The impact of planting distance on productivity and profit of *Eucheuma cottonii* seaweed cultivation in Karimunjawa Islands, Indonesia

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Abstract. *Eucheuma cottonii* seaweed cultivation has become one of the main livelihoods for the local community of Karimunjawa Islands, Indonesia. Therefore, research on seaweed cultivation is important to improve the welfare of seaweed farmers, including planting distance of seaweed. The purpose of this research was to estimate the effect of different planting distance treatments on the growth and profitability of E. *cottonii* farming in Kemojan Island, Karimunjawa Islands. In this study, a field experiment using simple longline was conducted with planting distance of 25 cm, 30 cm and 35 cm in 42 days culture time. The variables studied include absolute biomass growth, specific growth rate (SGR), and RC (revenue cost) ratio, as well as a statistical test on these variables. The research results showed that the planting distance of seaweed have not a significant effect on the confidence level of 95% (α = 0.05). The planting distance treatment of 25 cm gave the highest yield, both on seaweed growth and RC ratio. The planting distance treatment of 35 cm provided the lowest performance, both the growth of absolute biomass, SGR and RC ratio. With an average initial biomass of 3,532 g per line, treatment of 25 cm can produce an average final biomass of 11,318 g per line, or an average biomass growth of 7,787 g per line, with an average SGR value of 2.72% and an average RC ratio of 2.34.
Key Words: *Eucheuma cottonii*, growth, Karimunjawa Islands, planting distance, RC ratio.

Introduction. Seaweed cultivation has become one of the main livelihoods for the local community of Karimunjawa Islands, Indonesia. Seaweed farming in the Karimunjawa Islands was undeveloped in 2016-2017 due to 'ice-ice' disease and low selling prices of seaweed. The revival of the seaweed cultivation business in the Karimunjawa Islands began in 2018. Then seaweed cultivation business has become one of the main livelihoods of the local community of Kemojan Island, Karimunjawa Islands. During this time, Karimunjawa Islands are known as tourism destinations and conservation areas (low-land tropical forests and sea-waters). Conservation requires support of local community. Without welfare, local people can return to destructive behaviours, such as cutting mangrove trees, mining coral reefs and fishing with poison (Zamroni 2018; Wijayanto et al 2019).

The local community of Karimunjawa Islands rely on fisheries, tourism and agriculture to fulfil their daily needs (BPS-Statistics of Jepara Regency 2019). The development of seaweed cultivation could increase diversification of local community livelihoods as one of 'the economic backbone' of Karimunjawa people, so that it does not only rely on traditional capture fisheries, agriculture and tourism. The research results of Wijayanto et al (2019) proved that by seaweed cultivation with an average of 19 longline units and an average length of 129 m per longline can meet the average of economic-household needs of Kemojan Island people where Kemojan Island is the second largest Island in Karimunjawa Islands.

Seaweed cultivation in the Karimunjawa Islands is centred on coastal of Kemojan Village or Kemojan Island. Seaweed cultivation is conducted by the people of Kemojan Village uses *Eucheuma cottonii* seeds. Their cultivation method uses relatively simple longline media and low investment. The distance between the seeds that used by seaweed farmers is about 30 cm. Several research was proved that seaweed stocking density affects the growth of seaweed (Fermin & Hurtado 2001; Soenardjo 2011; Irfan et al 2016). To find the optimal planting distance, some field research is needed. Optimal planting distance can increase the productivity and profit of seaweed cultivation in Karimunjawa Islands. The purpose of this study was to estimate the effect of different planting distance treatments on the seaweed growth and profit of *E. cottonii* cultivation in Kemojan Village. The results of this study can be a reference in the development of seaweed cultivation in the Karimunjawa Islands.

