperature and nutrient limitation on seasonal dynamics among species of Sargassum from a coral reef in Southern Taiwan*. Journal of Phycology, 40(3): 463–73.

Januar, H.I., Ekowati C., Dianne M.T., Cherie A.M., Catherine H.L., Anthony D.W. 2015. *Influence of anthropogenic pressures on the bioactivity potential of sponges and soft corals in the coral reef environment*. Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology, 10(2): 51–59.

Kantachumpoo A., Shinya U., Thidarat N., Teruhisa K. 2014. *Levels and distribution patterns of mitochondrial COX3 gene variation in brown seaweed, Sargassum polycystum C. Agardh (Fucales, Phaeophyceae) from Southeast Asia*. Journal of Applied Phycology, 26(2): 1301–1308.

Kerrison P.D., Michele S.S., Maeve D.E., Kenneth D.B., Adam D.H. 2015. *The cultivation of European kelp for bioenergy: site and species selection*. Biomass and Bioenergy, 80: 229–42.

Li J., Yingchao L., Yan L., Qiaohan W., Xu G., Qingli G. 2019. *Effects of temperature and salinity on the growth and biochemical composition of the brown Alga sargassum fusiforme (Fucales, Phaeophyceae).* Journal of Applied Phycology, 31(5): 3061–68.

Liu F., Xingfeng L., Yu W., Zhe J., Fiona W.M., Song S. 2018. *Insights on the Sargassum horneri golden tides in the yellow sea inferred from morphological and molecular data.* Limnology and Oceanography*,* (April 2017).

Matanjun P., Suhaila M., Noordin M.M., Kharidah M. 2009. *Nutrient content of tropical edible seaweeds, Eucheuma cottonii, Caulerpa lentillifera and Sargassum polycystum*. Journal of Applied Phycology, 21(1): 75–80.

Mattio L., Claude E.P. 2009. *Taxonomic revision of Sargassum Species (Fucales, Phaeophyceae) from New Caledonia based on morphological and molecular analyses*. Journal of Phycology, 45(6):1374–88.

May-Lin B.Y., Wong C.L. 2013. *Seasonal growth rate of Sargassum species at Teluk Kemang, Port Dickson, Malaysia.* Journal of Applied Phycology, 25(3): 805–14.

Mehdi Y., Jean L.H., Louis I., Isabelle D. 2013. *Selenium in the environment, metabolism and involvement in body functions.* Molecules, 18(3): 3292–3311.

Mei X., Chunhui W., Jin Z., Tian Y., Peng J. 2019. *Community structure of bacteria associated with drifting Sargassum horneri, the Causative species of Golden Tide in the Yellow Sea.* Frontiers in Microbiology, 10: 1–17.

Muta Harah Z., Japar S.B., Natrah F.M.I., Emmclan L.S.H., Wan Hazma, W.N., Nordiah B. 2014. *Seaweed community of the Merambong Shoal, Sungai Pulai Estuary, Johore*. Malayan Nature Journal, 66(1, 2): 117–31.

Niwa K., Kazuhiro H. 2013. *Physiological responses to nitrogen deficiency and resupply in different blade portions of Pyropia yezoensis f. narawaensis (Bangiales, Rhodophyta).* Journal of Experimental Marine Biology and Ecology, 439: 113–18.

Noiraksar T., Tetsuro A., Chatcharee K. 2006. *Species of S. Argassum in the East Coast of the Gulf of Thailand*. Science Asia, 32(1): 99–106.

Noiraksar T., Tetsuro A. 2008. *Taxonomy and distribution of Sargassum (Phaeophyceae) in the Gulf of Thailand*. Journal of Applied Phycology, 20(5): 963–77.

Noiraksar T., Vipoosit M., Aunkul B., Teruhisa K. 2017. *Growth and reproductive seasonal pattern of Sargasswn polycystum C. Agardh (Sargassaceae, Phaeophyceae) population in Samaesarn Island, Chon Buri Province, Thailand*. La Mer*,* 55: 11–23.

Osredkar J., Natasa S. 2011. *Copper and zinc, biological role and significance of copper/zinc imbalance. J*ournal of Clinical Toxicology, S3(001): 1–18.

Perumal B., Chitra R., Maruthupandian A., Viji M. 2019. *Nutritional assessment and bioactive potential of Sargassum polycystum c. Agardh (Brown Seaweed).* Indian Journal of Geo-Marine Sciences, 48(4): 492–98.

