The Use of Seaweeds Aquaculture for Carbon Sequestration: A Strategy for Climate Change Mitigation

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The Use of Seaweeds Aquaculture for Carbon Sequestration: A Strategy for Climate Change Mitigation

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Abstract: Seaweed has the ability to use carbon from the environment through photosynthesis to produce biomass. The aim of this study is to estimate carbon sequestration by seaweed aquaculture as a strategy for climate change mitigation. The study was undertaken at Gerupuk Bay, Lombok Island, West Nusa Tenggara Province, Indonesia. Four seaweed variants, such as *Kappaphycus alvarezii* var. Tambalang and Maumere, *K. striatum* and *Eucheuma denticulatum*, were cultivated with long-line system for three cultivation periods, starting from July to November, 2013. Each cultivation period was taken about 45 days. Parameters including weight increasement and carbon content of seaweeds were measured every 15 days of culture for each cultivation period in order to calculate carbon sequestration rate. The results showed that *E. denticulatum* had the highest carbon sequestration rate and significantly different ($P < 0.05$) compared with other variants for every cultivation period. Different seaweed variants have different capacity on carbon sequestration. Optimal utilization of the potential area for seaweed aquaculture could reduce a great quantity of CO_2 from the atmosphere and help to mitigate global climate change process.

Key words: Carbon sequestration, seaweed variants, cultivation, West Nusa Tenggara, Indonesia.

1. Introduction

CO_2, the main anthropogenic greenhouse gas, if that releasing into the atmosphere, is responsible for increasing the greenhouse effect leading to global warming. Climate change is caused by the massive increase of GHG (Green House Gases) emission to the atmosphere, for example carbon dioxide, which is caused not only from natural factors but also from human activities (anthropogenic factors) including the burning of fossil fuels and deforestation [1, 2]. The impact of climate change on marine environment is already apparent, such as sea level rise, ocean surface warming, changing course of currents, acidification of surface waters, and shifting ranges of natural species [1, 3-5].

CO_2 gas is present in considerably higher concentrations in seawater (34-56 ml/l) than in the atmosphere (0.3 ml/l), partially due to the ability of water to absorb more CO_2 than air, in equal volume [6]. There has been a good deal of interest in the potential of marine vegetation as a sink for anthropogenic carbon emissions which known as Blue Carbon. The concept of Blue Carbon or atmospheric carbon captured by coastal ecosystems, has recently been the focus of reports by UNEP (the United Nations Environment Programme) and IUCN (the International Union for the Conservation of Nature) [7]. Seaweed is a potential marine vegetation which can use solar energy for the bio-fixation of concentrated CO_2 sources from atmosphere into biomass that can be used to produce phycocolloid compound [8]. These macroalgae have relatively better capability on carbon sequestration than terrestrial plants [9, 10]. Seaweeds are currently used commercially in the production of high-value products such as agar, carrageenan, and alginate, and also produce for human food, animal feed, fertilizers, biofuel, and cosmetics [11].

Mass cultivation of seaweeds can be more effective

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methods for CO_2 capture and sequestration from the environment, because CO_2 can be transformed and become more valuable products through photosynthesis. The rate of carbon sequestration by seaweeds would be different; influenced by seaweed species and environmental conditions where they were cultivated [12, 13]. The aim of this study is to estimate carbon sequestration by different seaweed cultured variants as a strategy for climate change mitigation.

2. Materials and Methods

The study was undertaken from July to November, 2013 at Gerupuk Bay, Lombok Island, West Nusa Tenggara Province, Indonesia (Fig.1). Four seaweed variants, including *Kappaphycus alvarezii* var., Tambalang and Maumere, *K. striatum* and *Eucheuma denticulatum*, were cultivated with long-line system for three cultivation periods. Each cultivation period was taken during 45 days. The size of a long-line unit was 50 x 50 m^2 which consists of 24 lines/unit. A long-line unit was divided into four parts for each seaweed variant. The seeds were bound to the line which separated about 20 cm for each other.