Material and Method

Material and treatment. The research material was seaweed *E. cottonii*. Seaweed was cultivated using the simple longline method. Seeds were obtained from local seaweed farmers. In this research, an experimental field was conducted with planting distance of 25 cm, 30 cm and 35 cm. The culture media used longline according to the method used by seaweed farmers on Kemojan Island. The length of each longline was 3 meter. For the planting distance of 25 cm, seaweed was planted in 12 points (average initial weight per point of 294 g). Treatment of 30 cm was planted seaweed of 10 points (average initial weight per point of 295 g). Treatment of 35 cm was planted seaweed of 8 points (average initial weight per point 293 g). Longline was given ballast so that it was not washed away and given a float so the line did not sink at the bottom of the water. To analyze the growth of seaweed without being affected by predatory animal (herbivorous fish), we used 9 basket-longline to culture of seaweed. We used basket with size of 47 cm long, 32 cm wide and 26 cm high. The average seaweed planted per basket was 1,637 g. The longline layout design of our experiment can be seen in Figure 1.

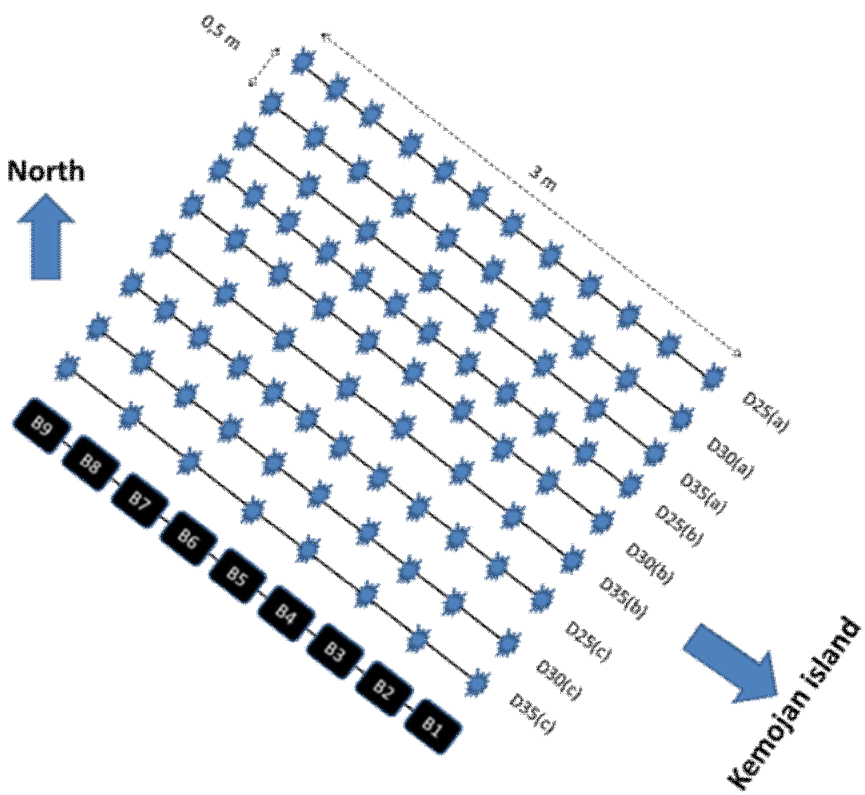

Figure 1. Longline layout (Note: D25 (planting distance of 25 cm), D30 (planting distance of 30 cm), D35 (planting distance of 35 cm) with the longline method, while a, b and c were the first, second and third replications of each treatment. B1 to B9 was a seaweed experiment using basket-longline).

Research location and time. The research location was on Kemojan coast, especially in the northwest coast waters of Kemojan Island (see Figure 2). The research location was in the seaweed cultivation area conducted by local people of Kemojan Village. The location of seaweed cultivation is in accordance with the marine-culture zone of Karimunjawa waters conservation area. According to BSN (2011), good location for *E. cottonii* cultivation are protected waters from big wave, water flow velocities of 20 to 40 cm per sec, depth at lowest tide of 2 m, far from river mouth, uncontaminated waters, not a marine transportation line, not fishing ground, rock sandstone at bottom water, naturally seaweed habitat and at correct location legally. According to Dinda et al (2012), the current pattern at the research site on Kemojan Island is from northeast to southwest at low tide to high tide, whereas at high tide to low tide is reversed applies.

