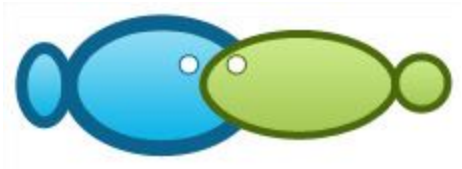

Growth response and quality of seaweed *Kappaphycus alvarezii* cultivated in various coastal ecosystems in the waters of West Sulawesi, Indonesia

[1]Parman Parakkasi, [2]Chair Rani, [2]Radjuddin Syam, [2]Zainuddin, [2,3]Marlina Achmad

[1] Postgraduate School, Fisheries Science Study Program, Universitas Hasanuddin, Makassar, Indonesia; [2] Faculty of Marine Sciences and Fisheries, Universitas Hasanuddin, Makassar, Indonesia; [3] Excellent Center for Development and Utilization of Seaweed, Hasanuddin University, Makassar, Indonesia. Corresponding author: M. Achmad, marlina.achmad@unhas.ac.id

Abstract. Seaweed *Kappaphycus alvarezii* cultivation is still a potential business and is the main preference in coastal areas both in Indonesia and in the world, due to the relatively easy and inexpensive cultivation techniques, and shorter harvest time. The development of seaweed cultivation technology has undergone many changes and modifications in accordance with the region and the business capacity of fishermen. At the moment, the application of seaweed cultivation technology is dominated by the long-line system. Furthermore, the difference in the substrate as one of the technologies applied is used in improving the growth and quality of seaweed. Coral reef, seagrass and sand ecosystems are used as substrate for seaweed growth. The results of this study showed that the influence of aquatic bottom ecosystems was significant on the growth of seaweed *K. alvarezii* at culture length of 30 and 45 days. The quality of the content of carrageenan showed significantly different results from different ecosystems, although the strength of gel and viscosity produced were the same from coral, seagrass and sandy ecosystems. Based on the principal component analysis (PCA) analysis, high seaweed growth and gel content were associated with high pH and PO_4 content. While the high carrageenan content, is associated with high NO_3 and total organic matter contents. Whereas, high seaweed viscosity value is associated with high salinity and dissolved oxygen content.

Key Words: aquatic bottom ecosystem, *Kappaphycus alvarezii*, growth, seaweed quality, West Sulawesi.

Introduction. Seaweed *Kappaphycus alvarezii* is a fishery commodity with a very wide distribution area covering almost all the world, including Asia, Africa, and America, and greater production is contributed by Asian countries (Kim et al 2017). Total global seaweed production was 30,139 tons of wet weight in 2016 and the largest contributors from the main producing countries are China, Indonesia, and Philippines with production percentage of 47.9%, 28.7%, and 4.7% respectively (FAO 2018). Several areas in Sulawesi Island are main sources of seaweed *K. alvarezii* from Indonesia e.g. Southeast Sulawesi (Nesih 2013), Gorontalo (Fadilah et al 2016), North and Southeast Sulawesi (Yulianto et al 2017). The other part of Sulawesi i.e. West Sulawesi, that dominated by coasts and seas is a potential and promising location for seaweed culture.

West Sulawesi has an area of 16,937.16 km^2 which spreads between $0^o12'$-$3^o38'$ South latitude and $118^o43'15"$-$119^o 54'3"$ East longitude. Topographical conditions indicate that West Sulawesi is an area on the western coastline of Sulawesi Island and consists of deep sea, shallow sea, mountains, hills, and plain. The western part of the area was developed for fishery potential including seaweed culture activities which were able to produce 17,552 tons in 2010 (https://www.slideshare.net/ssuser200d5e/rpjm-provinsi-sulawesi-barat-2012-2016).

Development of seaweed *K. alvarezii* culture expands very quickly due to the simple technology of cultivation, low start-up capital, and the cycle of rapid growth

(Webber et al 2012), as well as the potential benefits would be substantial carrageenan (Sahu et al 2011; Ingle et al 2018). Carrageenan is widely utilized as a gel forming agent for stabilizers and emulsifiers in the pharmaceutical, cosmetic and food industries (Raman & Doble 2015). Carrageenan quality may be measured physically through gel strength and viscosity (Webber et al 2012). In addition to carrageenan, growth is also an indicator of the success of seaweed production. High production can be achieved by considering the growth factors of seaweed including seeds, nutrition, environment and water conditions including substrate waters. In general, seaweed cultivation is carried out at a depth of 0.5 m to 2 m with a substrate of coral bottom (Mulyani et al 2018).

When the seaweed culture has been established in an area, the location of cultivation is often producing a problem, for example the closure of access to the beach and social conflicts in claiming lands. In fact, it often has penetrated into seagrass and coral reef ecosystems. On the other hand, scientific information regarding the comparison of the growth response of seaweed maintained in various ecosystems is not available yet.

Seaweed *K. alvarezii* culture have been practiced with some methods such as the long-line, off-bottom, floating raft, and basket methods (Kim et al 2017). Commonly used method is the long-line because of the materials invested may be used in the longer term. The purpose of this study was to analyze the response of growth and quality of *K. alvarezii* cultivated in various aquatic ecosystems (bottom ecosystem) using long-line method in the waters of West Sulawesi.

Material and Method

Collection of seaweed seed and culture location. This research was conducted in May to October 2017 at the Mamuju Coastal meeting, Mamuju Regency, West Sulawesi Province, Indonesia. Seed of young and healthy seaweed *K. alvarezii* was collected from the cultivation sites of the seaweed in Mamuju, West Sulawesi. Furthermore, the seagrass seed was brought to the location of the research to be cultivated in the coastal waters with different ecosystems i.e. in the area of seaweed culture with coral reef, seagrass and sandy ecosystems (Figure 1).

