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Analysis of Carbon Sequestration Rate in Seaweed (*Kappaphycus alvarezii*) Based on Environmental Mitigation

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ABSTRACT Blue economy is a development concept that develops by relying on marine or aquatic resources. An increase in carbon dioxide (CO_2) in the atmosphere is fueling climate change. This study aims to analyze the rate of carbon uptake in the waters, using seaweed *Kappaphycus alvarezii* which utilizes carbon to be converted into biomass before returning to the air. The results showed that highest carbon absorption rate was found in location A with the highest total carbon absorption of 94.87±0.77 tons C/planting cycle, then treatment B with 83.96±0.54 tons C/planting cycle, and the lowest in treatment C with 76.88±0.18 tons C/planting cycle. Water quality parameters are still mostly in decent condition for the cultivation of *Kappaphycus alvarezii* seaweed. Salinity conditions of waters are relatively high (35-39 ppt) even though the optimum seaweed grows in the range of 30-34 ppt. The conclusion of the study is that the highest total carbon is found at Location A, which is 94.87±0.77 tons C/planting cycle. The suggestion of this study is that it is necessary to analyze the suitability of seaweed cultivation land with various water quality parameters, so that mapping of potential types of seaweed that can be cultivated according to the characteristics and quality of the waters.

Keywords: Blue economy; climate change; carbon; seaweed; *Kappaphycus alvarezii*

INTRODUCTION

Blue economy terminology is the latest development concept that develops by relying on marine or aquatic resources based on three integrated pillars, namely ecosystem, economy, and social. Of course, all policies and activities carried out are expected to be based on these principles. However, the development of human activities has the opposite impact. The increase in the concentration of greenhouse gases (Green House Gases / GHGs) caused by carbon dioxide (CO_2) in the atmosphere is one of the triggers for the phenomenon of global climate change. The main human contribution to the increase in the amount of carbon present in the atmosphere is due to respiration and the burning of fossil fuels, such as petroleum, coal, and natural gas. The impact of increasing CO_2 includes increasing earth surface temperature, rising sea levels, climate anomalies, and the emergence of various diseases in humans and animals (IPCC, 2014).

Carbon in nature undergoes a material cycle that we know as the carbon cycle. The cycle undergoes a transfer or exchange between biotic reservoirs (biosphere) and abiotic (ocean, atmosphere and crust). Carbon exchange between reservoirs involves several processes within them, such as chemical, physical, geological and biological processes. The biological process itself involves biological agents, namely living things. Living things that play an important role in the carbon cycle are groups of photosynthetic organisms such as vegetation on land and in waters (Nuruddin, 2019).

One effort to reduce carbon dioxide content, both in the atmosphere and in the ocean, is to use vegetation on land and in the sea to absorb and store carbon (Indriani *et al.*, 2017). The reduction in the amount of free carbon is not without constraints. This is due to the decreasing forest area due to the opening of new agricultural and residential land, which actually increases the amount of CO_2 in the atmosphere (Pratama & Parinduri, 2019). Even according to research, carbon dioxide (CO_2) emissions are increasing, with atmospheric CO_2 exceeding 416 ppm in February 2021 (Hill *et al.*, 2015).

Environmental mitigation based on aquatic plants has the potential to be carried out to reduce carbon emissions, namely the coastal and marine ecosystem approach or blue economy (Ganefiani *et al.*, 2019). Improving the ability of coastal ecosystems to assimilate and store carbon is an important aspect of climate change mitigation (Harper *et al.*, 2018). Plants have the ability to photosynthesize by utilizing CO_2 gas and sunlight as raw materials, then the results of photosynthesis in the form of oxygen and food substances needed by plants and other living things (Sukmawati *et al.*, 2015). One of the aquatic plants that can be improved is the seaweed type *Kappaphycus alvarezii*.

Kappaphycus alvarezii seaweed is one of the coastal vegetation that is able to utilize CO_2 through photosynthetic activities to be converted into Biomass (Erlania & Radiarta, 2014). For growth and development, seaweed carries out the process of photosynthesis by utilizing CO_2 and light energy which is converted into carbohydrates. Although the factors needed for seaweed growth are relatively simple (nutrients, trace minerals, CO_2 water, and sunlight) and relatively the same as terrestrial plants, this group of algae can utilize them very efficiently resulting in higher productivity (Erlania *et al.*, 2013).

