Carbon sequestration in macroalgae *Kappaphycus striatum* in seaweed aquaculture site, Alaang village, Alor Island, East Nusa Tenggara

M S Fakhraini 1* , W Wisnu 1, R Khathir 2 and M P Patria 1

1 Department of Biology, Faculty of Mathematics and Natural Sciences, University of Indonesia, Indonesia
2 Department of Agricultural Engineering, Faculty of Agriculture, Syiah Kuala University, Indonesia

*E-mail: mpatria@sci.ui.ac.id

**Abstract.** Carbon sequestration in macroalgae through photosynthesis can contribute to the mitigation of the climate change problem. This research aimed to analyze carbon sequestration potential on macroalgae *Kappaphycus striatum* with different harvested ages; i.e. young (25 days) and adult (60 days). Samples were collected randomly from off-bottom seaweed aquaculture system, at Alaang village, Alor island, East Nusa Tenggara. The parameter observed was carbon content determined by using gravimetric analysis. Growth rate measurement and light-dark bottle experiment were also conducted to be further analyzed. Results showed in total area 1,552 m², it was estimated that the carbon sequestration potential of macroalgae *Kappaphycus striatum* was 13.28 tonnes C/cycle for young and 26.63 tonnes C/cycle for adult. These results were equal to 66.07 tonnes C/ha/cycle and 125.51 tonnes C/ha/cycle, respectively. Therefore, the carbon sequestration potential of adult seaweed was higher about 32.78% than that of young seaweed, followed by its lower growth rate and higher primary productivity. It can be concluded that the carbon sequestration potential was influenced by growth rate and primary productivity. Further study on sustainable management of seaweed aquaculture sites, by considering ecological and economic values, could potentially provide multiple functions both for human and ecosystem.

**Keywords:** adult, carbon, seaweed, sequestration, young

1. **Introduction**

Global warming has been inferred as a major factor of today’s phenomenal climate change. Since industrial era, massive use of fossil fuels has resulted in greenhouse gas emissions in the form of carbon dioxide, which in large quantities has been trapped in the atmosphere. Following this issue, all member states gathered in United Nations has set national carbon emission reduction targets and formulated a periodic climate change mitigation strategy through Conference of Parties (COP). Many strategies have been formulated to achieve these targets, including the use of marine ecosystems in carbon sequestration.
The marine ecosystem is one of reservoirs that potentially absorb carbon emissions in large quantities. Referring to blue carbon, this ecosystem can capture up to 2.3 Gt C/year of total 6.3 Gt carbon released from anthropogenic activities (Hairiah et al 2011). Macraолжae, one of marine vegetations that has been explored for its potential to sequester carbon in their habitats. It had been estimated that macroalgae could sequester higher amount of carbon than terrestrial plants due to its high adaptability (Erlania and Radiarta 2015, Jensen et al 2018). Through photosynthesis, macroalgae can convert inorganic carbon into carbohydrate, permanently store it into their biomass and might be exported through food chain (Diaz-Pulido and McCook 2008). In addition, macroalgae had high primary productivity in our ocean, as could produce up to ≥ 3,000 g cm\(^{-2}\) year\(^{-1}\) (Chung et al 2010).

Nonetheless, the inclusion of macroalgae in blue carbon scheme has not been specifically considered as one of kind. Since its natural cycle is exporting high amount of fixated carbon outside their own habitats, it is critical to measure carbon sequestration as in other dependable habitats; mangrove and seagrass (Krumhansl et al 2012). Hence, many kinds of research have been conducted to estimate macroalgae’s contribution in long-term carbon sequestration. In Japan, it has been estimated that several aquaculture sites in total area 230,000 ha could sequester carbon up to 4.7 million C/year (Kuwae and Hori 2019). Chung et al (2010) showed that the utilization of macroalgae productivity through appropriate and integrated cultivation can contribute greatly to carbon sequestration.