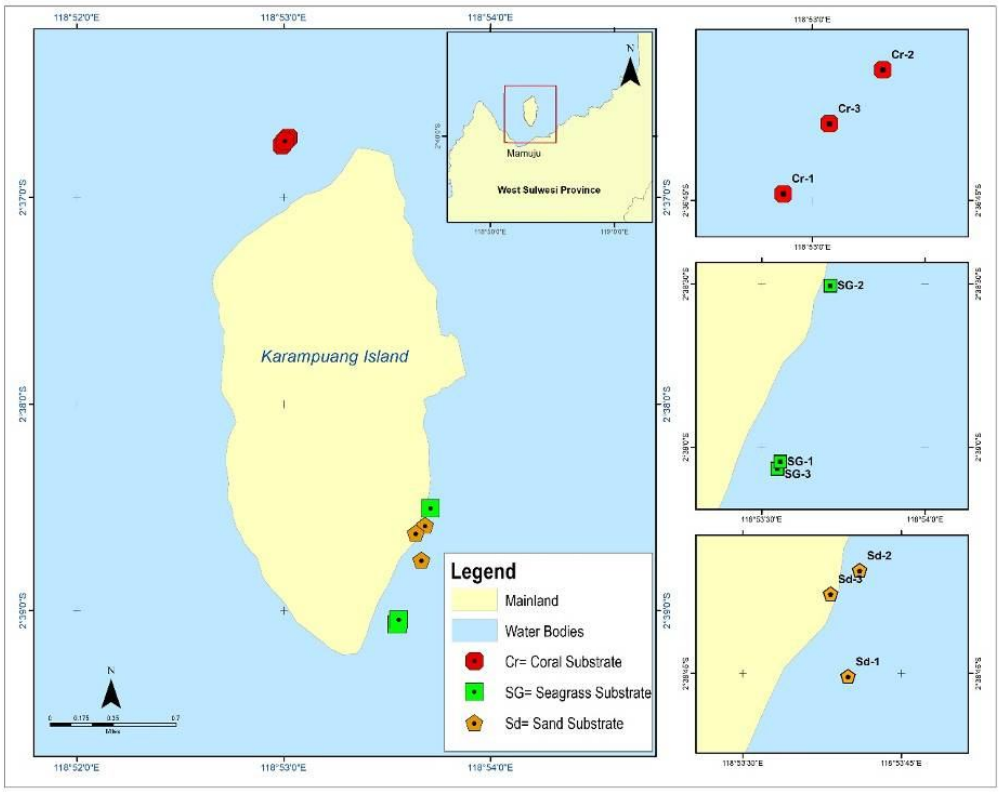

Figure 1. Location of seaweed culture media placement in the waters of Mamuju Regency, West Sulawesi, Indonesia.

Areas of seaweed cultivation in seagrass area was placed at coordinates of 118°53'30" East Longitude and 2°39'0" of South Latitude. Furthermore, the location of cultivation in the area of coral reefs was at coordinates 118°53'0" of East Longitude and 2°36'45" of South Latitude. The location of seaweed culture in the sandy area was located at coordinates 118° 53'36" of East Longitude and 2°36'45" of South Latitude. The initial weight of seedlings used in this study was 50 grams.

Culture techniques applied. Seaweed culture method performed in the study was a long-line method (Kasim & Mustafa 2017). One unit of culture media with the technology applied in this study (Figure 2), installed as many as 160 lines with a length of each line of 15 m and a distance between two lines as wide as 50 cm. The binding distance of the seedlings was 20 cm wide, so in one line, it was bound 75 seeds. The weight of seaweed seeds used was approximately 100 grams. The total number of ties in one seaweed culture unit was 12,000 seedlings. Subsequently, the seaweed cultivation unit was moved to a coral, seagrass and sandy ecosystems.

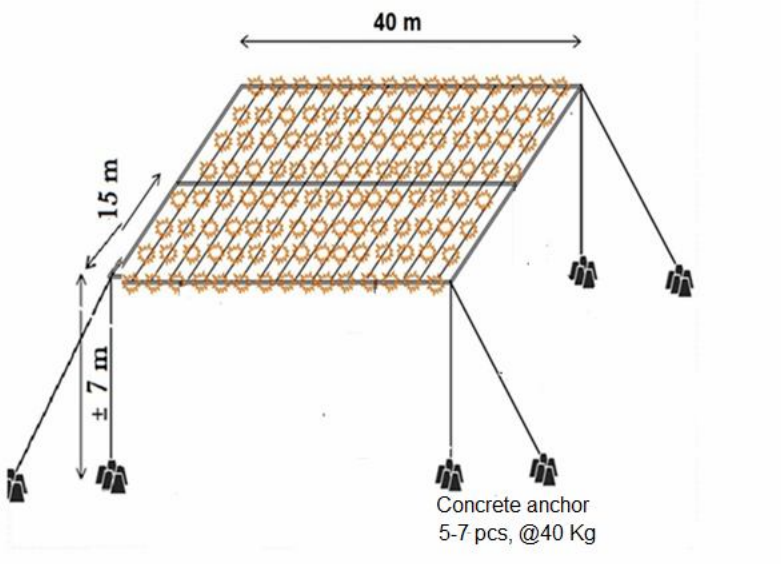

Figure 2. Longline used in the study.

Measurement of growth and quality of seaweed. The wet weight of each seaweed was recorded every 15 days. Growth was measured by the daily growth rate (DGR, % per day) for each seaweed maintenance location based on the formula Yong et al (2013):

$$\mathbf{DGR\ (\%\ per\ day)} = \left[\left(\frac{W_t}{W_0}\right)^{\frac{1}{t}} - 1\right] \times 100$$

where: W_t = final wet weight at time t (g);
W_0 = initial wet weight (g);
t = number of maintenance days.

Semi refine carrageenan extraction followed the method described by Istini et al (1994). Five gram of dry weight of *K. alvarezii* (Ws) was washed with running water until the salts out of the seaweed. Samples were cooked within 6% potassium hydroxide, KOH, the solution was preheated at 80°C for 30 minutes. The cooked seaweed was then cooled and washed using sterile water several times. Semi-refine carrageenan was extracted by filtration using a pressure pump. The semi-refined carrageenan precipitate was then dried at 50°C for 24 hours in the oven. Dry semi-refined carrageenan was weighed as final weight (Wc) and the percentage of carrageenan content was calculated following the formula of de Goes & Reis (2012):

$$\mathit{Carragenan\ Content}\ (\%) = \frac{W_c}{W_s} \times 10$$

Extracts of carrageenan that have been produced, furtherly were analyzed their viscosity (Muñoz et al 2004). Viscosity measurement was done by taking as much as 1.5% of carrageenan extracts, and dissolved in 20 mL of hot water for 20 minutes. Next, the carrageenan solution was homogenized in a water bath at 75^{o}C, and the viscosity was determined using a viscometer.

Gel strength analysis was performed by a combined method (Hayashi et al 2011b; Bono et al 2014). The strength of the gel was done by taking carrageenan as much as 1.2%, and was added with KCl 0.3% at room temperature, and measured using a Texture Analyzer (TXT 32).

Water quality analysis. Water quality variables at three seaweed farming locations were monitored once every two weeks during the cultivation. Water quality parameters such as temperature, pH, salinity, and dissolved oxygen (DO) were measured directly in the field (in situ). The content of nitrate, phosphate, and total organic matter (TOM) was determined by carrying surface water samples from each seaweed cultivation location, which was then analyzed by spectrophotometrically according to the methods described by Strickland & Parsons (1972) in the laboratory.