Sampling was conducted every 15 days from the day 0 (initial), 15, 30, to 45 (replanting) for every cultivation period. Parameters were measured including weight increasement for seaweed (in situ) and total carbon content (laboratory analysis). Six bonds of each seaweed variant were taken every 15 days to measure weight increasement that calculated based on different weight of seaweed samples between sampling period (seaweed age). Estimation of carbon sequestration rate (ton C/ha/year) was calculated by using formula as follows [13]:

$$C_{seq} = A \text{ x } S \text{ x } P\text{-}B \text{ ratio x } C_{cont} \quad (1)$$

where:

A is a total wide area of seaweed cultivation (m^2), *S* is standing stock (g/m^2), *P-B* ratiois production-biomass ratio, and $C_{cont}$is the carbon content (%).

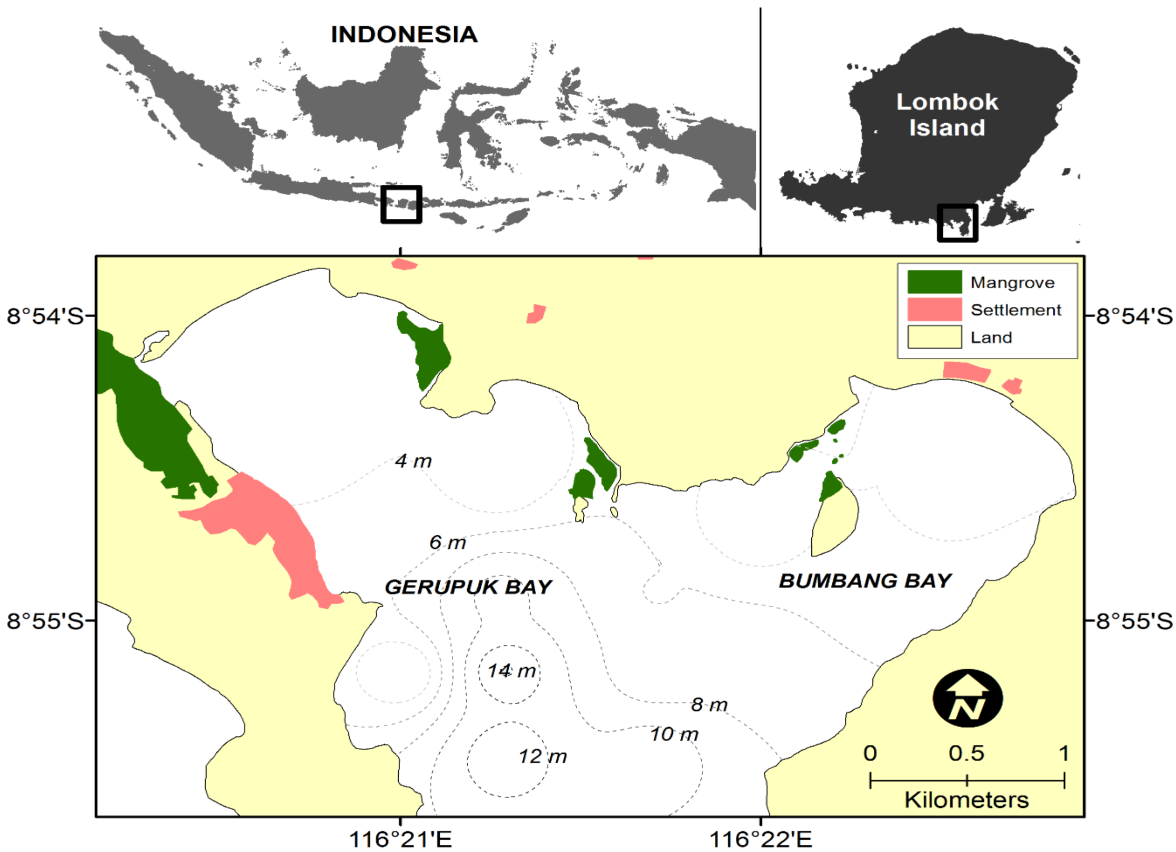

Fig. 1 Research location at Gerupuk Bay, Central Lombok, West Nusa Tenggara, Indonesia.

