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INFLUENCE OF SEAWEED SPECIES AND CULTIVATION METHODS ON CARBON SEQUESTRATION IN KUPANG BAY

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Abstract

The increasing concentration of carbon dioxide (CO_2) as the main greenhouse gas encourages the need for climate change mitigation efforts, one of which is through the farming of seaweed that has the potential to absorb carbon. This study aimed to analyze carbon absorption in Kappaphycus alvarezii and Kappaphycus striatum farmed with different methods in Kupang Bay waters, including Tablolong, Kuanheum, Tesabela, and Pasir Panjang. The study used a survey method through observation, measurement, and laboratory analysis. Samples were taken from farming using Longline, Off-bottom, and Anaconda net methods, at the base, middle, and tip of the thallus representing different ages. Analysis included were biomass, carbon content, standing stock, production-biomass ratio (P/B), estimation of total carbon absorption, and measurement of water quality parameters. The results showed that seaweed biomass ranged from 45.70–51.05 g, with the highest biomass obtained from the Anaconda net method and the K. alvarezii species. Carbon content ranged from 10.46–22.44%, with the highest values found in Tablolong, farmed using the Anaconda net method. Although K. alvarezii produced the highest biomass, K. striatum had higher carbon content and total carbon uptake. These results indicated that differences in species and farming methods influenced the carbon uptake capacity of seaweed, thus providing a basis for developing farming that supports climate change mitigation.

Keywords: *Kappaphycus spp, Carbon Sequestration, Longline Method, Anaconda Net Method, Kupang Bay.*

1. INTRODUCTION

Global warming is a major environmental problem characterized by increasing global temperatures due to the accumulation of greenhouse gases in the atmosphere. One of the greenhouse gases that plays the largest role is carbon dioxide (CO_2) (Azzahra et al., 2020). According to NOAA, atmospheric CO_2 concentrations continue to increase annually and in 2023 had reached an average of 419.33 ppm, an increase of approximately 2.8 ppm compared to the previous year. This condition marks the 12th consecutive year with an annual increase in CO_2 concentration exceeding 2 ppm, so various efforts are needed to reduce carbon emissions and the impact of climate change (Erlania et al., 2013). The continuous increase in atmospheric CO_2 concentration has encouraged the development of mitigation strategies that not only focus on reducing emissions but also enhance natural carbon absorption processes through ecosystem-based approaches.

To reduce the impact of climate change, various approaches have been taken, one of which is through the concept of blue carbon, which refers to three main ecosystems, namely seagrass, mangroves and salt marshes that are able to absorb and store carbon. This approach has also been carried out by the Ministry of Maritime Affairs and Fisheries by carrying out reforestation of coastal vegetation so as to reduce CO_2 concentrations in the atmosphere (Erlania et al., 2015). Currently, seaweed farming is also positioned as a subsector that plays a role in blue carbon, as cultivated seaweeds have demonstrated potential for carbon fixation and contribution to climate change mitigation strategies (Duarte et al., 2017; Froehlich et al., 2019).

Several studies that have been conducted in Japan (Muraoka, 2004b) and Indonesia (Erlania et al., 2015; Tisera, 2024; Tjaronge & Sahabuddin, 2012) have proven the potential for carbon absorption in various types of farmed seaweed. Several studies have demonstrated that seaweed ecosystems contribute significantly to carbon capture through biomass accumulation and carbon storage processes (Krause-Jensen et al., 2018). Therefore, evaluating carbon absorption capacity under different cultivation conditions is important for optimizing the contribution of seaweed farming to climate mitigation programs.

East Nusa Tenggara Province is one of Indonesia's seaweed production centers. Most coastal communities in Kupang City and Regency rely on seaweed farming as their primary livelihood, particularly in the Kupang Bay Marine Nature Tourism Park (TWAL) and the Sawu Sea Marine National Park (TNP). Commonly farmed seaweed species include Kappaphycus alvarezii (trade name cottonii) and Kappaphycus striatum (trade name sakol), with the dominant farming methods being the longline and off-bottom methods. Cultivation techniques affect water circulation, nutrient availability, growth performance, and biomass accumulation, which ultimately influence the carbon sequestration potential of farmed seaweed (Hurtado et al., 2019). The commonly applied cultivation methods in Kupang Bay include longline and off-bottom systems, while the Anaconda Net method has recently been introduced in several locations and is expected to improve seaweed growth performance by providing better support and reducing physical stress on thalli. Differences in cultivation methods may therefore produce different levels of biomass accumulation and carbon uptake capacity.