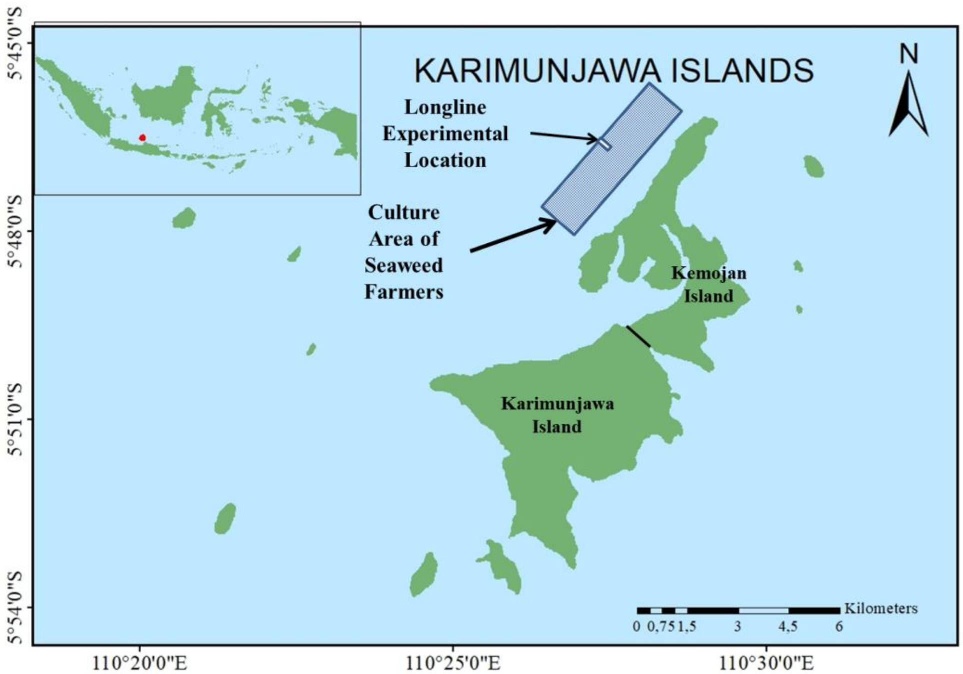

Figure 2. The research location.

This study was conducted in June to July 2019. Seaweed culture time was 42 days. During the culture of seaweed, we cleaned the culture media from parasitic plants. According to de San (2012), the most damaging parasitic algal is epiphytic filamentous algae (EFA), including: *Enteromorpha*, *Ulva*, *Chaetomorpha*, *Hypnea* and *Hydroclathus*. Meanwhile, according to Kasim et al (2017), macro epiphyte species attached to the thallus of *Eucheuma spinosum* include: *Acanthophora spicifera*, *Chondrophycus papillosus*, *Chaetomorpha crassa*, *Jania longifurca*, *Pomatoceros triqueter*, *Ulva lactuca*, and *Turbinaria ornata*.

Water quality measurement. Water quality measurements were conducted during the seaweed culture process. Measurements were taken in the morning and afternoon in the range of once a week. Water quality parameters observed were dissolved oxygen (DO), surface water temperature, pH, and salinity using a portable multi-parameter water quality meter.

Biomass growth and specific growth rate. Seaweed biomass weight (wet weight) was measured at the beginning of planting and end of cultivation. To calculate absolute biomass growth and specific growth rates, we used the following formula:

$$W = Wt - Wo \quad (1)$$

$$SGR = \frac{LnWt - LnWo}{t} \quad (2)$$

where: W = the absolute biomass growth of seaweed (g);
Wt = the weight of seaweed at the time of t (g);
Wo = the weight of seaweed at the beginning (g);
t = time of culture (days);
SGR = specific growth rate (% per day);
ln = the logarithm of natural.

This analysis method has been used by several researchers of seaweed cultivation, including: Munoz et al (2004), Soenardjo (2011), and Sulystyaningsih et al (2019).