Data analysis. Growth data, carrageenan content, gel strength, and viscosity were analyzed statistically with SPSS software version 16.0 used ANOVA and if there were differences then proceed with further Tukey's Tests. Next, water quality data were analyzed using Principal Component Analysis (PCA). PCA was carried out to determine the traits or characteristics that distinguish each component of water quality parameters in relation to the growth and quality of seaweed, and to make sure the characters that cause these clusters.

Results

Growth. The results of this study showed that seaweed *K. alvarezii* are successfully breed in different substrates, namely coral, seagrass and sand substrates. Although, it was seen that the growth pattern decreased until the end of the study (Figure 3). The coral growing substrate showed the same growth decline until the end of the study. While seagrass and sand substrates produce drastically decline at the end of the study. The decline in the trend of growth rate for all substrates is associated with changes in water quality during the culture.

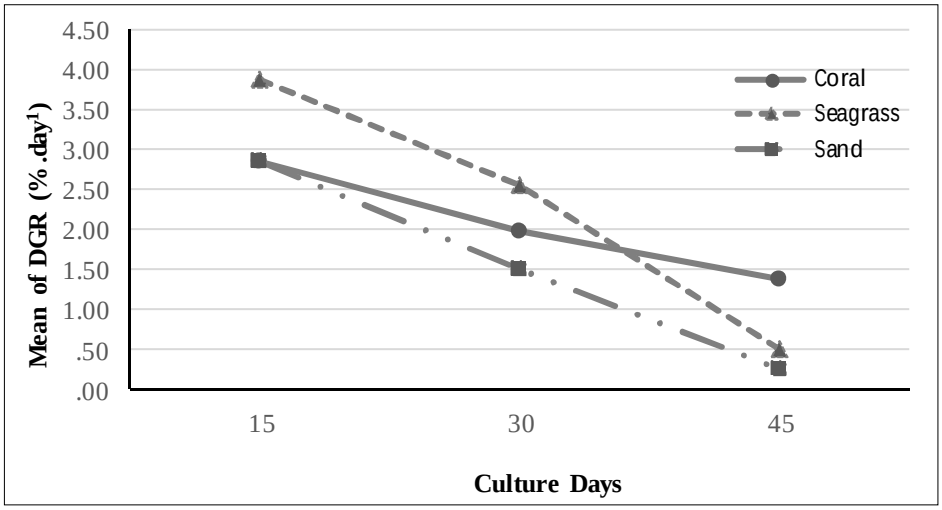

Figure 3. Growth patterns of *K. alvarezii* on coral, seagrass and sand substrates during the study.

Seaweed *K. alvarezii* on all of the three substrates shows varied growth rate at specific culture age (Table 1). The 15-day of culture period shows the same daily growth rate on all three substrates. Furthermore, the coral and seagrass growing substrates produced

significantly different seaweed growth rates ($p < 0.05$) from the sand substrate during the 30-day of culture period. DGR of seaweed obtained at 30 days was between 1.49±0.14 and 2.39±0.13% per day. The coral ecosystem shows a significantly different DGR from seagrass and sand substrates at 45 days of culture (Table 1). DGR achieved in the 15 days of culture for the three ecosystems was between 2.85±0.18 and 3.65±0:33 % per day (Table 1). Nutrients around the growing substrates are considered to be sufficient for the growth requirement of *K. alvarezii* seaweed. Furthermore, a dramatic decrease in growth was observed in seagrass substrate reaching 1.97% per day in the culture period after 30 days to 45 days (Table 1). This indicates that seagrass substrate is experiencing faster nutrient depletion than other substrates.

Table 1

Daily growth rate of seaweed *K. alvarezii* at 15, 30 and 45 days cultivation with coral, seagrass, and sand substrates

Ecosystem	*Daily growth rate (% day^{-1})*		
	15 (days)	*30 days)*	*45 (days)*
Coral	2.85±0.18^{a}	1.97±0.11^{a}	1.36±0.11^{a}
Seagrass	3.65±0.33^{a}	2.39±0.13^{a}	0.42±0.14^{b}
Sand	2.86±0.26^{a}	1.49±0.14^{b}	0.29±0.13^{b}

Different letters on the same line indicate significant differences at alpha 5%. The mean±standard error; n = 30.

Seaweed quality. The quality of seaweed *K. alvarezii*'s in this study was indicated from its carrageenan content, gel strength, and viscosity (Table 2). The carrageenan content within seaweed with sand ecosystem is different from coral ecosystem, however it shows the same carrageenan content with seaweed with seagrass ecosystem. The average value of carrageenan content of sand ecosystem is higher than seagrass and coral substrates, 53.24%, 47.05%, and 44.76%, respectively. This indicates that the substrate of sand provides nutrients to support the formation of carrageenan in *K. alvarezii*.

Furthermore, the gel strength is similar in all of these three seaweed ecosystems. The average strength values of seaweed *K. alvarezii* gel produced in the study were in range of 169.43±5.17 - 280.10±88.26 g cm^{-2}. All three areas of the ecosystems that grow seaweed are indicated to have the same temperature for seaweed *K. alvarezii*. Viscosity is an indicator of the quality of seaweed *K. alvarezii*. Viscosity is similar for seaweed *K. alvarezii* in all three growing ecosystems. The average value of the viscosity of the seagrass substrate is higher (110 cps) than coral (81.7 cps) and sand (83.33 cps).

Table 2

Carrageenan, gel strength, and viscosity of seaweed K.alvarezii of corals, seagrass and sand substrates

Ecosystem	*Carrageenan (%)*	*Gel strength (g cm^{-2})*	*Viscosity (cps)*
Coral	44.76±0.62^{b}	169.43±5.17^{a}	81.67±4.41^{a}
Seagrass	47.05±2.10^{ab}	280.10±88.26^{a}	110.00±20.82^{a}
Sand	53.24±2.42^{a}	195.10±28.10^{a}	83.33±3.33^{a}

Different letters in the same column indicate significant differences. Mean±standard error, n = 3.

Environmental factors and relationship to seaweed growth and quality. Environmental factors that support the growth of seaweed in a different ecosystem are presented in Table 3. The parameters of temperature, salinity, and pH are relatively the same for all cultivation sites. The value of DO and nitrate content is higher in seagrass and sand locations compared to coral reefs. While phosphate is lower at the location of coral reefs and sand. Whereas the highest TOM content was found in seagrass location.