Although seaweed farming in Kupang Bay has developed rapidly, information regarding the carbon absorption capacity of *Kappaphycus* spp. cultivated using different farming methods remains limited. Most previous studies have focused primarily on production performance, carrageenan quality, and cultivation efficiency, while assessments integrating biomass production, carbon content, and total carbon uptake under different cultivation systems are still scarce. Understanding these relationships is essential because sustainable seaweed farming should not only aim to increase economic productivity but also maximize ecological functions, particularly its contribution to climate change mitigation.

Furthermore, identifying the most effective combination of seaweed species and cultivation methods is necessary to support the development of carbon-oriented aquaculture management. Information regarding species-specific carbon storage capacity and cultivation system performance can provide scientific guidance for farmers, policymakers, and coastal managers in designing sustainable blue carbon initiatives. Therefore, this study aimed to analyze the carbon absorption capacity of *Kappaphycus alvarezii* and *Kappaphycus striatum* cultivated using different farming methods in Kupang Bay waters. The results are expected to provide valuable information for improving seaweed cultivation practices while strengthening the role of seaweed farming as a nature-based solution for climate change mitigation.

2. METHODS

2.1 Time and Locations of Research Implementation

This research was conducted over a period of three months along the coast of Kupang Bay, specifically in the waters of Tablolong Village, Lifuleo Village, Tesabela Village, Oenaek Village, Sulamu Village, and Pasir Panjang Village. Samples were analyzed at the Eksata Laboratory and the Biology Laboratory of Artha Wacana Christian University.

2.2 Research Procedures

a. Farming Methods

The farming methods used consisted of three methods: the bottom-off method, the longline method, and the anaconda net method. Sampling locations using the off-bottom method were in Tesabela Village, Sulamu Village, and Pasir Panjang Village. Locations using the longline method were in Lifuleo Village and Sulamu Village; while the anaconda net method was in Tablolong Village.

Figure 1. Of-Bottom Method (A), Longline Method (B), Anaconda Net Method (C)

b. Sampling

Sampling was carried out by taking 25 samples of *K. alvarezii* and *K. striatum* to be harvested, with a 45-day planting period between the three methods. This point was determined to represent the diversity of characteristics and growth.

c. Carbon Content Analysis

Analysis of carbon content in Kappaphycus spp. samples was carried out using the following stages as referred to by Tjaronge and Sahabuddin (2012):

1) Water content measurement
The sample was weighed in a cup of known weight and then heated in an oven at 105ºC for 3 hours. The cup was then cooled in a desiccator and weighed (SNI, 1992). The test was repeated twice until a constant weight was achieved.

2) Measurement of volatile substances
Volatile substances were measured using a porcelain cup, where the cup was filled with the sample, then tightly closed and placed in a furnace at a temperature of 900 ± 15ºC for 6 minutes. The sample was cooled in a desiccator for 1 hour and weighed. The volatile substance content was expressed as a weight percentage (SNI 1995).

3) Ash content test
The ash content test was conducted based on the Indonesian National Standard (SNI) 01-2891-1992 ash content test procedure. The seaweed biomass sample was weighed in a porcelain cup of known weight. The sample was first ashes and charred over a burner. The Ashed was carried out in a furnace at 550ºC until complete ashed (the furnace door was opened occasionally to allow oxygen to enter). The cup containing the ashed sample was cooled in a desiccator and then weighed (SNI, 1992).

2.3 Data Analysis Methods and Data Interpretation

The data analysis used in this study were as follows:

a. Water Content

Water content was obtained using the formula (SNI, 1992):

$$Water\ Content = \frac{B - C}{B - A} x\ 100\%$$

Description:

A : Weight of empty cup (gr)

B : Weight of cup + sample (gr)
C : Weight of final cup + sample (gr)

b. Volatile substance content
The level of volatile matter was obtained by the formula (Tisera, 2024b):

$$Volatile\ substance\ content = \frac{a - b}{a} x\ 100\%$$

Description:
a : Weight of dry sample after heating at 105 ºC (gr)
b : Weight of sample after heating at 950ºC (gr)

c. Ash content
Ash content was obtained by the formula (SNI, 1992):

$$\text{Ash content} = \frac{b - c}{a} x\ 100\%$$

Description:
a : Sample weight before ash (gr)
b : Weight of sample + cup after ashed (gr)
c : Weight of empty cup (gr)

d. Carbon content
Carbon content is obtained using the formula (Ludang & Jaya, 2007):

$$Carbon\ content = 100\% - Water\ content - Volatile\ substance\ content - Ash\ content$$

e. Standing stock
Standing stock is the sample weight per square meter (Muraoka, 2004a), with the formula:

$$Standing\ stock = \frac{a}{b}$$

Description:
a : Sample weight (gr)
b : Sample point area (m^2)