Based on the results of literature studies that have been conducted, research so far has only looked at the rate of carbon sequestration in different seaweed commodities, the influence of the growing season, and carbon sequestration on seaweed in nature. Thus, this study has novelty value in terms of assessing carbon absorption rates at different cultivation sites, so that the relationship between carbon sequestration rates based on location or growing place will be seen. In addition, this study will also look at the best cultivation locations in terms of utilizing carbon into Biomass.

This study aims to analyze the rate of carbon uptake in the waters, using seaweed *Kappaphycus alvarezii* which utilizes carbon to be converted into biomass before returning to the air.

MATERIALS AND METHODS

Materials

The materials used are seaweed type *Kappaphycus alvarezii*, plastic clips, label paper, seawater, PP indicator (Phenolphthalein), Na_2CO_3 0,0454 N, and NaOH 0,0227 N. The tools used are, Rope Ris, sample bottle, drop pipette, furnace, erlenmeyer, pH pen type O_2, DO Meter type DO9100, Handrefracto meter, Thermometer, Secchi disk, digital scales, and camera.

Methods

The research location point is Location A / station 1 is close to the mouth of the river, location B/ station 2 is close to residential areas, and location C/ station 3 is close to shrimp pond waste disposal. The point was considered to represent the condition of the waters at the study. The location of the research data collection (Figure 1).