Table 3

Environmental factors of seaweed *K.alvarezii* on different substrates

Parameter	*Unit*	*Environmental conditions of bottom ecosystems/ substrates (mean±SE)*		
		Coral	*Seagrass*	*Sand*
Temperature	^{o}C	30.42±0.25 5[a]	30.26±0.201[a]	30.93±0.118[a]
Salinity	ppt	31.85±0.396[a]	31.12±0.379[a]	30.78±0.264[a]
pH	-	7.63±0.076[a]	7.80±0.124[a]	7.70±0.084[a]
DO	(ppm)	4.71±0.275[a]	5.14±0.159[a]	5.27±0.413[a]
NO_3	(ppm)	0.026±0.004[a]	0.04±0.006[a]	0.031±0.004[a]
PO_4	(ppm)	0.009±0.001[a]	0.05±0.002[a]	0.009±0.001[a]
TOM	(ppm)	43.59±1.448[a]	46.34±1.921[a]	44.07±1.904[a]

The same letters at the same row shows that there is no significant difference at $p > 0.05$.

In this research, PCA was applied to determine the clustering of different variables with specific characteristics, as illustrated in Figure 4. The use of two main axes can explain approximately 57% of the distribution of cultivation area according to time based on growth and quality of seaweed and water quality. There are four groups of locations formed by months of observation. Group 1, at the Seagrass-October-1 area is characterized by high growth and gel content of seaweed and these parameters are associated with high pH and content of PO_4. Group 2, which consists of coral, seagrass and sand in October-2, is characterized by high carrageenan content and is associated with high NO_3 and TOM content. Group 3, consisting of coral, seagrass and sand in November-1, is characterized by a low content of gel and growth, characterized by low TOM content. Group 4, consisting of sand and coral in October-1, is characterized by the high content of seaweed viscosity with water quality characteristics such as high temperature, salinity, and DO.

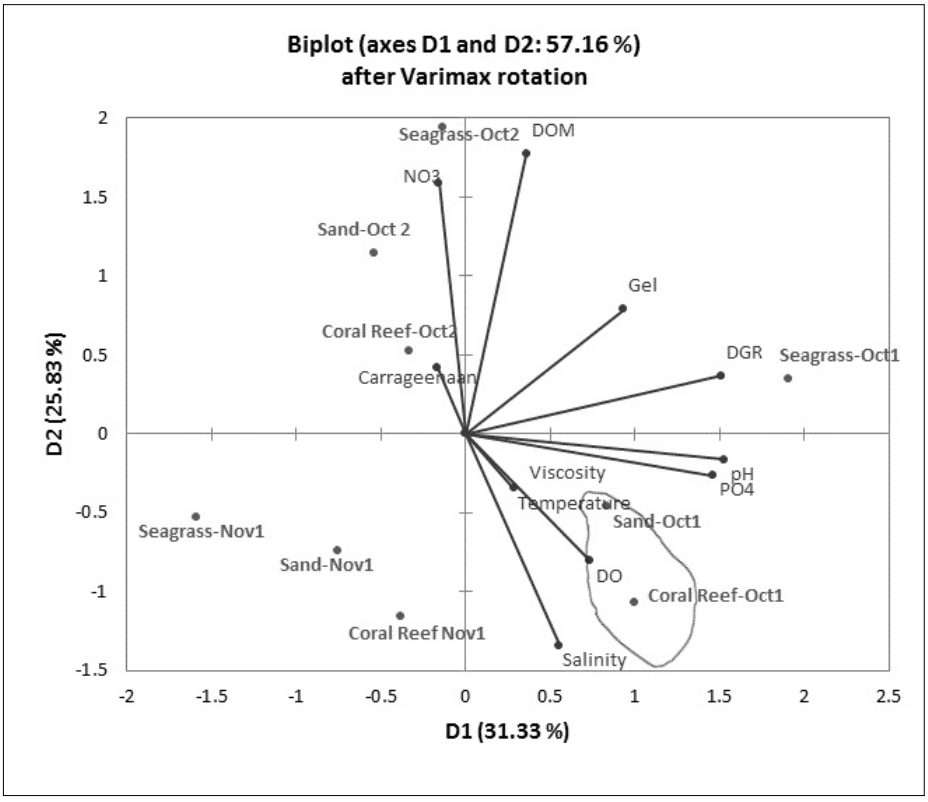

Figure 4. Analysis Map of PCA toward parameter of water quality at the time of culture of seaweed *K. alvarezii* in coastal ecosystems in the waters of West Sulawesi.

Discussion

Growth rate. Seaweed shows similar growth response in seagrass, sand and coral ecosystems, which tends to decrease until the end of the study (Figure 3). Similar growth pattern is shown in seaweed *Euchema denticulatum* cultivated both with long-line method or the floating cage in May, June, July, August, September, and October (Kasim et al 2016), and seaweed *K. striatum* which is cultivated by long-line method (Ali et al 2014). Shrinkage of growth that occurred on the 30th day and uniform in all areas was caused by an ice-ice attack. Seaweed showed bleaching symptoms on the surface of the thallus found in all three culture ecosystems i.e. coral, seagrass and sand. Decrease in growth of seaweed *K. alvarezii* at a particular age, which is caused by the attack of ice-ice disease were also reported among others, age 59 days (Hayashi et al 2007), and culture after 30 days (Zuldin & Shapawi 2015).

Higher DGRs were sequentially obtained in October at 15-day, 30-day of culture, and as low as 45 days at November (Table 1). In other words, the highest growth rate was obtained in October in the seagrass ecosystem, and the lowest in November in the sand ecosystem. This indicates that in October, seagrass ecosystems support the growth of seaweed *K. alvarezii*. Seagrass is a coastal plant that is abundantly found from tropical to cold waters and has leaves that can provide a place for the seaweed growth (Lobban & Harrison 1997). Furthermore, seagrasses can stabilize sediments, filter terrestrial runoff, bind and absorb carbon and nutrients (McGlathery 2001; Thomsen et al 2012; Msuya 2013), so metabolic by products such as anoxia and sulfides are lower for seaweed.

Low growth response of seaweed was obtained in the sand ecosystem and cultivation length of 45 days. This reflects, that seaweed *K. alvarezii* cannot grow with a maximum performance in the sand ecosystem. Seaweed can grow well on hard substrate types such as dead coral, rock, or stick to the soft substrate of seagrass and other macroalgae, as well as on mud and sand (Norashikin et al 2013). Sand is an ecosystem as well as a substrate of seaweed but only for a few species of seaweeds, and several other species cannot grow because seaweed tends to attach its holdfast to hard subsites such as corals (Harah et al 2014) or to anchors from seagrass leaves (Norashikin et al 2013).

Table 1 also shows that the drastic reduction in growth is known in the cultivation of 30 days to 45 days i.e. entering November and in the seagrass ecosystem. This indicates that, the absorption of nutrients by seagrass is faster than the seaweed and the availability of nutrients is only available in a short time around the seagrass. The ability of seagrass to quickly remove the available nitrogen, reflect its adaptation to the environment in which the concentration of nutrients is usually very low. Furthermore, in competition for high nutrition, seagrasses may have a competitive advantage over seaweed because they can explore short-lived nitrogen pulses from the water column more efficiently (Burkholder et al 1994; Touchette & Burkholder 2000).

