



Production Performance of *Gracilaria verrucosa* using Verticulture Method with Various Wide Planting Area in Karimun Jawa

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ABSTRACT

Gracilaria verrucosa is one type of seaweed that can be developed into a high-value product. Market demand for agar reaches 21.8% per year, but only 13.1% can be met. This is due to the low level of production of *G. verrucosa* in Indonesia. Utilization of *G. verrucosa* is still relying on aquaculture from the farm, which causes low production. Cultivation of seaweed with verticulture methods can increase the production of *G. verrucosa*. Karimun Jawa is a potential area for seaweed cultivation. This study aims to determine the effect of different density areas on the growth and production of *G. verrucosa* and to determine the best density area for its production in Karimun Jawa. This research used *G. verrucosa* wrapped in mesh size of 0.5 cm with a weight of 50 g per pack. Each verticulture strap contains four packs, and each treatment consists of 9 straps. The treatment was in the form of differences in the planting area of 25x25 cm² (A), 50x50 cm² (B) and 75x75 cm² (C). The results showed significant differences ($P < 0.01$) between each treatment. The planting area of 75x75 cm² has the best yield on absolute growth, relative growth rate (RGR) and specific growth rate (SGR) of 83.10 ± 4.12 g; 3.96 ± 0.20 % / day and 2.33 ± 0.07 %/day. The best results of *G. verrucosa* production obtained at an area of 50x50 cm² (5.32 ± 0.26 kg/m²).

Keywords: seaweed, *Gracilaria verrucosa*, production, verticulture, area

1. Introduction

Gracilaria verrucosa is one type of seaweed that can be developed into a high-value product. According to Sugiyanto *et al.* (2013), the demand for agar (gel) in Indonesia is increasing every year. Therefore, the development of the business of *Gracilaria* sp. will have the potential to generate large profits. The market demand for *G. verrucosa* reaches 21.8% every year. However, fulfillment has not been sufficient, which is only around 13.1%. This is due to the low level of production of *Gracilaria verrucosa* in Indonesia (Abdan *et al.*, 2013). Some types of seaweed can be used as food ingredients and also additives in food products because they contain amino acids such as serine, glycine, arginine, alanine, tyrosine, methionine, valine, phenylalanine, isoleucine, leucine and lysine (Dewi *et al.*, 2018). Apart from being used as food, beverages, and medicines, some processed seaweed products such as agar, alginate, and carrageenan are quite important compounds in

the industry (Istini and Suhaimi, 1998; Erlania and Radiarta, 2017). Some types of seaweed can be processed into "dodol" (Hermawan *et al.*, 2018).

According to Sulistijo and Atmadja (1996), 555 species of seaweed were found in Indonesian waters. Some types of them can produce agar, namely *Gracilaria* sp, *Gelidium* sp, *Gelidellia* sp., and *Gelidiopsis* sp. Type of *Gracilaria* sp. often found in Indonesia are *G. lichenoides*, *G. gigas*, and *G. verrucosa*.

Utilization of *Gracilaria* sp. still relying on aquaculture from ponds and the production is low, because farmers use *Gracilaria* sp. as their side business. Also, the planting of *G. verrucosa* in ponds is only used as a filter that can improve survival in fish and shrimp farming (Jasmanindar *et al.*, 2015). It causes the production of *G. verrucosa* to be low, and it is different from *Eucheuma* sp., which is often cultivated in the sea and used as the main culture. Therefore, it is necessary to do research related to the cultivation of *G.*

verrucosa in the sea to know and increase production.

Karimunjawa Islands, Jepara has good water clarity. The clarity around the beach can penetrate to the bottom of the water. Good clarity is one of the factors that influence the cultivation of seaweeds, including the type of *G. verrucosa*. The clarity in such a way makes the water column more optimized in its utilization. According to Fikri *et al.* (2015), seaweed cultivation method has been carried out by raft method and horizontal long-line (parallel) to the sea level, based on the assumption that light is still able to penetrate to the bottom of the water and the existing water column can be optimally utilized.

Furthermore, it is suspected that the nutrient content of nitrates and phosphates are needed for the growth of seaweed is also at a certain depth. According to Hendri *et al.* (2017), the use of a water column as a planting medium (verticulture) has not been utilized. The verticulture method is a method of planting seaweed in a vertical manner using depth (water column) as a medium. The depth of water used can vary depending on the ability to penetrating sunlight. The use of this method is expected to increase seaweed production. The light penetration for seaweed production can be obtained not only from one side of the surface of the water but also from every angle of the height of the light.