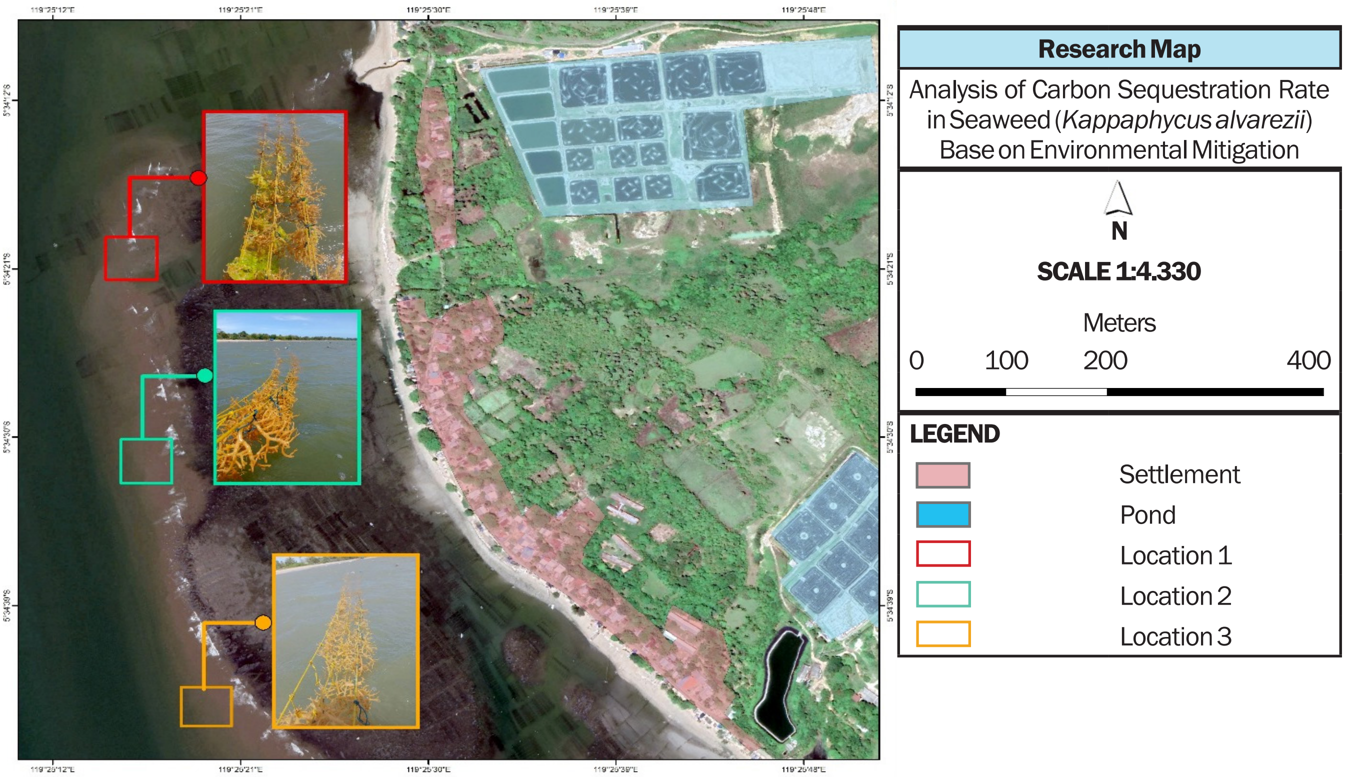

Figure 1. Location of research data collection (Source: Research Location Map Data, 2023).

Preparation and cultivation process

Kappaphycus alvarezii seaweed was tied to a rope according to a predetermined planting distance. The cultivation method used was the Rawai method (Long line). The long line unit to be used is 0.6 m x 20 m consisting of 3 ropes per maintenance location point. One rope consists of 20 planting points. Seaweed seeds were tied to ropes weighing 100 gr per planting point. Before maintenance, seaweed and water samples were tested at each location point.

Data collection

During the research or cultivation process, seaweed and water samples were also taken on days 15, 30, and 45 at each maintenance site. The samples that have been taken were then dried for 3-4 days, then put into plastic clips as much as 50 g/sampling location. The samples were then subjected to laboratory testing at the Productivity and Water Quality Laboratory of Hasanuddin University, Makassar. The carbon content in water is carried out insitu to maintain the validity of the measurement results using the titration method (Winkler). To support the research process, daily water quality parameters such as temperature, salinity, pH, dissolved oxygen (DO), and brightness were measured.

Sample analysis

Analysis of carbon content was analyzed by Gravimetric method. The stages of seaweed carbon content analysis were as follows:

Water content measurement

Test samples that have been weighed and cleaned heated using an oven at 105°C for three hours. The sample was then cooled in an excitator and weighed. The moisture content was determined by the following equation:

$$\text{Water content} = a\text{-}b/a \times 100\%.$$

Where : a = Sample weight before heating (g)
b = Sample weight after drying (g)

Volatile substances measurement

Samples that have been heated for 105°C, will be inserted into a porcelain dish and then tightly closed. The sample is then put into the kiln at 900ºC for 6 minutes. The volatile substance content is determined by the following equation:

Volatile substances = a-b/a x 100%

Where: a = Weight of dry sample with heating 105ºC (g)
b = Weight of dry sample after heating 900ºC (g)

Standing stack

Standing stak is the wet weight of the sample per square meter

Standing stock (g/m^2) = a/b

Description: a = Wet sample weight (g)
b = Sample point area (m^2)

Biomass

Biomass is the weight calculated after heating using an oven for 2-4 days at a temperature of 80-90 ºC.

Biomass (%) = a/b x 100 %

Description: a = Wet sample weight (g)
b = Sample weight after heating at 90 ºC (g)

Wet weight-biomass ratio (P-B ratio)

Wet Weight – Biomass ratio is the ratio between Wet Weight and Biomass with the following formula:

P – B = a/b

Description: a = Wet sample weight (g)
b = Biomass sample weight (g)

Ash content test

The sample to be opened is first charred on a burner. Graying is carried out using a furnace at a temperature of 550 ºC until complete ashing. The cup containing the ash is cooled into an excitator and then weighed. The determination of ash content is determined by the following equation:

Ash content = b/a x 100%

Where: a = Sample weight (g)
b = Ash weight (g)

Carbon content

The absorption of cabon can be obtained by the following equation:

Carbon content = 100% – moisture content –volatile substance content – ash content.

Calculation of estimated carbon sequestration

The calculation of carbon sequestration uses an equation, namely by entering the variables of cultivated area (km^2), standing stock (g/m^2), production-biomass ratio, and carbon content (%) (Jamal, 2010). Where carbon sequestration per cycle is:

Total carbon sequestration (C) = [Total area] x [Standing Stock] x [P-B Ratio] x [Carbon Content].