On the cultivation of 45 days, the average DGR obtained the highest sequence on coral ecosystems, seagrass, and sand is 1.36%, 0.42% and 0.29% respectively. These values when compared to several previous studies show the same as DGR of seaweed *K. alvarezii* in the Philippines which is 0.1-8.4% (Dawes et al 1994) and Mandapam, southeast coast of India 0.34-5.5% (Eswaran et al 2002). Nevertheless, the DGR value obtained is lower than that of seaweed *K. alvarezii* resulted by other studies, including Zanzibar in Tanzania 1.7-6.8% (Msuya 2013), Yucatan Peninsula Mexico 2.0-7.0% (Muñoz et al 2004). The low DGR obtained is considered to be caused by differences in cultivation locations, water conditions, as well as the species of cultivation method, as well as the habitat used.

Coral ecosystems are known to have the highest DGR in 45 days of seaweed *K. alvarezii* culture. *K. alvarezii* plant at the age of 45 days has entered the adult stage. This is reinforced that adult marine plants are more likely to need hard substrates for the comfort of their habitat (Patton et al 1994; Deysher et al 2002). Furthermore, aside from being a habitat, corals also contribute to facilitating the growth of seaweed *K. alvarezii* (Zuldin & Shapawi 2015), and seaweed propagation (Hughes et al 2007; Littler & Littler 2007; Smith et al 2010; Brown et al 2018). Seaweed nutrition, especially nitrogen and

phosphorus in coral substrate, is suspected to be very abundant, thus supporting the multiplication and impact on the rapid seaweed growth.

Seagrass and sand ecosystems as a substrate with low seaweed growth, are below 0.5% at the age of 45 days of cultivation (Table 1). However, seaweed in seagrass ecosystems showed the highest growth on day 15 of the cultivation. This is related to the uptake of N in the seaweed thallus tissue so that the N requirement becomes limited at the beginning of the cultivation. In another study, seaweed was known to have high nutrient uptake at day 10-15 of cultivation, and further down when the cultivation length increased (Hurd et al 2014a). Seagrass leaves are suitable algal substrate that have a flat surface that helps in the process of photosynthesis, gas diffusion, and nutrient uptake (Hurd et al 2014b). Seaweed culture on 0-30 days is expected to be more effective in seagrass substrate, and after 30 days, the culture in coral substrate will help accelerate the growth of seaweed *K. alvarezii*.

Seaweed quality. Carrageenan is an anionic polysaccharide extracted from marine red algae. Chemically, this polymer is composed of soluble, straight galactan sulfate, composed of disaccharides of 3-linked β - D-galactopyranose (unit G) and 4-linked α -d-galacto pyranose (unit D) or 4-linked 3,6-anhydro D-galactopyranose (unit DA) (Van de Velde et al 2005; Thrimawithana et al 2010). The results showed that the amount of seawater cultivated in the sand substrate produced the highest carrageenan of 53.24%. This value is higher than the yield of seaweed that grows in seagrass and coral substrates, which is 47.05% and 44.76%, respectively. The carrageenan value of the three substrates still meets the minimum carrageenan standard requirements according to the FAO of 40% (FAO 2007; Kreckoff et al 2019) and the world carrageenan industry requirements of 38% (Muñoz et al 2004). Another study also obtained carrageenan of *K. alvarezii* which is 46.1% (de Góes & Reis 2012). This study also confirmed that the range of carrageenan values obtained was the same as seaweed treated with growth hormone as reported by Rustam et al (2017). This shows that seaweed cultivation in the waters of West Sulawesi produces high carrageenan content.

Furthermore, the viscosity value obtained is inversely proportional to the value of seaweed carrageenan. The highest seaweed viscosity is obtained in seagrass and the lowest one is resulted from coral substrate, with the values of each are 110 and 81.67 cps respectively. The viscosity values of seaweed *K. alvarezii* obtained is still lower than other studies, including 222.6 cps (de Góes & Reis 2012). The relationship between viscosity and carrageenan is directly proportional. The higher the carrageenan sulfate content, the higher the viscosity value. This is because the high sulfate content in carrageenan polymers and excess K^+ cations cause an increase in the thickness value (Pine et al 1980; Supriyantini et al 2017). Different results are thought to be related with the presence of different ecosystem factors as seaweed growing substrate. However, the value of viscosity obtained still fullfills the standard requirements for seaweed quality, which is a minimum of 5 cps as stipulated by FAO (Stanley 1987).

The study result also shows the viscosity value is inversely proportional to the strength of the gel. Gel strength is the main physical property of carrageenan, i.e. the ability of carrageenan to form a gel. The highest value of gel strength obtained from seagrass was 280.10 g cm cm^{-2} and the lowest was 169.43 g cm cm^{-2} produced from coral substrate. The results obtained are still lower than the standard strength of commercial gel strength that is 685.50 g cm cm^{-2}, and from other studies that are 395.1 g cm^{-2} (de Góes & Reis 2012). The low gel strength obtained is associated with important factors that affect the gel strength, namely NaOH, temperature and extraction time (Yarnpakdee et al 2015). Furthermore, the three seaweed ecosystems of *K. alvarezii* confirm the same carrageenan quality both viscosity and gel strength.

Environmental factors and their relationship to seaweed growth and quality. This study shows that the environmental conditions of seaweed farming are the same for all three ecosystems, i.e. coral, seagrass and sand ecosystems (Table 3). Environmental factors for the three basic ecosystems support the growth and quality of seaweed *K. alvarezii*. The relationship of water quality parameters assoxiated with growth (DGR),

carrageenan content, gel strength, and viscosity of seaweed *K. alvarezii* is presented in Figure 4. In this study, the gel content and DGR associated with high pH and PO_4. Macroalgae in tropical regions generally have a low saturation levels of the nutrients, and produce a higher growth rate (Nascimento et al 2014). High phosphorus concentrations are strongly linked in inducing rapid growth in algal groups. Furthermore, nutrients uptake mainly phosphorus by algae depend on factors that affect growth such as light, temperature and water movement (Zacharias 2012). One indicator of carrageenan quality is the gel content or strength of the gel produced. The quality of carrageenan is highly dependent on the environmental conditions that are suitable for seaweed growth (Hidayat et al 2015). This indicates that, high gel strength may be associated with environmental conditions that affect algal growth such as pH and PO_4.