Cultivation of *G. verrucosa* needs to be done in order to get maximum production, that can meet market needs. In general, cultivation of *G. verrucosa* uses the horizontal long-line method. However, the horizontal long-line method can interfere with traffic in the waters around the cultivation, because it uses long transverse straps. Also, the horizontal long-line method is also not able to utilize the water column well, so the production results are not optimal. According to Widowati *et al.* (2015), if the horizontal long-line method can only cultivate seaweed on a single line, then several vertical rows can be cultivated in the same column. The results obtained with these cultivation methods will certainly result in more seaweed production.

The verticulture method is a method of cultivation using a rope to tie seaweed seeds in a vertical position (perpendicular) by utilizing the water column to the limit of water clarity. Usually, seaweed can be maintained to a depth of 3-5 meters, with specifications of water locations suitable for verticultural development. The application of the vertical line method can increase the productivity of the minimum cultivation area by 420% compared to the long-line method application which only uses the

surface waters column (Pong-Masak and Sarira, 2015). Farmers often have conflicts with other farmers because of the struggle for the cultivation area. This happens because the area that they have is not enough to produce seaweed optimally. Therefore, we need to know the optimum area for planting seaweed to produce optimal production.

This study aims to determine the effects of different density areas on growth and production and find out the best density area for the production of *G. verrucosa* in Karimunjawa. The research was conducted in May - July 2018 at the Brackish and Sea Water Hatchery and Cultivation Center, the Karimunjawa Sea Fish Hatchery and Cultivation Unit, Jepara, Central Java.

2. Materials and Methods

2.1. Materials

G. verrucosa was harvested from BBPBAP Jepara, Central Java, with a planting weight of 50 g strand (Widiastuti, 2011). Polyethylene (PE) diameter of 9 mm along ± 3 m as a stretch rope and PE rope 6 mm in diameter for ± 3 m as a rope, net mesh size 50 mm was used as a test plant medium. Seaweed wrapped in nets. Nets were used as containers for each point of seaweed on each strand of the range that was contained in an area. There were 12 areas of seaweed which were divided into three areas in different sizes. The net was used to accommodate each seaweed hanger and to protect seaweed from the attack of herbivorous fish that can attack the seaweed.

2.2. Verticulture Methods

This study used three treatments and four replications. The treatment was the difference in the planting area of *G. verrucosa*, i.e., 25x25, 50x50, and 75x75 cm² as Treatment A, B, and C, respectively.

G. verrucosa cultivation was carried out in the waters off the Karimunjawa Islands using the verticulture method or vertical long-line method where each seaweed hanger was wrapped in 50 mm net-eyed "waring" which serves as a seaweed protection tool against various pest attacks and aggregation of herbivorous fish such as baronang fish (*Siganus* sp.) which can inhibit growth. Seaweed seeds that have been selected and wrapped in "waring," were tied using raffia rope and then hung on 12 vertical lines of seaweed which were divided into three different area arrangements using PE (Polyethylene) rope (**Figure 1**). The treatment given was based on

the best results from Desy *et al.*, (2016) and Sunarto (2009), the best spacing of *G. verrucosa* was 25cm. Treatment 1 - 4 was *G. verrucosa* with an area of 25x25cm², treatment 5 - 9 is seaweed *G. verrucosa* with an area of 50x50cm², and treatment 10-12 was *G. verrucosa* with an area of 75x75cm², where each area had nine vertical lines (strap) with four strands of seaweed in each strap.

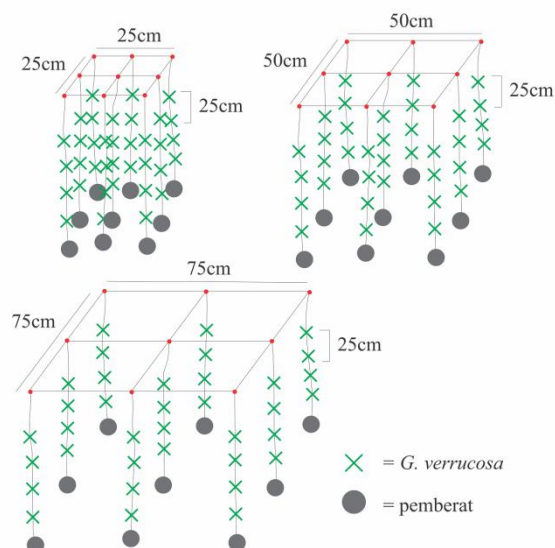


Figure 1. Treatment of planting *G. verrucosa* using verticulture method

2.3. Relative Growth Rate

According to Effendie (1997), the relative growth rate can be calculated by the formula:

$$RGR = \frac{W_t - W_o}{W_o \times t} \times 100\%$$

Which:

- RGR = Relative Growth Rate (%/day)
- W_t = Final weight of *G. verrucosa* (g)
- W_o = Initial weight of *G. verrucosa* (g)
- t = Length of cultivation (day)

2.4. Specific Growth Rate

According to Effendie (1997), the specific growth rate was calculated using the following formula:

$$SGR = \frac{\ln W_t - \ln W_o}{t} \times 100\%$$

Which:

- SGR = Specific growth rate (%/day)
- W_t = Biomassa of *G. verrucosa* at the end of the study (g)
- W_o = Biomassa of *G. verrucosa* at the beginning of the study (g)

t = Length of cultivation (day)

2.5. Absolute Growth

According to Basyarie *et al.*, (1987), absolute growth can be calculated by the formula:

$$W = W_t - W_o$$

Which:

- W = Absolute growth of *G. verrucosa* (g)
- W_t = Final weight of *G. verrucosa* (g)
- W_o = Initial weight of *G. verrucosa* (g)

2.6. Production

According to Basyarie *et al.*, (1987), production can be calculated using the formula:

$$P = \frac{W_t - W_o}{A}$$

Which:

- P = Production of *G. verrucosa* (g/m²)
- W_t = Final weight of *G. verrucosa* (g)
- W_o = Initial weight of *G. verrucosa* (g)
- A = Cultivation area of *G. verrucosa* (m²)

2.7. Water Quality

Observation of water quality, which includes temperature, pH, salinity, and DO was carried out every day in the morning and evening, using a thermometer, pH meter, and DO meter. While observing the content of ammonia, nitrite, and phosphate were carried out every week by conducting a laboratory test.

2.8. Data Analysis

Data analysis including the relative growth rate (RGR), and specific growth rate (SGR) were analyzed using variance analysis (ANOVA) with a confidence interval of 95% to see the effect of treatment. It was followed by testing Duncan's multiple regions to find out the differences between treatments. Data in the form of percentage was transformed to arcsine before testing (Srigandono, 1992).

3. Results and Discussion

3.1. The Relative Growth of *G. verrucosa*

Based on the results of the study, it was found that the growth of *G. verrucosa* in treatment C with a quadrant area of 75x75 cm² had higher relative growth than treatment B (50x50 cm²) and treatment A (25x25 cm²). Data on the relative growth rate of seaweed were shown in **Table 1**.

Table 1. *G. verrucosa* Relative Growth Rate (RGR) Data.

Repetition	Treatment (%)		
	A	B	C
1	22.93	133.22	171.08
2	22.89	133.05	169.79
3	18.92	121.11	170.08
4	16.83	118.42	153.87
Σx	81.57	505.80	664.82
Average $\pm$ SD	20.39 $\pm$ 3.03 ^a	126.45 $\pm$ 7.80 ^b	166.21 $\pm$ 8.24 ^c

Note: The average value for each treatment with different superscripts shows a significant difference ($P < 0.05$).

Based on the results, it was found that the RGR of treatment C had a value of 3.96 %/day. The RGR in treatment C was better than in treatments A and B. Treatment C had a wider planting area compared to treatment B, and treatment B had a wider area than treatment A. Therefore, with the same number of straps, treatment C had a lower density per unit area. Probably, the lower the density, the better the growth will be. On the contrary, if the density higher then the growth rate would be decrease. The low density of seaweed causing absorption of nutrients in the metabolic processes of seaweed can work optimally, so the results obtained showed that the treatment with the least seaweed density was treatment C (75x75 cm²) which has the highest final weight compared to the other two treatments. Stocking density or spacing and nutrients in the waters were very influential in the growth of seaweed. The balance of these two factors will trigger a good process of seaweed metabolism (Sakdiah, 2009). The wider the distance would

provide the flexibility of water to move in distributing nutrients, to accelerate the diffusion process and potentially increase the growth rate (Ponggarang *et al.*, 2013).