Where: Total area = Area of cultivation area (km^2)
Standing stock = Productivity (g/m^2)
Ratio P-B = Wet Production/Biomass
Carbon Content = (weight of ash/weight of Biomass) x 100

Statistical analysis

Data on carbon sequestration rates at each observation site were analyzed with the SPSS Version 22 application, if there were differences between treatments, analyzed using LSD (Least Significant Difference) follow-up tests to see the differences between treatments.

RESULTS AND DISCUSSION

Carbon content in seaweed

The carbon content of *Kappaphycus alvarezii* seaweed, at 3 different research location is presented in Table 1.

Based on Table 1, it can be seen that the carbon content in seaweed at each cultivation site shows different results. The highest carbon content was found at locations near river mouths (Location A) with an average of 9.21%, followed by locations near settlements (Location B) with 9.19%, and finally at locations near pond waste disposal (Location C) with a content of 9.06%. The difference in carbon content in seaweed is thought to be due to differences in the contribution of carbon sources from each research location. The high carbon in water is directly proportional to the carbon that can be absorbed by seaweed. The estimated rate of carbon sequestration will depend heavily on the ability to live and grow from plants, meaning that the ability to grow seaweed will depend largely on the environmental conditions in which the seaweed is cultivated. So that different environmental conditions will have the opportunity to absorb carbon (Jamal, 2010).

Carbon uptake is influenced by the source or location of cultivation with differences in carbon content in waters. The fertility of the aquatic environment is strongly influenced by the release of phosphorus (P) and organic carbon deposits because it functions as a nutrient regenerator in the water column (Barus *et al*., 2020). Another statement shows that carbon sequestration depends on organic matter found in waters (Sondak, 2017). Uptake rates also showed a decrease with seaweed age or length of maintenance (Table 1). The ability of *K. alvarezii* seaweed to absorb carbon in the aquatic environment decreases with increasing maintenance age (Erlania *et al*, 2013).

The results of the analysis of variance (ANOVA) showed that the absorption rate of carbon content in 3 different locations, showed a difference (≤0.05). The site of cultivation near the mouth of the river differs significantly from the site near the disposal of shrimp pond waste, but does not differ significantly from the site near the settlement.

Table 1. Carbon content in seaweed each research location.

Location of cultivation	Initial sampling (%)	Carbon content in seaweed (%)			Total (%)	Average (%)
		Sampling 1st	Sampling 2nd	Sampling 3rd		
A (Near the mouth of the river)	9.02	9.12	9.25	9.25	27.62	9.21±0.08[a]
B (residential areas)	9.02	9.12	9.23	9.21	27.56	9.19±0.06[a]
C (shrimp pond waste disposal)	9.02	9.04	9.08	9.07	27.19	9.06±0.02[b]

While the location near the settlement is also not much different from the location of shrimp pond waste disposal.

Total seaweed carbon sequestration

The study also looked at the total final carbon uptake of seaweed rearing at each study site. The total carbon sequestration from each site is presented in Table 2.

The results of measuring total carbon sequestration in each treatment showed very noticeable differences between each observation site. The treatment with the highest total carbon absorption is found in treatment A with the highest total carbon absorption of 94.87±0.77 tons C /planting cycle, then treatment B with 83.96±0.54 tons C/planting cycle, and the lowest in treatment C with 76.88±0.18 tons C/planting cycle. The high carbon content is directly proportional to the total carbon uptake produced. The decrease in absorbable CO_2 can vary, depending on the species cultivated, location, as well as the growing season (Roberts *et al.*, 2015).

Water Quality Parameters In addition to measuring the carbon content and total carbon uptake of seaweed at each reseach location (Station), this study also measured the water quality parameters of each location to strengthen and support the results of the study. The results of measuring water quality parameters are presented in Table 3.