Abiotic factors such as light intensity, temperature, salinity, pH and nutrients are important factors that affect growth, physiology as well as proximate components and biochemistry of seaweed species, such as *Gracillaria* sp. (Orduña-Rojas et al 2002; Harley et al 2012; Francavilla et al 2013; Hidayat et al 2015), *Laminaria* sp. (Roleda et al 2004; Zacharias 2012), and *Kappaphycus* sp. (Hayashi et al 2011b). pH is also responsible for the function of carrageenan e.g. when the pH is low, it causes depolymerization (de Góes & Reis 2012; Necas & Bartosikova 2013). This explains that, the strength of the gel as the main carrageenan function is strongly influenced by pH.

Furthermore, the PCA analysis map shows the relationship between carrageenan content with TOM and NO_3. The nitrogen (N) content in waters is associated with N content in thallus tissue, growth, carrageenan production, and photosynthesis (Neish et al 1977; Chopin et al 1995). The content of carrageenan is influenced by many factors such as the concentration of nutrients in the tissues of the thallus (Rui et al 1990). Carrageenan content is low when N availability is high, known as the Neish effect (Chopin et al 1995). Nitrate (NO_3) is part of the N cycle. In contrary to the Neish effect, the carrageenan content of seaweed *K. alvarezii* has a positive correlation with nitrate (Orbita 2013). Furthermore, total organic matter (TOM) is known to have a role in microbial metabolism in waters (Kline et al 2006). TOM existence is considered helping microbes in decomposition process included in the N cycle, which in turn will increase nitrate and content of carrageenan of seaweed *K. alvarezii*.

PCA analysis results show that viscosity is associated with temperature and salinity. Carrageenan viscosity occurs because of rejection between negatively charged sulfate groups along the polymer chain, causing the polymer chain to become rigid and stretch strongly, and hence the water molecule will bind with the carrageenan molecule making the viscosity rise (Moirano 1977). In other words, the viscosity is determined by the number of carrageenan sulfate fractions and cations. Carrageenan is recommended to have 18-40% sulfate, specifically *kappa*-carrageenan has an sulfate amount of 25-30%. Viscosity increases with cultivation time at a constant temperature. Temperature is an important environmental factor for the growth and quality of carrageenan of seaweed *K. alvarezii* (Hayashi et al 2007; Hayashi et al 2011b). Furthermore, salinity is also identified as a limiting factor for the life of seaweed *K. alvarezii* (Hayashi et al 2011a). Furthermore, salinity is also identified as a limiting factor for the life of seaweed *K. alvarezii* (Hayashi et al 2011a). This confirms that, it is important to maintain salinity in conditions that can be tolerated by seaweed, to maintain water molecules that will bind carrageenan molecules, thereby causing increased viscosity.

Conclusions. Corals, seagrass and sand as the bottom (seabed) ecosystems showed diverse responses to growth and quality of seaweed *K. alvarezii*. The cultivation period of *K. alvarezii* seaweed for 0-30 days is effective in seagrass ecosystem, and cultivation length of 30-45 days is effective in coral ecosystems. Furthermore, the best effective responses to the quality of seaweed is performed by seagrass.

High growth and seaweed gel content are associated with high pH and PO_4 content. While the high carrageenan content, is associated with a high NO_3 and TOM content. A high seaweed viscosity value is associate with high salinity and DO values.

Acknowledgements. Our highest gratitude and appreciation go to M. Aidil, S. Kel., Muh. Takbir Dg. Sijaya, S. Kel., Kasman, S. Kel., and Rara Adesuara, S. Kel., for their assistance in collecting data in the field.

References

Ali M. K. M., Wong J. V. H., Sulaiman J., July J. L., Yasir S. M., 2014 Improvement of growth and mass of *Kappaphycus striatum* var. Sacol by using plant density study at Selakan Island in Semporna Malaysia. Paper presented at the International Conference on Biological, Chemical and Environmental Sciences, Penang, Malaysia, pp. 58-63.

Bono A., Anisuzzaman S. M., Ding O. W., 2014 Effect of process conditions on the gel viscosity and gel strength of the semi-refined carrageenan (SRC) produced from seaweed (*Kappaphycus alvarezii*). Journal of King Saud University Engineering Science 26(1):3-9.

Brown K. T., Bender-Champ D., Kubicek A., Van der Zande R., Achlatis M., Hoegh-Guldberg O., Dove S. G., 2018 The dynamics of coral-algal interactions in space and time on the Southern Great Barrier Reef. Frontiers in Marine Science 5:181.

Burkholder J. M., Glasgow H. B., Cooke J. E., 1994 Comparative effects of water-column nitrate enrichment on eelgrass *Zostera marina*, shoalgrass *Halodule wrightii*, and widgeongrass *Ruppia maritima.* Marine Ecology Progress Series 105:121-138.

Chopin T., Gallant T., Davison I., 1995 Phosphorus and nitrogen nutrition în *Chondru scrispus* (Rhodophyta): effects on total phosphorus and nitrogen content, carrageenan production, and photosynthetic pigments and metabolism. Journal of Phycology 31(2):283-293.

Dawes C., Luisma A., Trono G., 1994 Laboratory and field growth studies of commercial strains of *Eucheuma denticulatum* and *Kappaphycus alvarezii* in the Philippines. Journal of Applied Phycology 6:21-24.

de Góes H. G., Reis R. P., 2012 Temporal variation of the growth, carrageenan yield and quality of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) cultivated at Sepetiba bay, southeastern Brazilian coast. Journal of Applied Phycology 24(2):173-180.

Deysher L. E., Dean T. A., Grove R. S., Jahn A., 2002 Design considerations for an artificial reef to grow giant kelp (*Macrocystis pyrifera*) in Southern California. ICES Journal of Marine Science 59:201-207.

Eswaran K., Ghosh P. K., Mairh O. P., 2002 Experimental field cultivation of *Kappaphycus alvarezii* (Doty) Doty ex. P. Silva at Mandapam region. Seaweed Research and Utilization 24(1):67-72.

Fadilah S., Alimuddin, Pong-Masak P. R., Santoso J., Parenrengi A., 2016 Growth, morphology and growth related hormone level in *Kappaphycus alvarezii* produced by mass selection in Gorontalo Waters, Indonesia. HAYATI: Journal of Biosciences 23:29-34.

FAO, 2007 The State of World Fisheries and Aquaculture 2006. FAO, Rome, 162 pp.

FAO, 2018 The State of World Fisheries and Aquaculture 2018. Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO.23:29-34, 210 pp.

Francavilla M., Franchi M., Monteleone M., Caroppo C., 2013 The red seaweed *Gracilaria gracilis* as a multi products source. Marine Drugs 11:3754-3776.