Another factor that causes differences in the value of the relative growth rate in *G. verrucosa* was the presence of aggregation of herbivorous fish. The presence of herbivorous fish in waters planted with seaweed can reduce the growth rate of seaweed itself because herbivorous fish consume *G. verrucosa*. In this study, the problem was handled using small nets, to minimize the aggregation of herbivorous fish. The number of herbivorous fish that do aggregation will affect the growth of *G. verrucosa*. According to Toth and Pavia (2007), seaweed is one of the diets of herbivorous fish.

3.2 Specific Growth Rate of *G. verrucosa*

The results of the specific growth rates of *G. verrucosa* were shown in **Table 2**.

Table 2. Specific growth rate data (SGR) of *G. verrucosa*.

Repetition	Treatment (%/day)		
	A	B	C
1	0.49	2.02	2.37
2	0.49	2.01	2.36
3	0.41	1.89	2.37
4	0.37	1.86	2.22
Σx	1.76	7.78	9.32
Average $\pm$ SD	0.44 $\pm$ 0.06 ^a	1.95 $\pm$ 0.08 ^b	2.33 $\pm$ 0.07 ^c

Note: The average value for each treatment with different superscripts shows a significant difference ($P < 0.05$).

Table 3. Absolute Growth of *G. verrucosa*

Repetition	Treatment (g)		
	A	B	C
1	11.47	66.61	85.54
2	11.44	66.53	84.90
3	9.46	60.55	85.04
4	8.42	59.21	76.93
Σx	40.79	252.9	332.41
Average $\pm$ SD	10.20 $\pm$ 1.51 ^a	63.23 $\pm$ 3.90 ^b	83.10 $\pm$ 4.12 ^c

Note: The average value for each treatment with different superscripts shows a significant difference ($P < 0.05$).

From this results (**Table 2**), SGR values of *G. verrucosa* showed that the growth in treatment C was better than treatment B and A. The highest SGR was found in treatment C which had an average of 2.33 %/day, while the lowest rate was in treatment A which had an average of 0.37 %/day.

The SGR of seaweed is a description of the growth of weight units of seaweed compared to the unit of time. The results of planting *G. verrucosa* using the verticulture method, on the treatment area of 25x25 cm² (A) had an SGR of 0.44 %/day, an area of 50x50 cm² (B) of 1.95 %/day and an area of 75x75 cm² (C) of 2.33 %/day. Based on these data, it can be seen that the best specific growth rate was in the treatment C. The difference in treatment of *G. verrucosa* planted greatly determines the growth rate of seaweed itself. The SGR itself was calculated based on the weight gain of seaweed at a certain time. According to Sulistijo *et al.* (1978), daily growth above 2% has shown good growth. This is due to the type and quality of seaweed and environmental conditions that are very supportive. The environment in question includes the treatment given at the time of planting.

It was known that the best specific growth occurred in treatment C (2.33 %/day), where this result was greater than treatment A and B. Many factors influence the differences in the specific growth rates, including the quality of seeds, conditions environment such as physical and chemical factors and planting density. In this study, the spacing given to each treatment greatly affects the planting density of *G. verrucosa*, and it affects the rate of growth of the seaweed itself. The wider the distance means the planting density of seaweed was increasingly tenuous so that seaweed can grow better. Likewise, vice versa, the closer the distance will provide a narrower space so that nutrients carried by the flow will be hampered

(Sunarto, 2009). The closer the distance also means the density becomes higher. High density will inhibit water circulation. This was also conveyed by Ihsan *et al.*, (2019), which stated that density culture of *G. verrucosa* impedes the water circulation.

Other factors that cause the SGR to be less than maximal (<2%) can be caused by the inhibition of nutrients to be absorbed by seaweed because the net was covered by dirt and attachment organisms. The organism can be either moss or other attaching organisms. This was by the study of Widyorini (2010). The *G. verrucosa*, which is planted in water flow with a lot of dissolved material will have a less favorable growth compared to cleaner water flow.

3.3. Absolute Growth of *G. verrucosa*

Based on the results of the study, it was found that *G. verrucosa* in treatment C with an area of 75x75cm² had higher relative growth than treatment B (50x50cm²) and treatment A (25x25cm²). Data on the relative growth rate of seaweed were shown in **Table 3**.