The quality of waters where seaweed cultivation is located can affect the survival and growth of seaweed (Radiarta *et al.*, 2013). The range of water quality data obtained during aquaculture activities shows several ranges that can still be tolerated by seaweed. The degree of acidity (pH) in the study was 7.87-8.87, while for good seaweed growth ranged from 6-9. The optimum temperature for seaweed growth ranges from 20-30°C (Ruslaini, 2016). In this study, the temperature measured was still within these tolerances. Meanwhile, for brightness, the measurement results range from 26-100 cm. This condition is also still within the tolerance limit for seaweed. The rate of carbon sequestration by seaweed has the highest positive correlation with the internal factor of seaweed, namely pigment content, and the external factor, namely the brightness of the waters (Buschmann *et al.*, 2017). The brightness of the waters is related to the amount of light intensity that can be absorbed by seaweed as an energy source in the process of photosynthesis. Meanwhile, the oxygen content based on the measurement results (Table 3) shows good conditions for seaweed. The desired dissolved oxygen content in aquaculture systems is about 5 ppm, while the dissolved oxygen concentration of <3 ppm is a barrier for most aquatic organisms (Radiarta & Erlania, 2015).

Water quality parameters are still not optimal for the growth and development of *Kappaphycus alvarezii* seaweed in this study is salinity. Salinity conditions of waters are relatively high (35-39 ppt) even though the optimum seaweed grows in the range of 30-34 ppt. Chlorophyll increased in algae samples at a salinity of 30 ppt and reached a maximum at a salinity of 35 ppt. However, conditions in the field based on the measurement results show a salinity range of 35-39 ppt. Good salinity can make seaweed grow well, because it relates to the balance of cell membrane function. Salinity is a chemical factor that affects the physical properties of water, including osmotic pressure in seaweed with liquids in the environment (Andreyan *et al.*, 2021). This balance will help the absorption of nutrients as nutrients, for photosynthesis, so that seaweed growth will be optimal (Yuliyana et al, 2015).

CONCLUSION AND RECOMMENDATION

Conclusion

The results of this study showed that the average carbon content in seaweed was highest at Location A at 9.21%, then at Location B at 9.19%, and the lowest at Location C at 9.06%. The carbon content is directly proportional to the total carbon uptake. The highest total carbon absorption was found at Location A at 94.87±0.77 tons C/planting cycle, then Location B at 83.96±0.54 tons C/planting cycle, and the lowest at Location C with a total carbon absorption of 76.88±0.18 tons C/planting cycle. Water quality parameters of all study sites except salinity showed optimal content for the cultivation of seaweed type *Kappaphycus alvarezii*. Salinity at each study site is quite

Table 2. Total carbon sequestration in seaweed at each study site.

Location of cultivation	Area (m^2)	Standing stock (g/m^2)	P – B Ratio (g)	Carbon content (%)	Carbon sequestration (ton C/ planting cycle)
A (Near the mouth of the river)	20±0.00	5150.56±0.00	10±0.00	9.21±0.08	94.87±0.77[a]
B (residential areas)	20±0.00	4567.84±0.00	10±0.00	9.19±0.06	83.96±0.54[b]
C (shrimp pond Waste disposal)	20±0.00	4243.04±0.00	10±0.00	9.06±0.02	76.88±0.18[c]

Table 3. Water quality parameters of each study site.

No	Water quality parameters	Range of measurement results		
		Location A	Location B	Location C
1	pH	7.87-8.87	7.98-8.80	7.92-8.85
2	Temperature (°C)	27.1-29.1	27.50-28.70	28.10-28.30
3	Salinity (ppt)	36-38	35-36	35-39
4	Brightness (cm)	40-93	26-100	48-94
5	Dissolved Oxygen (ppm)	5.75-6.70	5.98-6.35	5.90-6.31
6	CO_2 (ppm)	4.79-9.59	2.29-480	3.84-3.99

high and is classified as exceeding the optimum limit for seaweed cultivation. Salinity conditions of waters are relatively high (35-39 ppt) even though the optimum seaweed grows in the range of 30-34 ppt.

Recommendation

Different cultivation locations show different rates of seaweed uptake and growth. However, the rate of carbon sequestration is not the only water quality parameter that affects seaweed growth. The success of seaweed cultivation must be seen from various aspects. It is necessary to conduct a land suitability analysis, in order to map the potential of cultivated land and determine a more optimal seaweed development strategy with measurable methods so that accountable data can be obtained. Spatial analysis with geographic information system (GIS) is one method to be able to solve these problems scientifically.

AUTHOR'S CONTRIBUTIONS

In this study, there were two other authors, namely IR as the corresponding author who was in charge of correspondence with the editor before the manuscript submission and UD as a co-author who was in charge of providing corrections to the method and analysis of research data.

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