RC ratio. Financial analysis in this study was conducted using RC (revenue cost) ratio analysis, with the following formula:

$$RC\ Ratio = TR / TC \quad (3)$$

where: TR = total revenue (IDR);
TC = total cost (IDR).

The business of seaweed culture is categorized profitable if the RC ratio is greater than 1.0. This analysis method has been used by several researchers of seaweed cultivation, including: Nuryadi et al (2017) and Limi et al (2018).

Statistical analysis. Statistical analysis was performed with Anova (analysis of variance) on the variables of W, SGR and RC ratio. The hypothesis of this study were: (H_0) there is no significant difference because of the planting distance treatment to W, SGR and RC ratio, and (H_1) there is a significant difference because of the planting distance treatment to W, SGR and RC ratio.

Result and Discussion. Karimunjawa Islands are located at coordinates 5°40’39” to 5°55’00” south latitude and 110°05’57” to 110°31’15” east longitude. Karimunjawa Islands consists of 27 islands and has a land area of 71,200 km^2 (BPS-Statistics of Jepara Regency 2019). Karimunjawa Island and Kemojan Island are the largest islands in Karimunjawa Islands. Karimunjawa Island and Kemojan Island are very close, and are already connected by bridges. The location of seaweed cultivation in Kemojan Island is in the northwest coast waters of Kemojan Island.

E. cottonii or *Kappaphycus alvarezii* is called ‘cottonii’ as commercially name. *E. cottonii* is found in the upper part of the sublittoral zone, from just below the low tide line, reef areas on sandy-coral to rocky substrates where sea-water flow is slow to moderate (McHugh 2003). During this time, seaweed production in the world is dominated by cultivation, not from capture in nature. The biggest producer of seaweed in the world is China, while Indonesia is ranked second. Seaweed cultivation in Indonesia is dominated by *Eucheuma* spp. and *Gracilaria* spp. for carrageenan and agar production (Ferdouse et al 2018; Waters et al 2019).

Seaweeds can reproduce both asexually (by simply dividing vegetative parts) and sexually. Algal life cycles can generally be categorized as gametic, zygotic and biphasic. Biphasic life cycles are characterized by cycling between separate, free-living, and independent haploid gametophyte and diploid sporophyte (Roesijadi et al 2008). The seeds of seaweed are obtained by taking young thalus from the seaweed harvest. But, some times the local government give seeds of seaweed to seaweed farmers from Marine-Culture Centre, both from Lampung and Sulawesi.

Water quality. The water quality in the location was relatively supportive for the life and growth of *E. cottonii*. According to Table 1, only salinity relatively high exceeds the standard. It was influenced by the season, when at the time of research there was summer. The level of water pollution around Kemojan Island was still relatively low. The source of pollution comes from households. Nitrate (0.3644 mg L^{-1}), phosphate (0.0179 mg L^{-1}) and current velocity (0.30 to 0.35 m s^{-1}) in the waters of Kemojan Island relatively support the growth of *E. cottonii* (Supriyantini et al 2017). Meanwhile, according to Munoz et al (2004), temperature, light intensity and nutrients were believed to be the most important factors affecting *E. cottonii* growth.

Table 1

Water quality during research

Parameters	*Min*	*Average*	*Max*	*Standard*
DO (ppm)	6.9	7.3	7.8	> 5[a]; > 4[b]
Temperature (^{o}C)	28.0	29.5	31.5	27 to 30[cd]; 20 to 32[e]; 24 to 32[f]; 25 to 35[g]
pH	7.0	7.6	8.5	7 to 9[c]; 7 to 8,5[df]
Salinity (‰)	35	37	39	30 to 35[c]; 28 to 33[f]; 29 to 33[d]; 23 to 38[e]

Sources: [a] Jamaluddin et al (2019); [b] Supriyantini et al (2017); [c] Hasyim et al (2012); [d] Limi et al (2018); [e] de San (2012); [f] BSN (2011); [g] Kasim et al (2017).