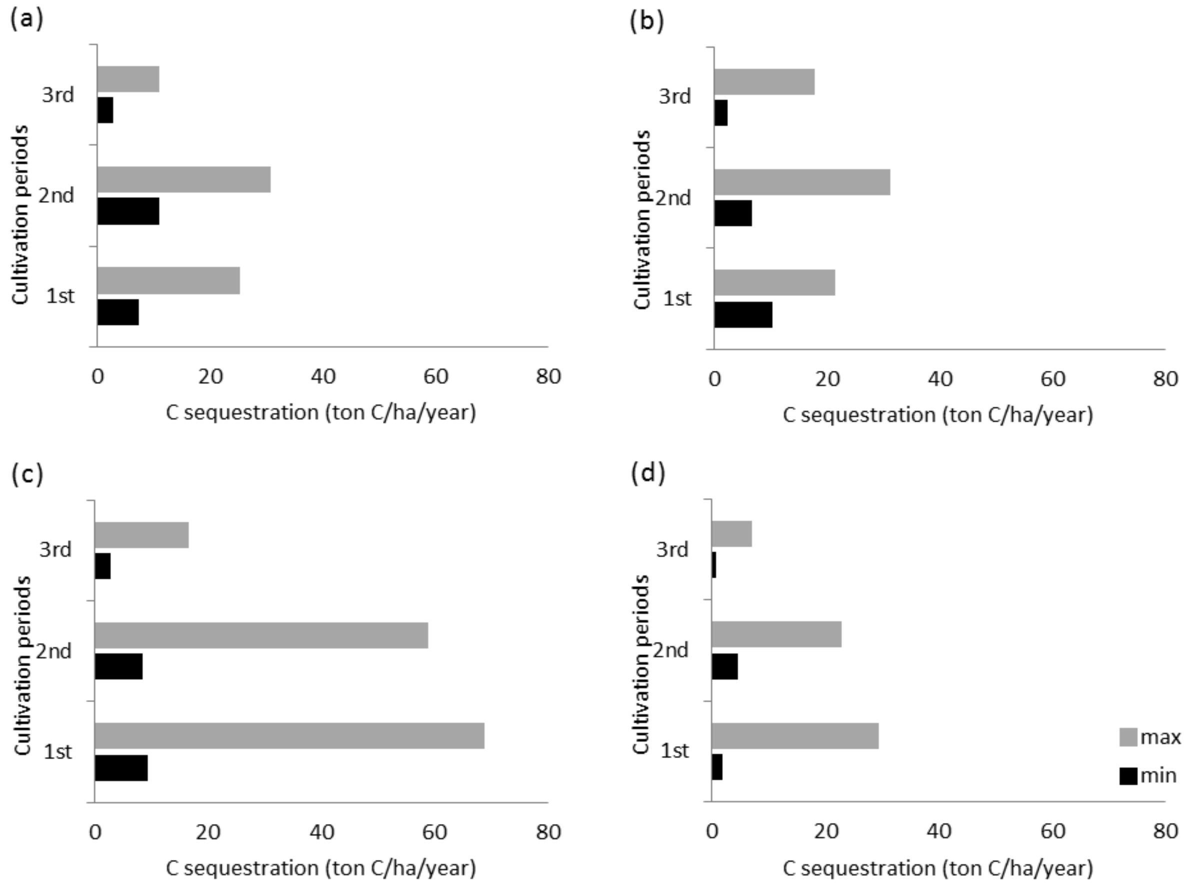

Fig. 2 Range of C sequestration by four seaweed variants cultured in Gerupuk Bay, West Nusa Tenggara, Indonesia: (a) *K. alvarezii* var. Maumere; (b) *K. alvarezii* var. Tambalang; (c) *E. denticulatum;* (d) *K. striatum.*

Table 1 ANOVA and Duncan Teston minimum and maximum values of C sequestration rate of four seaweed variants. Different letters indicate significant differences of the results (*P* < 0.05).