From the data obtained, it can be seen that the absolute growth of *G. verrucosa* planted for 42 days ranged from 8,42 - 85,54g during the planting period, with an average of A (10.20 g), B (63.23 g), and C (83.10 g). Table 3 shows that the highest absolute growth average was owned by treatment C.

It was found that the absolute best growth was the treatment C with an average absolute growth value of 83.10 g, greater than the treatment A and B. This was caused by differences in planting area in each treatment. The wider the planting area, the wider the distance between verticultural straps, so that the distribution of nutrients becomes more evenly distributed and can increase the growth of *G. verrucosa*. This was also conveyed by Ponggarang *et al.*, (2013), which stated that the

wider the distance would provide the flexibility of water to move in distributing nutrients, to accelerate the diffusion process and potentially increase the growth rate.

Planting area affects the health of *G. verrucosa*. Different distances and planting depths will lead to absorption of light penetration and the level of cleanliness of the different talus of seaweed, thus affecting the health and photosynthesis of seaweed. The spacing that was too close, causing waste and dirt can easily get caught on the rope or seaweed planted. Dirt that was stuck or attached to seaweed will prevent seaweed from absorbing nutrients from the waters, while the garbage that was stuck on the rope will block the light entering the waters, which can inhibit photosynthesis. The inhibition of photosynthesis will prevent the growth process of seaweed (Hernanto, 2015).

Different planting areas also influence nutrient absorption by *G. verrucosa*. The wider the spacing, the easier it will be for seaweed to absorb nutrients, because in a narrow distance there will be competition in the struggle for nutrients. Also, different planting areas influence the rate of photosynthesis by seaweed *G. verrucosa* (May 2011; Jeslin et al., 2018).

3.4 Production of *G. verrucosa*

The production of *G. verrucosa* was shown in Table 4.

Table 4. Data of *G. verrucosa* Production.

Repetition	Treatment (kg/m ²)		
	A	B	C
1	6.60	9.59	5.47
2	6.59	9.58	5.43
3	5.45	8.72	5.44
4	4.85	8.53	4.92
Σx	23.49	36.42	21.26
Average ± SD	5.87±0.8 7 ^a	9.11±0.5 6 ^b	5.32±0.2 6 ^a

Note: The average value for each treatment with different superscripts shows a significant difference ($P < 0.05$).

Production data from *G. verrucosa* showed that the growth in treatment B with an area of 50x50 cm² had better production than treatment A and C. The highest production was found in treatment B which had an average of 9.11 kg/m².

Based on the results obtained, the best production of *G. verrucosa* was obtained in treatment B (50x50 cm²) with a yield of 9.11 kg / m² greater than that of treatment A (25x25 cm²) and C (75x75 cm²). This was different from absolute growth, which tends to be better in treatment C because treatment C had the widest area and stocking density, which tends to be more tenuous. Calculation of production is the difference between the initial weight and the final weight per unit area. Therefore, this production had different results because the results obtained were divided into units so that the best production in this study was treatment B. It means that the production of treatment C was low, and it concluded that the use of the area in treatment B was more optimal. The verticulture method is intended for land use to increase seaweed production. According to Pong-cook and Sarira (2015), verticulture technology is considered to be more efficient, feasible, and can reduce the level of conflict in the use of water lands as cultivation land, so that production activities are expected to run optimally for the development of seaweed cultivation. Based on the operational and investment costs incurred when applying the seaweed cultivation technology with the verticulture method, this method is more suitable to be developed by regional or industrial governments.

Compared to the long-line method or other methods, verticulture techniques obtained more production results. The advantage of the verticulture method is that it is very suitable for areas with little land or to utilize verticulture advantages as a crop enhancer. According to the study of Jeslin et al., (2018) using the long-line method with a distance of 30cm and a weight of 100g on a rope as long as 15m only produced 605 g/m *G. verrucosa*. This result is far different from the production of using verticulture. Ariyati et al., (2016), said that the method of planting seaweed perpendicular or known as the verticulture method aims to utilize the water column to a certain depth adjusting to the ability to penetrate sunlight. This method was carried out with the consideration of optimizing the use of water columns so that the productivity of cultivated land increases.

Vertical cultivation (verticulture) method that utilizes a water column in Karimunjawa did not affect the growth of *G. verrucosa* at all levels of planting. Planting at level 1 - 4 did not have a significant difference and even tended to be even or almost the same. Karimunjawa waters that were still clear and clean make the level of brightness up to the bottom of the water and sun irradiation can be evenly distributed so

that the growth of seaweed was not significantly different. This was because sunlight can enter evenly in the water column so that all levels of seaweed planting can obtain perfect light (Pratiwi and Ismail, 2004; Widowati *et al.*, 2015).