According to Nursidi et al (2017), the season affects the growth of seaweed, where in the case of Saugi Island (Indonesia), the growth of seaweed during the dry season is slower than the rainy season. In principle, seaweed growth is influenced by many complex factors, including nitrate and phosphate content, depth, temperature, salinity, season, amount of planted seaweed (McHugh 2003; BSN 2011; Irfan et al 2016; Yala et al 2017).

Growth. Based on experimental results (Table 2), the planting distance of 25 cm generated the largest production. The denser the planting distance cause more amount of seaweed planted and more biomass harvested. Therefore, seaweed farmers in Kemojan Island can increase their seaweed planting from a distance of 30 cm change to 25 cm. While the treatment of increasing planting distance to 35 cm actually causes a decrease in production of seaweed biomass.

Table 2

Seaweed growth of *E. cottonii* using longline

Variable	*Treatments*	*Replications*			*Average*
		1	*2*	*3*	
Initial weight or W_0 (g)	D25	4,030	3,005	3,560	3,532
	D30	2,980	2,965	2,900	2,948
	D35	2,565	2,495	2,853	2,638
Final weight or W_{42} (g)	D25	14,260	11,770	7,925	11,318
	D30	6,100	8,695	7,997	7,597
	D35	6,890	6,653	5,436	6,326
Absolute growth weight or W (g)	D25	10,230	8,765	4,365	7,787
	D30	3,120	5,730	5,097	4,649
	D35	4,325	4,158	2,583	3,689
SGR (% per days)	D25	3.01%	3.25%	1.91%	2.72%
	D30	1.71%	2.56%	2.42%	2.23%
	D35	2.35%	2.34%	1.53%	2.07%
Statistical analysis	W Sig = 0.086 (not significant at α=0.05)		SGR Sig = 0.394 (not significant at α=0.05)		

Based on the SGR, planting distance of 25 cm gave the highest daily growth compared to 30 cm and 35 cm. Actually, the lower density of seaweed planting increases the growth rate of seaweed (Fermin & Hurtado 2001; Soenardjo 2011). However, because the experiments D25, D30 and D35 used a simple longline method without protection against pests, therefore the factor of predator presence affects the rate of growth of seaweed.

Grazing of seaweed (by herbivorous fish, sea urchins and marine turtles) is indeed a challenge in seaweed farming. Siganids (rabbitfish) and puffersfish are common pests. Siganids are the most destructive and eat young thalluss (McHugh 2003; de San 2012).

In addition, the diversity of water conditions and the presence of epiphytic plants pose challenges in field research. According to Soenardjo (2011), mosses and epiphytes, can inhibit or affect the growth rate of seaweed, associated with space competition, interfere with effectiveness of the photosynthetic process and competition to get nutrients. Therefore, Castaños & Buendia (1988) give suggestions to remove grazers such as sea urchins and starfishes and epiphytes growing on seaweed as these compete for nutrients, light and space.

The daily growth rate of seaweed during the experiment was over 2% per day (Table 2). The growth rate of seaweed in the basket-longline experiment can be seen on Table 3. According to de San (2012), if a seaweed cultivation location was chosen as a good location, it can produce growth of 2% per day and even it can reach 4% per day. If we look at weekly growth in basket longline so we see that there was a decline in growth rate (Figure 3). As culture time increased, the seaweed biomass in basket-longline was increasing and the availability of space to grow seaweed decreased.

Table 3

Seaweed growth in basket-longline

W and SGR	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*B8*	*B9*	*Average*
W_0 (kg)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
W_{40} (kg)	3.7	3.6	3.4	2.8	4.0	4.0	4.2	2.6	3.2	3.7
SGR (% per days)										
0 to 7	1.9	1.9	1.4	1.1	2.1	2.7	2.1	1.8	1.9	1.9
7 to 14	1.8	2.2	1.8	1.7	2.1	2.5	2.6	1.8	2.1	2.0
14 to 21	5.5	3.7	4.9	1.7	5.7	4.1	4.8	1.1	3.3	3.9
21 to 28	1.7	1.2	1.8	0.9	1.1	2.1	1.9	0.8	0.7	1.4
28 to 35	0.4	1.5	0.4	2.0	1.2	1.0	1.6	0.8	1.1	1.1
35 to 42	0.3	1.1	0.3	0.4	0.7	0.4	0.6	0.3	0.8	0.4
SGR_{0-42} (% per days)	1.9	1.9	0.8	1.3	2.1	2.1	2.2	1.1	1.6	1.8