Macroalgae, as had been well known for the name seaweed, is one of the best commodities in global fisheries. Indonesia is one of top global seaweed producers, as manufactured for food, cosmetics, medicine, etc. Among all types of seaweed, *K. striatum* has high economic value for its best source of carrageenan (Kasim 2016, Thirumaran and Anantharaman 2009). This seaweed has been cultivated in several Indonesia’s coastal areas, including Alor Island, East Nusa Tenggara. Thus, it is essential to investigate ecological values in its seaweed aquaculture sites, notably in carbon sequestration.

Climate efforts have been overlapped with economic needs (e.g. mangrove deforestation), it is crucial to find alternatives which could integrate both aspects in term of sustainability. Erlania and Radiarta (2015) showed that further research by considering important aspects, such as seaweed age, could be taken to support blue carbon scheme development. Highlighting that harvesting time may differ in some regions, following farmers interests on seaweed cultivation practices, this may be prompted in carbon flux at seaweed aquaculture site. We realized that this rise as a pivotal point to unleash carbon sequestration potential in seaweed aquaculture system. Furthermore, we acknowledged that carbon sequestration also corresponds to the biological processes, which results in biomass increase. These processes may indicate the rate of increase and resultant rate of change in oxygen concentration. Thus, this research aims to examine the carbon sequestration potential on seaweed with different harvested ages, by also considering the growth rate and primary productivity.

### 2. Materials and methods

The research was established in two stations within seaweed aquaculture site in Alaang Village, Alor Island, East Nusa Tenggara with total area 1,577 m\(^2\) (figure 1). Station 1 was sampling location for young seaweed, while adult seaweed was sampled at station 2. Sample monitoring was also conducted for 25 days before sampling was taken, including morphological and environmental phenomena’s that might correspond with seaweed growth circumstantial. Noting with age differences in certain period of time, sampling was taken according to cultivating and harvesting calendar, in which young and adult seaweed reach preferable ages on this research at the same time. After sampling, samples were analyzed in affiliation Laboratory, Department of Chemistry, Mathematics and Natural Sciences, University of Indonesia.
2.1. Materials
The subject of this research was macroalga *K. striatum*, known as sacol seaweed, with different cultivation period; young seaweed (25 days) and adult seaweed (60 days), both were taken on 24 April 2019. Field equipments that were used including Global Positioning System (GPS), DO meter, refractometer, pH indicator universal, phosphate and nitrate multi-test, net plankton, glass bottles, rope, and digital weigh scale. Laboratory equipments were used in this research including desiccator, evaporating dish, laboratory oven, and digital weigh scale.

2.2. Methods
Samples were collected randomly from off-bottom aquaculture system. The size of sampling unit was 0.6×20 m, consisting of three lines for both young and adult seaweed. Among 100 seaweeds grown in each line, 10 samples were taken after 25 days of monitoring. The measurement of weight increase in both units was also conducted before sampling was taken. Primary productivity of seaweed samples was measured by conducting light and dark bottle experiment. Several parameters such temperature, pH, salinity, nitrate, and phosphate were also taken at different times (day 1, day 15, and day 30) to asses environmental condition.

2.2.1 Carbon sequestration measurement. Estimation of carbon sequestered in seaweed biomass was preceded by measuring carbon content. Carbon content was measured with gravimetric analysis (SNI 1995, UNEP 2004). Thus, carbon sequestration was calculated by using formula (Muraoka 2004):
\[ RGR = 100 \ln \frac{W_2}{W_1} \frac{T_2 - T_1}{T_2 - T_1} \]  

Where \( A \): Total area of cultivation site (m\(^2\)), \( S \): standing stock of seaweed (g/m\(^2\)), P-B ratio: implies with production-biomass, and \( C \): carbon content (%).