f. Biomass
Biomass is the weight calculated after being heated using an oven for 2 – 4 days at a temperature of 80 – 90ºC, with the following formula (Ludang & Jaya, 2007):

$$Biomass = a - b$$

Description:
a : Sample weight (gr)
b : Sample weight after heating at temperature 90ºC (g)

g. Wet weight-biomass ratio (P-B ratio)
The wet weight-biomass ratio is the comparison between wet weight and biomass with the following formula (Muraoka, 2004a):

$$Rasio\ P - B = \frac{a}{b}$$

Description:
a : Sample weight (gr)
b : Biomass sample weight (gr)

h. Calculation of carbon absorption estimates
The calculation of carbon absorption uses the equation used in Muraoka (2004) by entering the variables of farming area, standing stock, wet weight-biomass ratio, and carbon content. Where the carbon absorption formula is as follows:
Total Carbon Absorption (C) = [Total farming area (m^2)] x [Standing Stock] x [P – B Ratio] x [Carbon content]

3. RESULT AND DISCUSSION

3.1 Sample

The samples used for carbon absorption analysis at seaweed farming sites were taken from several farming sites in Kupang Bay and its surroundings, namely *Kappaphycus striatum* grass from the Anaconda Net method in Tablolong Waters, Kappaphycus striatum grass from the Longline method in Lifuleo Waters, Kappaphycus striatum grass from the Off-Bottom method in Tesabela Waters, Kappaphycus alvarezii grass from the Longline method in Oenaek Waters, Kappaphycus alvarezii grass from the Off-Bottom method in Pasir Panjang Waters, and Kappaphycus striatum grass from the Longline method in Sulamu Waters.

Sakol fromTablolong

Sakol from Lifuleo

Sakol from Tesabela

Cotonii from Oenaek

Cotonii from Pasir Panjang

Sakol from Sulamu

Figure 2. Seaweed species and cultivation locations in Kupang Bay and surrounding areas

The samples were then separated into two age/thallus diameter categories: older seaweed with a thallus diameter of 10.1–13.4 mm, while younger seaweed had a thallus diameter of 3.2–7.4 mm.

3.2 Water Content

The water content of Kappaphycus striatum and K. alvarezii seaweed from several cultivation locations is shown in Figure 3.

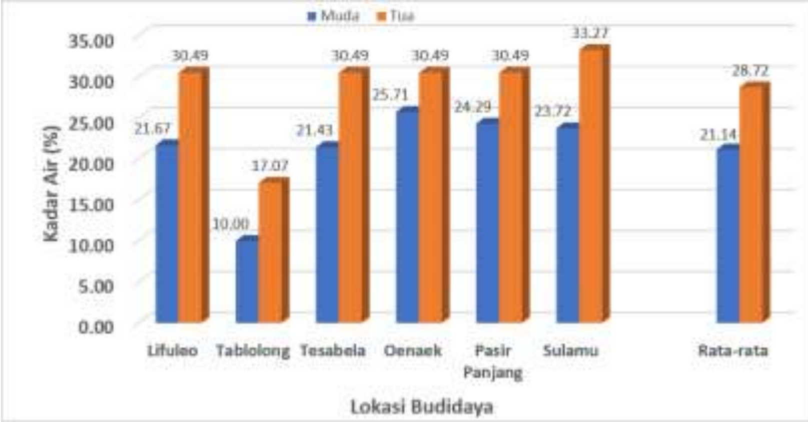

Figure 3. Water content of K. striatum and K. alvarezii seaweeds in different cultivation locations in Kupang Bay and its surroundings.

Figure 3 shows that the water content of young thallus ranges from 10.00 to 25.71%, lower than that of mature thallus, with an average of 21.14%. For mature thallus, the water content ranges from 17.07 to 33.27%, with an average of 28.72%.

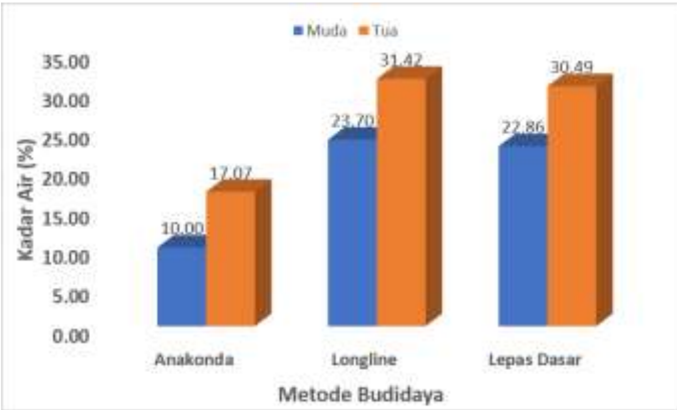

Figure 4. Water content of Kappaphycus striatum and K. alvarezii seaweed cultivated with different methods in Kupang Bay and its surroundings.