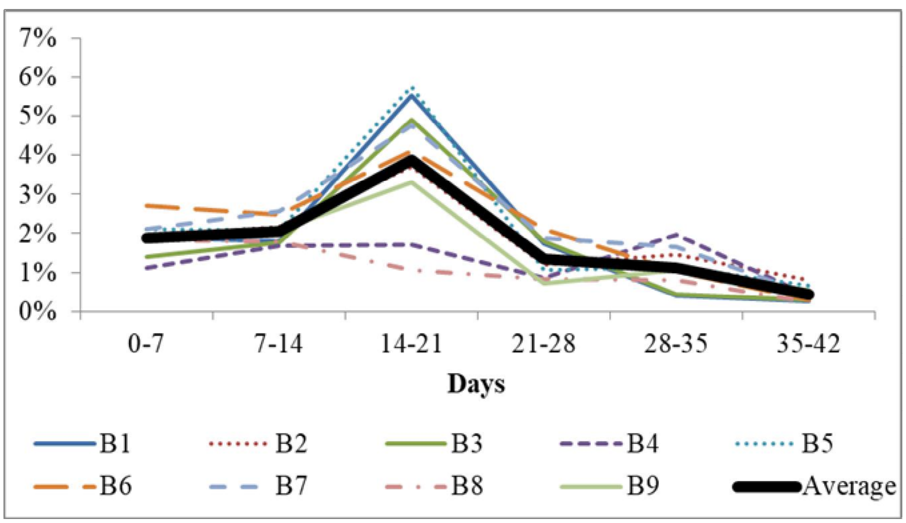

Figure 3. The progress of SGR during research in basket-longline.

The results of this study indicate that the growth of seaweed in nature is influenced by several factors, including water quality, seed quality, the presence of pests, diseases, epiphytic plants and mosses, not only treatment in the experiment (planting distance). If seaweed farmers use a simple longline method, the addition of seeds planting density can reduce the risk of farming failure due to pests and broken seaweed. At a distance of 25 cm, then the risk of the proportion of seaweed eaten by pests and broken seaweed will be even smaller when compared with a spacing of 30 cm. So, in this study it was proven that reducing the distance of seaweed planting from 30 cm to 25 cm can increase production. While the addition of planting distance from 30 cm to 35 cm actually reduces production. Therefore, it is recommended that seaweed farmers in Kemojan Island can increase the number of seaweed planting by shortening the planting distance from 30 cm to 25 cm to increase production. Castaños & Buendia (1988) have suggested that the distance between *Eucheuma* sp. seedlings is 20 to 25 cm.

Seaweed farmers also need to take into account the use of basket-longline in culture seaweed, especially during the big wave season. The basket-longline method is likely to cause a decrease in the seaweed growth rate compared to the simple longline method. That's because basket decreases water circulation. But the basket-longline method can reduce the risk of seaweed being eaten by pests, and the loss of seaweed due to breaking up by big wave.

The results of the normality test showed that the normality assumption was fulfilled, both on W and SR variables. Anova test results showed that plant spacing did not have a significant effect on the level of α = 0.05, both on W and SR variables (accept H_0). The results of this statistical test also support the recommendation that seaweed spacing can be shortened from 30 cm to 25 cm.

RC ratio. The RC ratio of the seaweed cultivation experiment with a simple longline method showed values above 1 (Table 4). This showed that the seaweed farming business in coastal of Kemojan Island is profitable. The largest RC ratio was produced by the treatment of 25 cm spacing, which was an average of 2.34. That is, each cost of IDR 1.00 generates IDR 2.34. Whereas the 30 cm spacing treatment produced an average RC ratio of 1.86, while the 35 cm treatment produced an average RC ratio of 1.73.