Phang S.M., Hui Y.Y., Edna T.GF., Khanjanapaj L., Anchana P., Le N.H., Grevo S.G., Koh S.T. 2016. *Marine Algae of the South China Sea bordered by Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam*. Raffles Bulletin of Zoology, 34: 13–59.

Puspita M., Nur A.R.S., Valérie S-P., Laurent V., Ita W., Ocky K.R., Gilles B., Nathalie B. 2020. *Indonesian Sargassum species bioprospecting. Potential Applications of bioactive compounds and challenge for sustainable development*, vol. 95, Elsevier Ltd.

Reidenbach L.B., Pamela A.F., Pablo P.L., Fanny N., Christina M.M., Andrew T.R., Catriona L.H., Janet E.K. 2017. *Growth, ammonium metabolism, and photosynthetic properties of Ulva australis (Chlorophyta) under decreasing ph and ammonium enrichment. PLoS ONE,* 12(11): 1–20.

Rice E., Baird R.B., Eaton A. 2017. *Standard methods for the examination of water and wastewater.* 23rd. Vol. 23. American Water Works Association, USA.

Rivera M., Ricardo S. 2006. *Population dynamics of Sargassum lapazeanum (Fucales, Phaeophyta) from the Gulf of California, Mexico*. Phycologia, 45(2): 178–89.

Roleda M.Y., Catriona L.H. 2019. Seaweed nutrient physiology*. Application of concepts to aquaculture and bioremediation*. Phycologia, 58(5): 552–62.

SETYAWIDATI N.A.R., MAYA P., AWALUDIN H.K., ITA W., ERIC D., NATHALIE B., VALÉRIE S-P. 2018. *Seasonal biomass and alginate stock assessment of three abundant genera of brown macroalgae using multispectral high resolution satellite remote sensing. A Case study at Ekas Bay (Lombok, Indonesia).* Marine Pollution Bulletin, 131(February): 40–48.

SFRISO A., FACCA C. 2013. *Annual* Growth and Environmental Relationships of the Invasive Species *Sargassum muticum and Undaria pinnatifida in the Lagoon of Venice*. Estuarine, Coastal and Shelf Science, 129: 162–72.

EL SHAFAY S.M., SAMH S.A., MOSTAFA M. E-S. 2016. *Antimicrobial Activity of some seaweeds species from Red Sea, against multidrug resistant bacteria.* Egyptian Journal of Aquatic Research*,* 42(1): 65–74.

SOE-HTUN U., MYA K.W., SOE P.P.K., MYO M.T., HSU M.O. 2012. *The Morphotaxonomy and phytogeographical distribution of the species of Sargassum section Polycystae (Fucales, Phaeophyta) from Myanmar: Sargassum polycystum C. Agardh.* Mawlamyine University Research Journal, 4(1): 1–19.

SRINIVASA R.A., UMAMAHESWARA R.M. 2002. *Seasonal growth pattern in Sargassum polycystum C. Agardh (Phaeophyta, Fucales) occurring at Visakhapatnam, East Coast of India.* Indian Journal of Marine Sciences, 31(1): 26–32.

WIDYARTINI D.S., WIDODO P., SUSANTO A.B. 2017. *Thallus variation of Sargassum polycystum from Central Java, Indonesia*. Biodiversitas, 18(3): 1004–1011.

WILLIAMS A., RUSTY F. 2010. *Sargassum as a natural solution to Enhance Dune plant growth.* Environmental Management, 46(5): 738–347.

WIRYAWAN B., DIETRIECH G.B., IRFAN Y., HANDOKO A.S., ALI K.M., MARIZAL A. 2002. *Profil Sumberdaya Pulau Sebesi*. Jakarta: Penerbitan Khusus Proyek Pesisir, Coastal Resources Center – University of Rhode Island. Narraganset, Rhode Island.

WONG C-L., SOOK Y.G., SIEW M.P. 2004. *Morphological and molecular characterisation and differentiation of Sargassum baccularia and S. Polycystum (Phaeophyta).* Journal of Applied Phycology, 16(6): 439–45.

XIAO X., SUSANA A., FANG L., CAICAI X., YAN Y., YAORU P., KE L., JIAPING W., CARLOS M.D. 2019. *Resource (light and nitrogen) and density-dependence of seaweed growth.* Frontiers in Marine Science, 6(October): 1–5.

ZOU X.X., SHAN S.X., XING S., JUN Z., HUI Q.H., SHI X.B. 2017. *The effects of temperature, salinity and irradiance upon the growth of Sargassum polycystum C. Agardh (Phaeophyceae).* Journal of Applied Phycology, 30(2): 1207–1215.