Harah Z. M., Sidik B. J., Natrah F. M. I., Emmclan L. S. H, Hazma W. N. W., Nordiah B., 2014 Seaweed community of the Merambong shoal, Sungai Pulai estuary, Johore. Malayan Nature Journal 66(1-2):132-148.

Harley C., Anderson K., Demes K., Jorve J., Kordas R., Coyle T., Graham M., 2012 Effects of climate change on global seaweed communities. Journal of Phycology 48:1064-1078.

Hayashi L., Oliveira E. C., Bleicher-Lhonneur G., Boulenguenguer P., Pereira R. T. I., von Seckendorff R. V., Shimoda V. T., Leflamand A., Valle P., Critchley A. T., 2007 The effects of selected cultivation conditions on the carrageenan characteristics of *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) in Ubatuba Bay, Sao Paulo, Brazil. Journal of Applied Phycology 19(5):505-511.

Hayashi L., Faria G. S. M., Nunes B. G., Zitta C. S., Scariot L. A., Felix M. R. L., Bouzon Z. L., 2011a Effects of salinity on the growth rate, carrageenan yield, and cellular structure of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) cultured *in vitro*. Journal of Applied Phycology 23:439-447.

Hayashi L., Santos A. A., Faria G. S. M., Nunes B. G., Souza M. S., Fonseca A. L. D., Barreto P. L. M., Oliveira E. C., Bouzon Z. L., 2011b *Kappaphycus alvarezii* (Rhodophyta, Areschougiaceae) cultivated in subtropical waters in Southern Brazil. Journal of Applied Phycology 23:337-343.

Hidayat N. S. M., Mohammad-Noor N., Susanti D., Saad S., Mukai Y., 2015 The effects of different pH and salinity on growth rates and carrageenan yield of *Gracillaria manilaensis*. Jurnal Teknologi 77(25):1-5.

Hughes T. P., Rodrigues M. J., Bellwood D. R., Ceccarelli D., Hoegh-Guldberg O., McCook L., Moltschaniwskyj N., Pratchett M. S., Steneck R. S., Willis B., 2007 Phase shifts, herbivory, and the resilience of coral reefs to climate change. Current Biology 17(4):360-365.

Hurd C., Harrison P., Bischof K., Lobban C., 2014a Nutrients. In: Seaweed ecology and physiology. Cambridge University Press, pp. 238-293.

Hurd C., Harrison P., Bischof K., Lobban C., 2014b Seaweed communities. In: Seaweed ecology and physiology. Cambridge University Press, pp. 100-135.

Ingle K., Vitkin E., Robin A., Yakhini Z., Mishori D., Golberg A., 2018 Macroalgae biorefinery from *Kappaphycus alvarezii*: conversion modeling and performance prediction for India and the Philippines as examples. BioEnergie Research 11(1):22-32.

Istini S., Ohno M., Kusunose H., 1994 Methods of analysis for agar, carrageenan and alginate in seaweed. Bull Mar Sci Fish Kochi Univ 14:49-55.

Kasim M., Mustafa A., 2017 Comparison growth of *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) cultivation in floating cage and longline in Indonesia. Aquaculture Reports 6:49-55.

Kasim M., Mustafa A., Munier T., 2016 The growth rate of seaweed (*Eucheuma denticulatum*) cultivated in longline and floating cage. AACL Bioflux 9(2):291-299.

Kim J. K., Yarish C., Hwang E. K., Park M., Kim Y., 2017 Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. Algae 32(1):1-13.

Kline D. I., Kuntz N. M., Breitbart M., Knowlton N., Rohwer F., 2006 Role of elevated organic carbon levels and microbial activity in coral mortality. Marine Ecology Progress Series 314:119-125.

Kreckhoff R. L., Ngangi E. L. A., Undap S. L., Kusen D. J., 2019 Crude extracts of *Kappaphycus alvarezii* algae cultivated in several seaweed production centers in North Sulawesi, Indonesia a immunostimulant. AACL Bioflux 12(2):678-686.

Littler M. M., Littler D. S., 2007 Assessment of coral reefs using herbivory/nutrient assays and indicator groups of benthic primary producers: a critical synthesis, proposed protocols, and critique of management strategies. Aquatic Conservation: Marine and Freshwater Ecosystem 17(2):195-215.

Lobban C. S., Harrison P. J., 1997 Seaweed ecology and physiology. Cambridge University Press, 366 pp.

McGlathery K. J., 2001 Macroalgal blooms contribute to the decline of seagrass in nutrient-enriched coastal waters. Journal of Phycology 37:453-456.

Moirano A., 1977 Sulfated seaweed polysaccharides. In: Food colloids. Graham H. D. (ed), AVI Publishing Company Inc., pp. 347-381.

Mulyani S., Tuwo A., Syamsuddin R., Jompa J., 2018 Effect of seaweed *Kappaphycus alvarezii* aquaculture on growth and survival of coral *Acropora muricata*. AACL Bioflux 11(6):1792-1798.

Msuya F., 2013 Effects of stocking density and additional nutrients on growth of the commercially farmed seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* in Zanzibar Tanzania. Tanzania Journal of Natural and Applied Sciences 4(1):605-612.