2.2.2 Growth rate measurement. Weight increase was measured for each sample before sampling was taken. Thus, the % increase per day was measured to determine the relative growth rate. The growth rate of each sample was calculated by using formula (Lüning, 1990):

\[ % \text{RGR} = \frac{100 \ln \frac{W_2}{W_1}}{T_2 - T_1} \]  

\( W_1 \): weight at time \( T_1 \), \( W_2 \): weight at time \( T_2 \) and \( T_2 - T_1 \) are times in days.

2.2.3 In situ primary productivity measurement. Primary productivity was measured by conducting light and dark bottle experiment at the same given period of time. The experiment was established based on Dhargalkar and Shaikh (2000), with slight modification (duration of incubation). Seaweed thallus of each sample was initially cut and weighed (10 g). Afterward, samples were incubated in seaweed aquaculture site for 6 hours. Dissolved oxygen was measured before and after incubation, to determine reproducible oxygen (refer to the rate of respiration, gross primary productivity, and net primary productivity). The experiment was conducted in triplicate (Dhargalkar and Shaikh 2000).

3. Results and discussion

3.1. Environmental condition at seaweed aquaculture site

Results showed that environmental condition at seaweed aquaculture site in Alaang Village was suitable for cultivation. It was evaluated that temperature varied at sampling time (30 days), between 26°C-29.6°C, salinity 28-29 ppt, pH 7.7-7.5, nitrate 0.3-0.4 mg/L, and phosphate 0.12-0.13 mg/L. The seaweed aquaculture site in this village is a shallow water area with the semidiurnal tide. In the near surroundings, there were found other marine biotics, such as mangrove, mollusk, crustacea, Bivalvia, seagrass, and many types of wild seaweed (e.g. Sargassum sp. and Padina sp.).

According to WWF (2014), January-April are the productive seasons for seaweed cultivation in Alor Island. It had been noted that the activities in the aquaculture site might be varied among seaweed farmers. Some farmers might be cultivating and harvesting every day, but some others might be on replanting every 25 days to fulfill all units. Moreover, harvesting period might be even different in overall units. The harvesting time would be at day 45, 60, or 90, according to farmer’s preferences. This suggests that carbon dynamic in this area may vary from time to time following preferable activities in seaweed aquaculture site.

3.2. Carbon sequestration on different harvested age of seaweed

The study showed that carbon sequestration in adult (60 days) seaweed was higher than that of young seaweed (25 days) (figure 2). The results varied significantly in these two different harvested ages (P<0.05). It was estimated that carbon sequestered in adult seaweed biomass reached up to 26.23 tonnes C/cycle, while young seaweed complies with 13.28 tonnes C/cycle. This showed that adult seaweed could capture up 32.78% more carbon than that of the young. It had been suggested that major factor of this difference may be due to higher number of branches in adult seaweed. According to Pickering et al (1995), the more branches formed, the larger surface area that seaweed thallus has. This implies to the higher amount of light that can be photosynthesized. Thus, the carbon that has been accumulated within their biomass also become higher. In addition, previous research also showed that carbon sequestration may differ following their age states. It had been estimated that higher carbon
sequestration was found at age 0-10 days. While the lowest rate was found at 20-30 days, study showed that the rate was getting increased as the increase of biomass until it reached harvesting time (Erlania and Radiarta 2013).

Figure 2. Carbon Sequestration in *K. striatum* with different harvested ages.

3.3. Growth rate and primary productivity in linked with carbon sequestration

The difference on carbon sequestration potential between young and adult seaweed had been investigated by comparing the growth rate and primary productivity. These two parameters may indicate biological processes of carbon fixation within their biomass. Results showed that growth rate in young seaweed was higher than in adult seaweed (figure 3). It was calculated that growth rate in young seaweed was 3.06% and in adult seaweed was 1.24%. According to Thirumaran and Anantharaman (2009), growth rate may be decreased as it is getting older. The previous study also showed that young seaweed had lower carbon sequestration rate since it was still in the developmental phase (Anggidenia 2015). Likewise, it can be postulated that fixated carbon by young seaweed is more processed to form new cells, which actively involves in many biochemical processes, rather than store it permanently within their biomass. Carbohydrate formed through photosynthesis is the highest amount of substance in seaweed and can be processed in many forms, e.g starch, cellulose, etc (Diniz *et al* (2011).