When comparing the cultivation methods used, the results varied considerably (Figure 4). For both thallus (young and old), the method that produced the highest water content was the Longline method, followed by the Off-Bottom method. For all three methods, the old thallus produced higher water content values than the young thallus.

When comparing the two species, Kappaphycus alvarezii produced higher water content values than K. striatum, both in the young and old thallus (Figure 5).

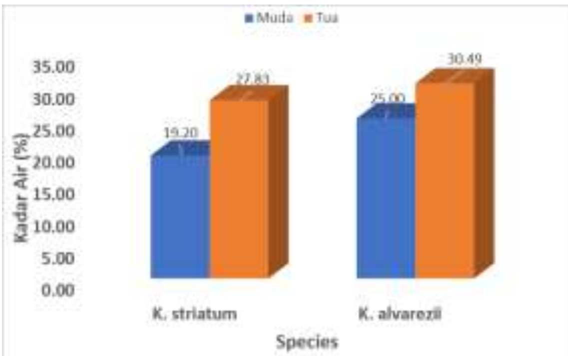

Figure 5. Water content of K. striatum and K. alvarezii seaweed in Kupang Bay and surrounding areas.

3.3 Biomass

The biomass of Kappaphycus striatum and K. alvarezii seaweed from several cultivation locations in Kupang Bay and surrounding areas is presented in Figure 6. Figure 6 shows that the biomass of young thallus ranges from 47.49 to 51.05 grams, higher than that of mature thallus, with an average of 49.66 grams. For mature thallus, the biomass ranges from 45.70 to 50.02 grams, with an average of 48.85 grams.

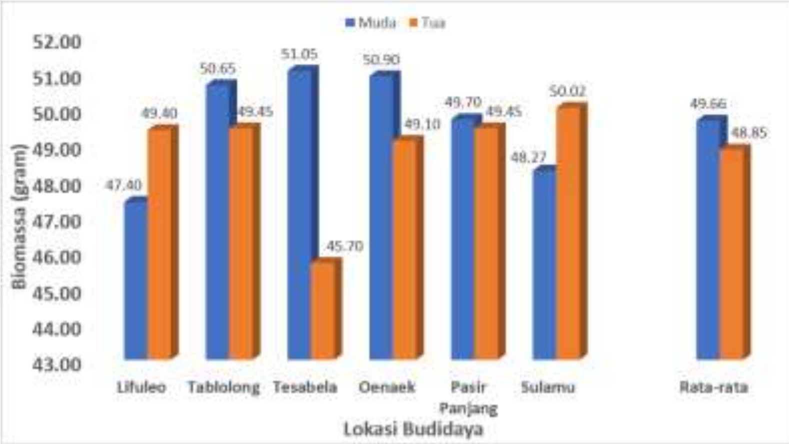

Figure 6. Biomass of K. striatum and K. alvarezii seaweeds cultivated at different locations in Kupang Bay and its surroundings.

Comparing the cultivation methods used, the results varied considerably (Figure 7). For both thallus (young and old), the method that produced the highest biomass was the Anaconda Net method, followed by the Off-Bottom method. For all three methods, young thallus produced higher biomass than young thallus, except for the longline method (where older thallus produced higher biomass).

Figure 7. Biomass of K. striatum and K. alvarezii seaweed cultivated using different methods in Kupang Bay and its surroundings.

Comparing the two species, K. alvarezii produced higher biomass than K. striatum, both in young and old thallus (Figure 8).

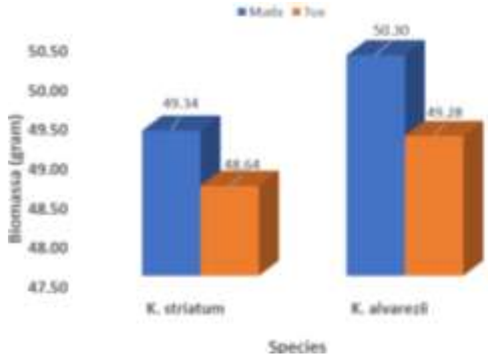

Figure 8. Biomass of K. striatum and K. alvarezii seaweed in Kupang Bay and its surroundings.

3.4 Ash Content

The ash content of Kappaphycus striatum and K. alvarezii seaweed from several cultivation locations in Kupang Bay and its surroundings is shown in Figure 9.