Muñoz J., Freile-Pelegrín Y., Robledo D., 2004 Mariculture of *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) color strains in tropical waters of Yucatán, México. Aquaculture 239:161-177.
Nascimento A., Coelho-Gomes C., Barbarino E., Lourenço S. O., 2014 Temporal variations of the chemical composition of three seaweeds in two tropical coastal environments. Open Journal of Marine Science 4(2):118-139.
Necas J., Bartosikova L., 2013 Carrageenan: a review. Veterinarni Medicina 58(4):187-205.
Neish A. C., Shacklock P. F., Fox C. H., Simpson F. J., 1977 The cultivation of *Chondrus crispus*. Factors affecting growth under greenhouse conditions. Canadian Journal of Botany 55(16):2263-2271.
Neish I. C., 2013 Social and economic dimensions of carrageenan seaweed farming in Indonesia. In: Social and economic dimensions of carrageenan seaweed farming. Valderrama D., Cai J., Hishamunda N., Ridler N. (eds), FAO Fisheries and Aquaculture Technical Paper No. 580, pp. 61-89.
Norashikin A., Harah Z. M., Sidik B. J., 2013 Intertidal seaweeds and their multi-life forms. Journal of Fisheries and Aquatic Science 8(3):452-461.
Orbita M. L. S., 2013 Growth rate and carrageenan yield of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) cultivated in Kolambugan, Lanao del Norte, Mindanao, Philippines. AAB Bioflux 5(3):128-139.
Orduña-Rojas J., Robledo D., Dawes C. J., 2002 Studies on the tropical agarophyte *Gracilaria cornea* J. Agardh (Rhodophyta, Gracilariales) from Yucatan, Mexico. I. Seasonal physiological and biochemical responses. Botanica Marina 45:453-458.
Patton M. L., Valle C. F., Grove R. S., 1994 Effects of bottom relief and fish grazing on the density of the giant kelp, *Macrocystis*. Bulletin of Marine Science 55(2-3):631-644.
Pine S. H., Hendrickson J. B., Cram D. J., Hammond G. S., 1980 Organic chemistry. 4th edition, New York, McGraw-Hill Book Co., 1039 pp.
Raman M., Doble M., 2015 κ-Carrageenan from marine red algae, *Kappaphycus alvarezii* - a functional food to prevent colon carcinogenesis. Journal of Functional Foods 15:354-364.
Roleda M. Y., Hanelt D., Kräbs G., Wiencke C., 2004 Morphology, growth, photosynthesis and pigments în *Laminaria ochroleuca* (Laminariales, Phaeophyta) under ultraviolet radiation. Phycologia 43(5):603-613.
Rui L., Jiajun L., Chaoyuan W., 1990 Effect of ammonium on growth and carrageenan content în *Kappaphycus alvarezii* (Gigartinales, Rhodophyta). Hydrobiologia 204:499-503.
Rustam, Syamsuddin R., Soekandarsih E., Trijuno D.D., 2017 Uptake of nutrients N, P, K seaweed of *Kappaphycus alvarezii* (Doty) were cultivated in media with different concentrations of BAP. International Journal of Sciences: Basic and Applied Research 31(2):249-259.
Sahu N., Meena R., Ganesan M., 2011 Effect of grafting on the properties of *kappa*-carrageenan of the red seaweed *Kappaphycus alvarezii* (Doty) Doty ex Silva. Carbohydrate Polymers 84(1):584-592.
Smith J. E., Hunter C. L., Smith C. M., 2010 The effects of top-down versus bottom-up control on benthic coral reef community structure. Oecologia 163(2):497-507.
Stanley N., 1987 Production, properties and uses of carrageenan. In: Production and utilization of products from commercial seaweeds, McHugh D. J. (ed), chapter 3, FAO, Rome, Technical Paper No. 288, pp. 97-147.
Strickland J. D. H., Parsons T. R., 1972 A practical handbook of seawater analysis. Fisheries Research Board of Canada, 310 pp.
Supriyantini E., Santosa G. W., Dermawan A., 2017 [Quality of carrageenan extract from seaweed "*Kappaphycus alvarezii*" aquaculture results in Kartini Coast and Kemojan Karimunjawa Island, Jepara Regency]. Marina Oceanographic Bulletin 6(2):88-93. [in Indonesian]

Thomsen M. S., Wernberg T., Engelen A. H., Tuya F. A., Vanderklift M., Holmer M., McGlathery K. J., Arenas F., Kotta J., Silliman B. R., 2012 A meta-analysis of seaweed impacts on seagrasses: generalities and knowledge gaps. PLoS ONE 7(1):e28595.
Thrimawithana T. R., Young S., Dunstan D. E., Alany R. G., 2010 Texture and rheological characterization of kappa and iota carrageenan in the presence of counter ions. Carbohydrate Polymers 82:69-77.
Touchette B. W., Burkholder J. M., 2000 Review of nitrogen and phosphorus metabolism in seagrasses. Journal of Experimental Marine Biology and Ecology 250(1-2):133-167.
Van de Velde F., Antipova A. S., Rollema H. S., Burova T. V., Grinberg N. V., Pereira L., Paula M. G., Tromp R. H., Rudolphe B., Grinberg V. Y., 2005 The structure of κ/ι-hybrid carrageenans II. Coil-helix transition as a function of chain composition. Carbohydrate Research 340(6):1113-1129.
Webber V., de Carvalho S. M., Ogliari P. J., Hayashi L., Barreto P. L. M., 2012 Optimization of the extraction of carrageenan from *Kappaphycus alvarezii* using response surface methodology. Food Science and Technology 32(4):812-818.
Yarnpakdee S., Benjakul S., Kingwascharapong P., 2015 Physico-chemical and gel properties of agar from *Gracilaria tenuistipitata* from the lake of Songkhla, Thailand. Food Hydrocolloids 51:217-226.
Yong Y. S., Yong W. T. L., Anton A., 2013 Analysis of formulae for determination of seaweed growth rate. Journal of Applied Phycology 25(2):1831-1834.
Yulianto H., Damai A. A., Delis P. C., Elisdiana Y., 2017 Spatial analysis to evaluate the suitability of seaweed farming site in Lampung Bay, Indonesia. Turkish Journal of Fisheries and Aquatic Sciences 17:1253-1261.
Zacharias M., 2012 Ecophysiological studies of selected macro- and microalgae: production of organic compounds and climate change interactions. PhD Dissertation, NUI Galway, Ireland, 411 pp.
Zuldin W. H., Shapawi R., 2015 Performance of red seaweed (*Kappaphycus* sp.) cultivated using tank culture system. Journal of Fisheries and Aquatic Science 10(1):1-12.
*** https://www.slideshare.net/ssuser200d5e/rpjm-provinsi-sulawesi-barat-2012-2016. Accessed: July, 2019.

Received: 24 October 2019. Accepted: 23 December 2019. Published online: 21 March 2020.
Authors:
Parman Parakkasi, Postgraduate School, Fisheries Science Study Program, Universitas Hasanuddin, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea-Makassar-90245, Indonesia, e-mail: p2.parman@gmail.com
Chair Rani, Faculty of Marine Sciences and Fisheries, Universitas Hasanuddin, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea-Makassar-90245, Indonesia, e-mail: erickch_rani@yahoo.com
Radjuddin Syam, Faculty of Marine Sciences and Fisheries, Universitas Hasanuddin, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea-Makassar-90245, Indonesia, e-mail: rajuddin_syamsuddin@yahoo.com
Zainuddin, Faculty of Marine Sciences and Fisheries, Universitas Hasanuddin, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea-Makassar-90245, Indonesia, e-mail: zainuddinlatif@gmail.com
Marlina Achmad, Faculty of Marine Sciences and Fisheries, Universitas Hasanuddin, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea-Makassar-90245, Indonesia; Excellent Center for Development and Utilization of Seaweed, Hasanuddin University, Jl. Perintis Kemerdekaan Km. 10 Tamalanrea-Makassar-90245, Indonesia, e-mail: marlina.achmad@unhas.ac.id

How to cite this article:
Parakkasi P., Rani C., Syam R., Zainuddin, Achmad M., 2020 Growth response and quality of seaweed *Kappaphycus alvarezii* cultivated in various coastal ecosystems in the waters of West Sulawesi, Indonesia. AACL Bioflux 13(2):627-639.