Figure 3. The growth rate of *K. striatum* in different harvested ages.

Biologically, growth refers to the physiological and biochemical processes as well as the products of the aforementioned processes. The products attribute to the balance between anabolism and catabolism, which indicates total outcome (yield) may be implied to the potential loss such as grazing, death cells, and exudation (Littler and Littler 1985). Thus, it is essential to investigate net growth which may be influenced by cyclical biochemical processes or physiological responses. We, therefore
established field light-dark bottle experiment to study the difference in carbon sequestration by also measuring primary productivity.

As shown in table 1, the mean of gross primary productivity and net primary productivity are higher in adult seaweed than that of young. Mean of gross primary productivity (GPP) in young and adult seaweed are 1.59±0.51 gC/m²/day dan 1.91±0.28 gC/m²/day, respectively. This indicates the difference is 1.2 times higher in adult seaweed. The following net primary productivity (NPP) showed 4.27 times higher than that of young; 1.58±0.38 gC/m²/day and 0.37±0.34 gC/m²/day, respectively. While, the results showed that mean of respiration in young and adult seaweed are 1.22±0.78 gC/m²/day dan 0.34±0.19 gC/m²/day, respectively. This indicates that results were intensified by the mean of respiration which showed 3.58 times higher in that of young. Hence, we postulated that carbon fixated in young seaweed was released more than further sequester it. According Kricher (2011), net primary productivity can describe total amount of carbon fixated as organic matter used for growth and reproduction. While gross primary productivity could be attributed to the amount of fixated carbon dioxide from the atmosphere to photosynthesize (Beer et al 2010). Thus, this gave us better understanding that in spite of fixation rate may not be significantly different, the rate of respiration also made it attributed to the overall carbon sequestration per day.