Planting seaweed with verticulture methods besides having more production results also has good ecological functions for the environment, such as the ability to absorb waste dissolved in seawater. This makes the waters planted with seaweed have less pollution. With this verticulture method, it is possible to absorb more dissolved waste by seaweed compared to the long-line method. According to Pong-cook and Sarira (2015), the technology of seaweed cultivation with the

verticulture method does not pollute the environment, does not damage, but on the contrary with the role of seaweed eco-physiology will be able to absorb excess loading of N and P waste, or other materials in the aquatic environment to minimize pollution with its absorbent nature. The more the amount of seaweed planted in the waters, the greater the absorption of waste by seaweed.

3.5 Water Quality

Water quality was supporting data of the research. The measured water quality data consists of physical and chemical parameters. Water quality range data during the study were presented in **Table 5**.

Table 5. Water Quality Data

Parameter	Unit	Score			Reference
		A	B	C	
Salinity	‰	31-33	31-33	31-33	15-35 ^a
Temperature	°C	29-30.1	29-30.1	29-30.1	26-33 ^b , 0-35 ^c
pH	-	7.36-7.56	7.36-7.56	7.36-7.56	6.2-8.2 ^b
Clarity	M	9.25-9.68	9.43-9.83	9.43-11.2	>5 ^d
Depth	M	10.53-11.32	10.53-11.32	10.53-11.32	>10 ^d
Current	cm/s	40-50	40-50	40-50	40-100 ^e
DO	mg/L	6.03-6.28	6.03-6.28	6.03-6.28	5.0-6.2 ^f
CO ₂	mg/L	2.97-4.95	2.97-4.95	2.97-4.95	2.5-3.5 ^g
Nitrate	mg/L	-	-	-	0.146-0.5 ^h
Phosphate	mg/L	0.071-0.124	0.071-0.124	0.071-0.124	0.0264-0.1044 ^h

Information:

^a)Widyorini, 2010; ^b)Aslan, 1998; ^c)Kim *et al*, 2016 ^d)Pong-masak and Sarira, 2015; ^e)Wood,1987; ^f)Tarigan and Sumadhirga, 1989; ^g)Ariyati *et al*, 2007; ^h)Ruslaini, 2016.

Based on the data, it was known that the range of water quality in the aquaculture waters was classified as feasible, and it supports *G. verrucosa* cultivation.

Water quality parameters are one of the most important things that need to be considered before doing seaweed cultivation because it will affect other parameters. According to Sunarto (2009) environmental parameters are variables that directly or indirectly affect the management and development of seaweed cultivation, besides that the water parameters are also a limiting factor for the life of living things in water, physical, chemical and biological factors.

Based on the results, clarity was about 9.25-11.2 m and a depth between 10.53-11.32

m. The deeper the waters, the clarity will decrease. Clarity is very influential on the growth of seaweed because it helps the process of photosynthesis of seaweed. The inhibition of photosynthesis will also inhibit the growth of seaweed itself. This is reinforced by Widowati *et al.*, (2015) which states that clarity factors affect growth because sediment or sand attaches to seaweed so that it will block the penetration of sunlight needed for photosynthesis. The role of depth on the growth of seaweed is related to vertical stratification of temperature, light penetration, density, oxygen content, and nutrients. The less than the optimal growth rate is caused by the availability of nutrients and lack of light intensity for the growth of seaweed.

The measurement of the water temperature obtained was ranging from 29-30.1°C. It was known that the temperature range was well used for *G. verrucosa* cultivation that resulted in the good growth. *G. verrucosa* has a high tolerance to the water temperature range. According to Kim *et al.* (2016), *Gracilaria* has a high tolerance to a temperature ranging from 0 - 35°C. The optimum temperature range can increase the growth of *Gracilaria* sp. because it can help to increase nutrient absorption, which is around 20-34°C (Rejeki *et al.*, 2018). Temperature changes that are too drastic will disrupt the growth process of *G. verrucosa*. This is by Hendri *et al.* (2017) whose results at an average temperature of 29.64°C with an initial weight of 75 g can reach a final growth of 202.32 g with a planting period of 42 days.