Source of Variation	**Means of C sequestration rate (ton C/ha/year)**			
Seaweed variants	***K. alvarezii*var. Maumere**	***K. alvarezii* var. Tambalang**	***E. denticulatum***	***K. striatum***
Minimum values	66,833 [a]	610 [a]	648 [a]	184 [b]
Maximum values	2,202 [b]	2,310 [b]	4,769 [a]	1,937 [b]
Cultivation periods	**1st**	**2nd**	**3rd**	
Minimum values	67,925 [a]	72,675 [a]	17,675 [b]	
Maximum values	35,890 [a]	3,560 [a]	1,265 [b]	

Data of carbon sequestration rate were analyzed using descriptive statistic methods then presented as graphs. ANOVA (Analysis of Variance) with completely randomized factorial design and Duncan Test were used to observe the different response of carbon sequestration rate which influenced by different variants of seaweeds in different cultivation periods and sampling periods.

3. Results and Discussion

3.1 Carbon Sequestration by Seaweed Cultivation

Capability of four seaweed variants on carbon sequestration was described with the range of C sequestration rate (Fig. 2). Analysis of variance and Duncan Test showed that seaweed variants indicated significant difference ($P < 0.05$) in influencing seaweed ability on carbon sequestration, either the maximum or minimum values (Fig. 2, Table 1). *K. striatum* had the lowest minimum value of carbon sequestration than *E. denticulatum, K alvarezii* var., Maumera and Tambalang about 0.12–4.03 ton C/ha/year.

While, *E. denticulatum* showed the highest maximum value of carbon sequestration rate which is significantly different from the other three variants (Table 1). *E. denticulatum* has the highest rate of C sequestration rate based on maximum values which range about 16.08–68.43 ton C/ha/year; while other variants have relatively similar values (Fig. 2).

Carbon sequestration rate has a direct correlation with internal factors of seaweed, including pigment content and growth rate [10]. Whereas, growth rate is influenced by seaweed variants, location, and seasonal cultivation periods [14]. Study on different seaweed variants, *K. alvarezii, E. denticulatum*, and *K. striatum*, shows that *E. denticulatum* has the highest daily growth rate which is significantly different from others [15].

Different capability of seaweeds on carbon sequestration rate was also indicated in different cultivation periods (Fig. 2). Statistic analysis result showed significant different carbon sequestration rate ($P < 0.05$) among three cultivation periods during this study (Table 1). The first and second cultivation periods indicated a higher rate, and significantly different than the third period, either minimum or maximum values (Table 1). Seaweeds cultivation which held during different seasonal cultivation periods would be influenced by temporal variabilities of environmental factors [12]. Seaweeds are exposed to seasonal variations of abiotic factors that influence their metabolic responses, including photosynthesis and growth rate [16]. Seaweeds absorb CO_2 from waters through photosynthesis process then transformed to carbohydrate compound [6, 10]. Good environmental conditions would give higher opportunities to absorb more CO_2 from the environment. The more higher CO_2 absorbed by seaweed, the more productive seaweeds cultivated.

Trends of carbon sequestration rate were influenced by different seaweed variants. Generally, *E. denticulatum* has higher sequestration rate than the other three seaweed variants (Fig. 3). Analysis of variance