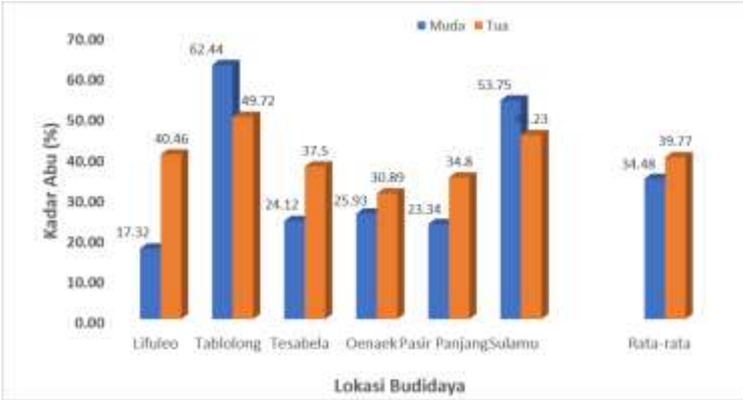

Figure 9. Ash content of K. striatum and K. alvarezii seaweed cultivated at different locations in Kupang Bay and its surroundings.

Figure 9 shows that the ash content of young thallus ranged from 53.69% to 85.77%, with an average of 68.09%, lower than that of mature thallus. For mature thallus, the ash content ranged from 98.61% to 85.07%, with an average of 90.83%.

Comparing the cultivation methods used, the results varied considerably (Figure 10). For both thallus (young and mature), the method that produced the highest ash content was the Anaconda Net method, followed by the Off-Bottom method. For all three methods, mature thallus produced higher ash content than young thallus.

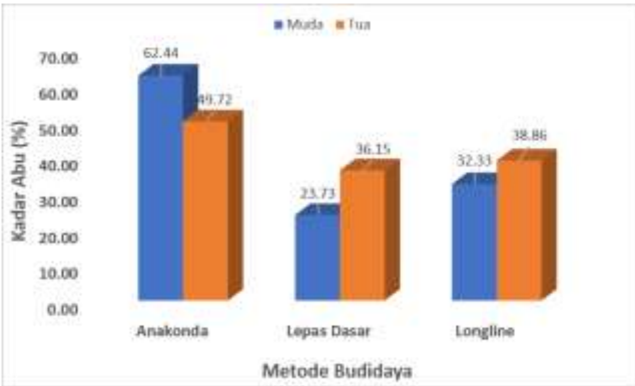

Figure 10. Ash content of K. striatum and K. alvarezii seaweed cultivated using different methods in Kupang Bay and its surroundings.

Comparing the two species, K striatum exhibited higher ash content than K. alvarezii, both in young and mature thallus (Figure 11).

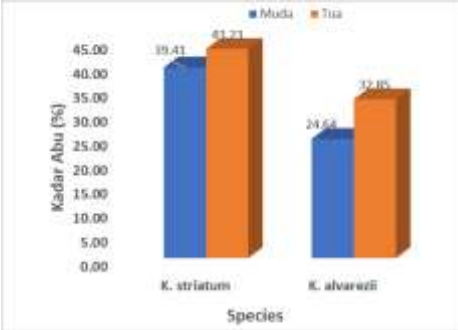

Figure 11. Ash content of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and surrounding areas.

3.5 Volatile Substance Content

The volatile substance content of Kappaphycus striatum and K. alvarezii seaweed from several cultivation locations in Kupang Bay and surrounding areas is presented in Figure 12. Figure 12 shows that in young thallus, the volatile substance content ranged from 31.56% to 57.30% with an average of 45.97%, lower than that of mature thallus, which ranged from 41.95% to 55.44% with an average of 54.23%.

Figure 12. Volatile Substance Levels of K. striatum and K. alvarezii seaweed cultivated at different locations in Kupang Bay and its surroundings.

Comparing the cultivation methods used, the results varied considerably (Figure 13). For young thallus, the method that produced the highest Volatile Substance Levels was the Anaconda Net method (57.30%), followed by the Off-Bottom method (46.35%). For mature thallus, the method that produced the highest Volatile Substance Levels was the Longline method (54.38%), followed by the Off-Bottom method (54.19%).

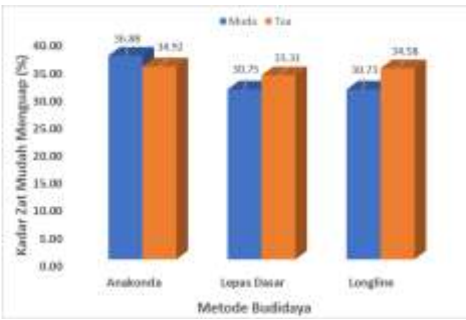

Figure 13. Volatile Substance Levels of K. striatum and K. alvarezii seaweed cultivated using different methods in Kupang Bay and its surroundings.