The results of measurements of current, pH, and salinity were between 40-50 cm/s, 7.36-7.56 and 31-33‰, respectively. This result was considered quite well for *G. verrucosa* cultivation. A current that is too strong can destroy the talus, and a current that is too small can inhibit the supply of nutrients to seaweed. The role of flows in seaweed cultivation is as a dissolved nutrient carrier. The current movement is one of the factors that greatly influence the growth of *G. verrucosa*, because it plays an important role in the process of nutrient transport, and plays a role in stirring the water in water columns (Prud'homme and Trono, 2001). The pH content contained in the waters during the study was calculated in the stable range and included in the good category for seaweed cultivation. pH can help metabolize nutrients by seaweed. The alkaline pH content is a good range for *G. verrucosa*. Bezerra and Marinho-Soriano (2010), argue that the optimum pH content of seaweed is 7–8. Salinity obtained from the measurement results is at the normal threshold or falls into the good category for *G. verrucosa* cultivation. It is known that *G. verrucosa* has a very high salinity range so that it can be cultivated almost all waters from brackish to sea water. *Gracilaria* sp. is one type of seaweed that has a broad salinity range, which is between 10-40 ppt (Gorman and Zucker, 1997; Yokoyama, 1999; Klionsky *et al.*, 2016). However, the optimum salinity for the growth of *G. verrucosa* is 30-35 ppt (Bezerra and Marinho-Soriano, 2010; Veeragurunathan *et al.*, 2015; Lee *et al.*, 2016).

Dissolved oxygen levels at the time of the study reached a range of 6.03-6.28 mg/L, while free carbon dioxide levels were 4.2-5.6 mL/L. The dissolved oxygen contained in the waters during the study was calculated to be high

because of the smooth flow of currents that occur around the cultivation area. Also, the amount of seaweed planted makes dissolved oxygen levels increase. This was because the more photosynthetic process occurs because of the planting of seaweed. This is reinforced by Patty (2013), high levels of dissolved oxygen in offshore waters because the water is clear so that the smooth flow of oxygen enters the water unhindered through the process of diffusion and photosynthesis. For free carbon dioxide content was also good. This showed that the quality of these waters was still feasible to be used as cultivation land. Carbon dioxide (CO₂) is also needed for seaweed for photosynthesis. The value of carbon dioxide during the study ranged from 4.2 - 5.6 mg/L. This value was quite high; it is reinforced by Ariyati *et al.* (2007), which states that the range of CO₂ values in the waters for seaweed cultivation is 2.5–3.5 mg/L. Carbon dioxide levels are above the normal range; this is thought to be due to the process of respiration from aquaculture fish around the floating net cages.

Nitrate content was not detected when tested, while for phosphate content ranged from 0.071-0.124 mg/L. The content of nitrate in the waters is needed by seaweed for metabolism. According to the study results of Jeslin *et al.*, (2018), with an initial weight of 100g and a spacing of 50cm and a nitrate content ranging from 0.146-0.05mg/L it produces a final weight of 202g. Based on the results of other studies, the optimum nitrate range for *Gracilaria* growth was 0.6-0.8 mg/L (Ganesan *et al.*, 2011; Glenn *et al.*, 1999). The phosphate content itself is below the range of phosphate content for *G. verrucosa* cultivation. Phosphate is one of the most important nutrients in cultivation to increase the growth of seaweed. According to the research results of Rejeki *et al.* (2018), phosphate content between 0.24-5.97 mL/L can produce SGR of 1.3 %/day. The range of the value of nitrate and phosphate which is feasible for seaweed fertility is 0.1 - 3.5 ppm.

4. Conclusion

The differences planting areas have a very significant effect on the growth and production of *G. verrucosa* cultivated by the verticulture method in Karimunjawa, Jepara. The planting area of 75x75 cm² has the best yield on absolute growth, relative growth rate (RGR) and specific growth rate (SGR) of 83.10 ± 4.12 g; 3.96 ± 0.20 %/day and 2.33 ± 0.07 %/day. The best results of *G. verrucosa* production obtained at an area of 50x50 cm² (5.32 ± 0.26 kg/m²). It is recommended to

conduct further research on the effect of the differences in the size of the nets as protection from herbivorous fish on the growth performance of *G. verrucosa*.

5. Acknowledgments

This research was supported by the Faculty of Fisheries and Marine Science, Diponegoro University (Research Grants 2018 number 167/UN.5.10/HK/2018).

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