| Table 1. Mean of respiration, gross primary productivity, and net primary productivity rate. |
|---------------------------------|---------------------------------|---------------------------------|
| Young seaweed                   | Adult seaweed                   |
| Respiration (gC/m²/day)         | Respiration (gC/m²/day)         | Respiration (gC/m²/day)         |
| 1.22±0.78                       | 1.91±0.28                       | 0.37±0.34                       |
| Gross Primary Productivity (gC/m²/day) | Gross Primary Productivity (gC/m²/day) | Gross Primary Productivity (gC/m²/day) |
| 1.59±0.51                       | 1.59±0.51                       | 0.37±0.34                       |
| Net Primary Productivity (gC/m²/day) | Net Primary Productivity (gC/m²/day) | Net Primary Productivity (gC/m²/day) |
| 3.4. Carbon sequestration potential at seaweed aquaculture site, Alaang Village, Alor Island, East Nusa Tenggara |
Carbon sequestration potential at this seaweed aquaculture site can be compared with other regions by first converting the results into tonnes C/ha/cycle (table 2). It is also essential to emphasize on the yield (adult seaweed) as the major corresponding. The study has shown that both young and adult seaweed could sequester carbon up to 66.07 tonnes C/ha/cycle and 125.50 tonnes C/ha/cycle, respectively. In 2015, Erlania and Radiarta were established carbon sequestration research in Gerupuk Bay, Lombok, West Nusa Tenggara. While the results showed that adult seaweed could sequester up to 4.04 tonnes C/ha/cycle, it can be suggested that carbon sequestration in Alaang Village has higher potential. This is presumably due to differences in cultivation systems and cultivation period, while seaweed farmers in Gerupuk Bay were using longline aquaculture system and harvesting after 45 days (Erlania and Radiarta 2015). Notwithstanding, carbon sequestration rate at seaweed aquaculture site, in Galesong, Takalar, South Sulawesi, shows higher potential than in Alaang Village. Akmal et al (2011) have estimated that adult seaweed could sequester carbon up to 611.8 tonnes C/ha/cycle. We suggested that the difference may infer to the better cultivation practices in Takalar. As postulated by Parenrengi et al (2016), seaweed farmers have been introduced with more advanced seed selection, which corresponds to the higher growth rate at 6.69-6.83%. While the growth rate of both young and adult seaweed in this study showed only 1.24% and 3.06%. This may be attributed to the use of seaweed seedlings repeatedly. As postulated by Parenrengi et al (2016), the use of seedlings that are unselected and only depending on availability in cultivation area could also increase potential of declining quality and relatively slow growth. Likewise, we also found some circumstantial evidence that may attribute to the seaweed growth results in Alaang Village, including; biofouling and ice-ice symptoms. Hence, further study on seaweed cultivation and management practices could be fostered to unleash carbon sequestration potential at seaweed aquaculture sites.
As shown in table 2, we also calculated the carbon sequestration potential on *Kapapaphycus striatum* at recent cultivation areas in Alaang Village, with total of 2.53 ha. The amount of sequestered carbon could reach up to 167.15 tonnes C/2.53 ha/cycle and 317.515 tonnes C/2.53 ha/cycle both for young and adult seaweed, respectively. However, these potential values show low average compared to other regions, such as in Gerupuk Bay and Takalar. While in Gerupuk bay, it had been estimated that seaweed aquaculture site could sequester carbon up to 6,656.51 tonnes C/cycle in total area 322 ha. In Takalar, with total area 237 ha, the seaweed aquaculture site could potentially sequester carbon up to 12,648.9 tonnes C/cycle. Thus, we suggested that if seaweed cultivation practices in Alaang Village being developed, it will potentially produce a great ecological value as well. Through some strategies, such as expansion of cultivation area and development of cultivation techniques, could be essential to foster climate change mitigation at seaweed aquaculture sites (Chung *et al* 2013).

| Table 2. Carbon sequestration in different rate. |
|------------------|------------------|------------------|
|                  | Tonnes C/ha/cycle| Tonnes C/2.53 ha/cycle| gr C/m²/day |
| Young seaweed    | 66.07            | 167.16            | 264.28       |
| Adult seaweed    | 125.50           | 317.52            | 529.20       |

As in per day, we also estimated that both young and adult seaweed could sequester carbon up to 264.28 gr C/m²/day and 529.20 gr C/m²/day. The estimation has been narrowed down their potential which may be accounted for blue carbon scheme. It is essential to note that long-term carbon sequestration in seaweed crops still remain unsolved. Thus, a comprehensive study on carbon sequestration potential can be attributed to mitigate climate change at certain period of time, while also providing greater supplies of seaweed in many advances.

Recent advances show that seaweed cultivation area can be applied to other purposes other than at food and medicine field, e.g. producing biomass as a substitute for fossil fuels. This shows more interests in the potential of seaweed crops in economic needs, while also may play a significant role in climate change mitigation. As projected, development of carbon sequestration potential in seaweed aquaculture site can be escalated through Clean Development Mechanism (CDM) (Chung *et al* 2013). Furthermore, it is possible to generate economic added value in this area through ecological perspectives, such as but not limited to carbon trading. Thus, seaweed aquaculture site can be managed to not only improve the welfare of coastal communities but also to contribute to climate change mitigation.

4. Conclusion

It can be concluded that carbon sequestration could be considered on different harvested ages, following differences in growth rate and primary productivity. The development of cultivation practices could be drawn upon to elevate both ecological and economic values in seaweed aquaculture site. Thereupon, the ecological study about carbon sequestration could potentially bring positive impacts both for climate change mitigation and economic prosperity.

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