Comparing the two species, Kappaphycus alvarezii exhibited higher Volatile Substance Levels than K. striatum in both young and mature thallus (Figure 14).

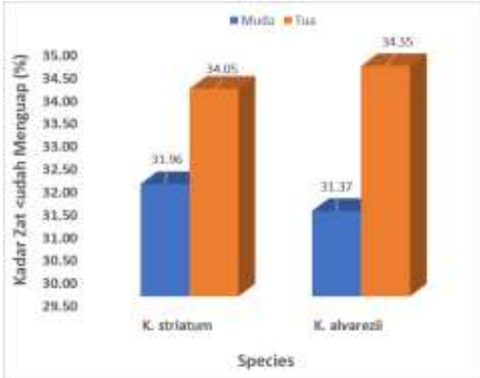

Figure 14. Volatile matter content of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and surrounding areas.

3.6 Carbon Content

Carbon content is obtained by subtracting 100% from the moisture content, ash content, and volatile matter content. The results are shown in Figure 15.

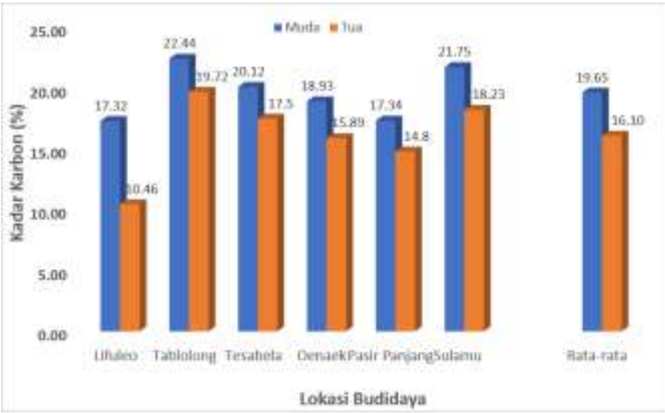

Figure 15. Carbon content of K. striatum and K. alvarezii seaweed cultivated at different locations in Kupang Bay and its surroundings.

Figure 15 shows that in young thallus, carbon content ranged from a low of 17.32% at the Lifuleo site to a high of 22.44% at the Tablolong site, with an average of 19.65%. For mature thallus, carbon content ranged from a low of 10.46% at Lifuleo to a high of 19.72% at Tablolong, with an average of 16.10%. For all locations, carbon content for young thallus was higher than for mature thallus.

Comparing the cultivation methods used, the results varied considerably (Figure 16). For young thallus, the method that produced the highest carbon content was the Anaconda net method (22.44%), followed by the Longline method (19.33%). For old talus, the method that provided the highest carbon content was also the anaconda net method (19.72%), followed by the Bottom Release method (16.15%).

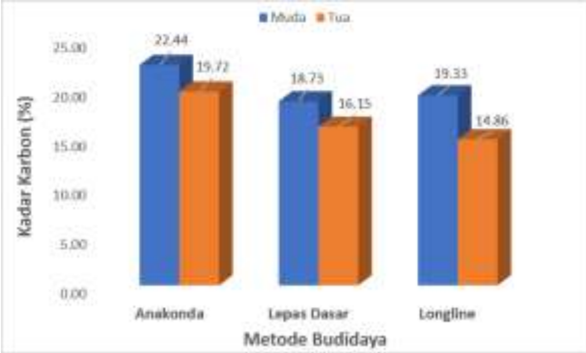

Figure 16. Carbon content of K. striatum and K. alvarezii seaweed cultivated using different methods in Kupang Bay and its surroundings.

Comparing species, Kappaphycus striatum exhibited higher carbon content in both young and mature thallus compared to Kappaphycus alvarezii (Figure 17).

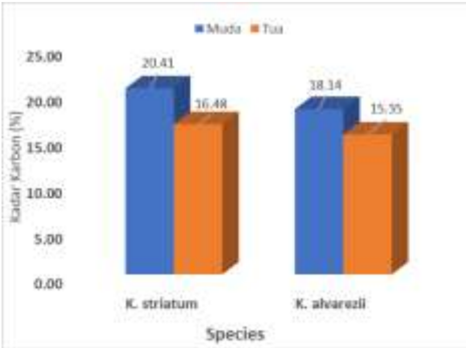

Figure 17. Carbon content of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings.

3.7 Standing Stock

Standing Stock is the wet weight of a sample per square meter. Standing Stock reflects the productivity of the seaweed cultivation area. Standing Stock of Kappaphycus striatum and K. alvarezii seaweed from several cultivation locations in Kupang Bay and its surroundings is presented in Table 1.