Table 4

RC ratio

Variable	*Treatments*	*Replications*			*Average*
		1	*2*	*3*	
Cost (IDR per meter per cycle)	D25	2,763	2,080	2,450	2,431
	D30	2,062	2,052	2,009	2,041
	D35	1,651	1,654	1,659	1,655
Revenue (IDR per meter per cycle)	D25	7,130	5,885	3,963	5,659
	D30	3,050	4,348	3,999	3,799
	D35	3,177	3,160	2,265	2,867
RC ratio	D25	2.58	2.83	1.62	2.34
	D30	1.48	2.12	1.99	1.86
	D35	1.92	1.91	1.37	1.73
Statistical analysis of RC ratio	Sig = 0.297 (not significant at α=0.05)				

The normality test results on the RC ratio variable indicate that the normality assumption was fulfilled. While the Anova test results showed that the planting distance did not have a significant effect on the RC ratio at the level of α = 0.05 (accept H_0). The result of this statistic test is also support the recommendation that seaweed distant planting can be shortened from 30 cm to 25 cm.

So, besides increasing production, it is evident that the addition of seaweed biomass planted by shortening plant spacing (from 30 cm to 25 cm) has also been shown to increase profits and RC ratio. A decrease in planting density by increasing the spacing of seaweed from 30 cm to 35 cm actually reduces profits. The biggest cost of seaweed cultivation is the cost of seeds with the seed price of IDR 2,000 per kg wet and the harvest price of IDR 1,500 per kg wet. The addition of seaweed biomass planted has a significant contribution in the success of the seaweed cultivation business. With the cost of seeds can reach more than 90% of the cost per cycle. Then seaweed farmers anticipate using part of their crops to be used as seeds (vegetative method). According to the World Bank Group (2016), the cost of procuring propagules (seeds) on *E. cottonii* seaweed cultivation in Indonesia reaches 80.4% of the total variable costs.

RC ratio of seaweed cultivation in the coastal of Kemojan Island is relatively high. Although it has a high RC ratio, however the nominal value of seaweed cultivation is relatively small and can be grouped as micro and small scale businesses (Wijayanto et al 2020). The seaweed selling price factor greatly determines the prospects for seaweed cultivation in Kemojan Village. When the seaweed selling price is only IDR 600 per kg wet, then seaweed farmers prefer other business professions. But when the price of seaweed is IDR 1500 per kg wet, then the seaweed farmers in Kemojan Village again chose the profession of seaweed farmers. Even some fishermen in Kemojan Village turned to seaweed farmers when seaweed prices were IDR 1500 per kg wet because it is considered more profitable than being a traditional fisherman. As a comparison, RC ratio analysis results of *E. cottonii* seaweed cultivation in several regions of Indonesia also showed a value above one (profitable). The RC ratio of seaweed cultivation in Kendari was 1.16 (Limi et al 2018), in Konawe Selatan Regency was 1.71 with a profit of IDR 6,194,916 per ha (Nuryadi et al 2017), while the RC ratio in Kolaka was 1.71 (Asni 2017).

Conclusions. The treatment of seaweed planting distance has proven not generate a significant effect (at the level of $\alpha = 0.05$), both for biomass growth, SGR and RC ratio. The 25 cm spacing treatment gave the highest average yield, both from the aspect of absolute biomass growth (production), SGR and RC ratio. The 35 cm spacing treatment provided the lowest performance, both absolute biomass growth, SGR and RC ratio. With an average initial biomass of 3,532 g per line, treatment of 25 cm spacing can produce an average final biomass of 11,318 g per line, or an average biomass growth of 7,787 g per line, with an average SGR value of 2.72% and an average RC ratio of 2.34. Therefore, seaweed farmers in Kemojan Village are advised to increase the biomass of seaweed seeds planted by shortening the planting distance from 30 cm to 25 cm.

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