Table 1. Standing Stock (gr./m^2) of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings

Thallus Age	Cultivation Location						Average
	Lifuleo	Tablolong	Tesabela	Oenaek	Pasir Panjang	Sulamu	
Young	6470	7607	6903	6445	5700	7603	6788
Old	6720	7857	7153	6695	5950	7853	7038

Table 1 shows that the Standing Stock value of the seaweed species K. striatum and K. alvarezii cultivated in Kupang Bay and its surroundings ranges from 5700-7857 gr./m^2, with an average of 6788 gr./m^2 for young thallus and 7038 gr./m^2 for old thallus. The highest Standing Stock value is possessed by the seaweed species K. striatum cultivated using the anaconda net method at the Tablolong location, with a value of 7607 gr./m^2 for young thallus and 7857 gr./m^2 for old thallus.

H. P-B Ratio

The P-B Ratio, or Wet Weight-Biomass Ratio, is the ratio of wet weight to biomass weight. The P-B ratio of seaweed species K. striatum and K. alvarezii from several cultivation locations in Kupang Bay and its surroundings is shown in Figure 18.

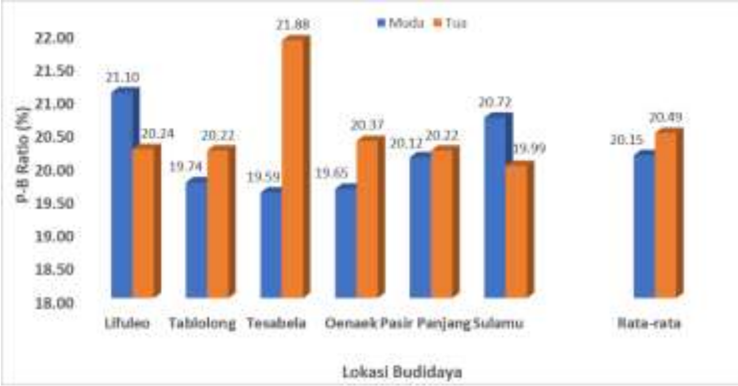

Figure 18. P-B Ratio of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings.

Figure 18 shows that the P-B Ratio of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings ranges from 19.05 to 21.88%, with an average of 20.15% for young thallus and 20.49% for mature thallus. For young thallus, the highest P-B Ratio was found in K. striatum cultivated using the off-bottom method in Tesabela, at 21.88%; while for mature thallus, the highest P-B Ratio was found in K. striatum cultivated using the longline method in Lifuleo, at 21.10%.

3.8 Total Carbon Sequestration

Total Carbon Sequestration is the combined value of Standing Stock, P-B Ratio, and Carbon Content. The Total Carbon Absorption Value of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings is presented in Figure 19.

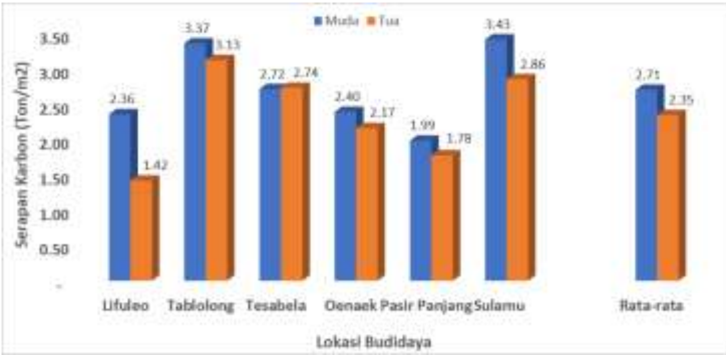

Figure 19. Total Carbon Uptake of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings

The total carbon uptake of K. striatum and K. alvarezii seaweed cultivated in Kupang Bay and its surroundings ranged from 1.42 to 3.43 tons of carbon per m^2/cycle, with an average of 2.35 tons of carbon per m^2/cycle for mature thallus and 2.71 tons of carbon per m^2/cycle for young thallus. These findings support previous studies indicating that macroalgae cultivation has considerable potential as a nature-based solution for carbon sequestration due to rapid biomass accumulation and high carbon fixation efficiency (Froehlich et al., 2019). For young thallus, the highest total carbon uptake was achieved by K. striatum cultivated using the longline method in Sulamu, at 3.43 tons of carbon per m^2/cycle. Meanwhile, for mature thallus, the highest total carbon uptake was achieved by K. striatum cultivated using the anaconda net method in Tablolong, at 3.37 tons of carbon per m²/cycle.

3.9. Implications of Seaweed Cultivation Practices for Carbon Sequestration Potential

The findings of this study highlight that cultivation practices and biological characteristics of seaweed species are key factors influencing carbon sequestration potential in *Kappaphycus* spp. farming systems. The differences observed in biomass production, carbon content, and total carbon uptake among cultivation methods indicate that farming techniques can modify the environmental conditions experienced by seaweed, including water circulation, nutrient availability, and light exposure. The higher carbon uptake obtained from the Anaconda Net method suggests that cultivation systems providing optimal growth conditions can enhance biomass accumulation and carbon fixation efficiency. According to Buschmann et al., (2017), seaweed cultivation performance is strongly influenced by environmental conditions and farming techniques because these factors regulate physiological processes, growth rates, and the accumulation of organic carbon in seaweed tissues.

The relationship between biomass and carbon sequestration capacity observed in this study confirms that biomass accumulation is one of the main mechanisms determining carbon storage in cultivated seaweed. However, the results also show that higher biomass does not always correspond directly with higher carbon content, as *Kappaphycus striatum* exhibited greater carbon content and total carbon uptake despite producing lower biomass than *Kappaphycus alvarezii*. This difference may be associated with species-specific variations in biochemical composition, tissue structure, and carbon allocation patterns. Caprara et al., (2016) reported that macroalgae species exhibit different capacities for carbon fixation and storage due to variations in growth characteristics, environmental adaptation, and biochemical composition. These differences influence the contribution of individual seaweed species to carbon cycling and long-term carbon sequestration processes.

The higher carbon content found in younger thallus compared with mature thallus indicates that growth phase is an important consideration in optimizing carbon sequestration from seaweed farming. Younger tissues generally have higher metabolic activity and active carbon assimilation during growth, whereas mature tissues may allocate more energy toward structural development and reproduction. Previous research by Chow et al., (2019) demonstrated that growth stage and physiological condition significantly influence photosynthetic performance, biomass production, and carbon fixation efficiency in cultivated seaweeds.

The carbon sequestration potential identified in this study further supports the role of *Kappaphycus* cultivation as a component of blue carbon strategies in tropical coastal areas. Although traditionally developed for economic purposes, seaweed aquaculture can provide additional ecosystem services through carbon capture, nutrient cycling, and coastal ecosystem improvement. Macreadie et al., (2019) emphasized that marine carbon ecosystems, including macroalgal systems, should be considered in climate mitigation frameworks because of their capacity to remove carbon from the atmosphere and transfer it into long-term marine carbon reservoirs.

Therefore, the integration of carbon sequestration objectives into seaweed aquaculture management is important for maximizing both ecological and economic benefits. In Kupang Bay, the selection of suitable cultivation methods, appropriate harvesting periods, and species with higher carbon storage capacity should be considered in future development programs. Such approaches can strengthen the contribution of seaweed farming to sustainable coastal livelihoods while supporting regional climate change mitigation initiatives.

4. CONCLUSIONS AND RECOMMENDATIONS

The results of this study demonstrate that the carbon absorption capacity of cultivated *Kappaphycus* spp. in Kupang Bay is influenced by seaweed species, cultivation methods, and thallus age. Variations in moisture content, biomass, ash content, volatile matter content, and carbon content indicate that environmental conditions and cultivation techniques affect the carbon sequestration potential of seaweed. The carbon content was consistently higher in young thallus compared to mature thallus across cultivation locations. Among the cultivation methods evaluated, the Anaconda Net method showed the highest potential for carbon storage and total carbon uptake compared with the Longline and Off-Bottom methods. In addition, *Kappaphycus striatum* demonstrated greater carbon content and total carbon uptake than *Kappaphycus alvarezii* for both young and mature thallus. These findings answer the research objective by confirming that differences in cultivation systems and seaweed species significantly determine the carbon absorption potential of farmed seaweed in Kupang Bay.

Based on these findings, seaweed farmers and local aquaculture practitioners in Kupang Bay are recommended to consider the use of cultivation methods that optimize biomass production and carbon uptake, particularly the Anaconda Net method, while maintaining sustainable farming practices. Local government agencies, fisheries management authorities, and coastal development planners are encouraged to incorporate seaweed cultivation into blue carbon mitigation strategies by supporting environmentally friendly farming systems, providing technical guidance, and developing policies that enhance sustainable seaweed production. Further research institutions and scientists are recommended to conduct long-term studies involving larger cultivation areas, seasonal variations, and additional environmental parameters to improve the accuracy of carbon sequestration estimates and strengthen the role of seaweed farming as a nature-based solution for climate change mitigation.

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