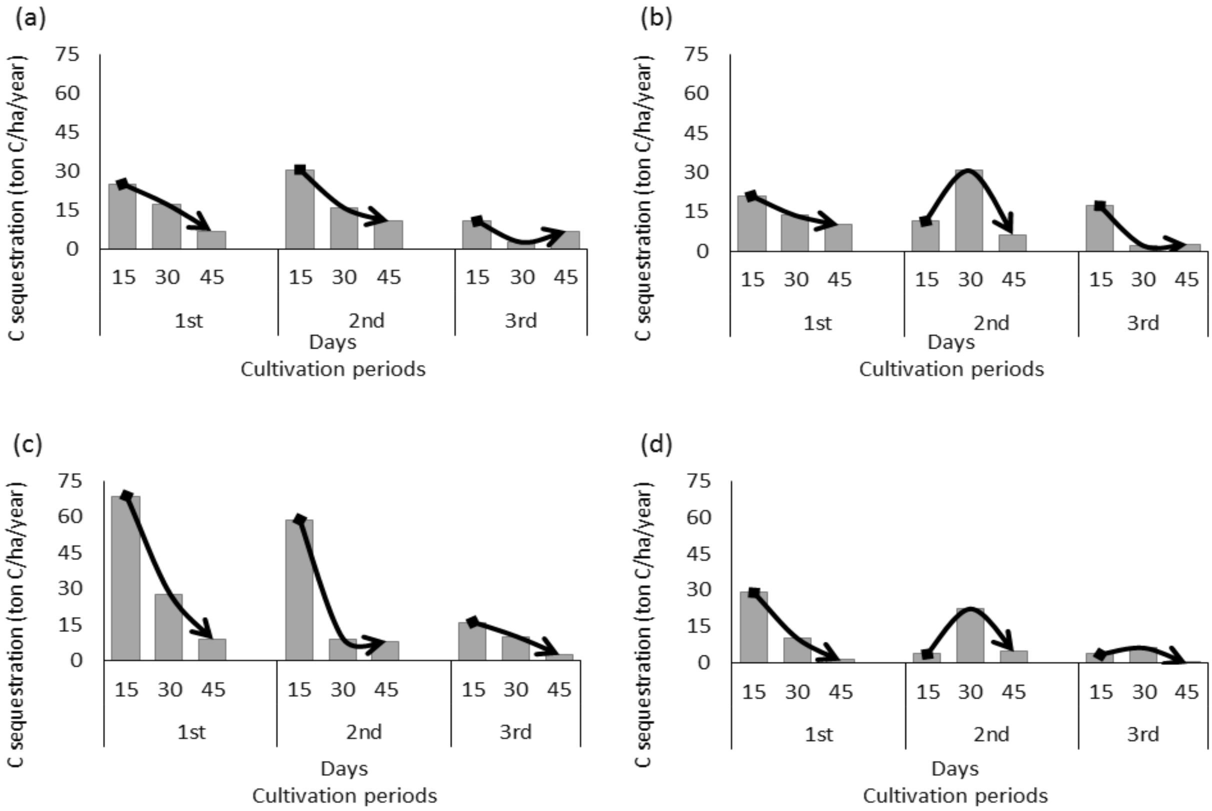

Fig. 3 Trend of C sequestration by four seaweed variants cultured in Gerupuk Bay, West Nusa Tenggara, Indonesia: (a) *Kappaphycus alvarezii* var. Maumere; (b) *Kappaphycus alvarezii* var. Tambalang; (c) *Eucheuma denticulatum;* (d) *K. striatum.*

Table 2 ANOVA and Duncan Test on trend of C sequestration rate of four seaweed variants. Different letters indicate the significant difference of the results (*P* < 0.05).

Source of Variation	Means of C sequestration rate (ton C/ha/year)			
Seaweed variants	***K. alvarezii* var. Maumere**	***K. alvarezii*var. Tambalang**	***E. denticulatum***	***K. striatum***
	1,203 [ab]	1,282 [a]	2,329 [a]	920 [b]
Cultivation periods	**1st**	**2nd**	**3rd**	
	1,853 [a]	1,773 [a]	674 [b]	
Days of culture	**Day-15**	**Day-30**	**Day-45**	
	2,293 [a]	1,448 [ab]	559 [b]	

and Duncan Test showed significant difference ($P < 0.05$) on trend of carbon sequestration rate among seaweed variants (Table 2). *Gracilaria gigas* showed almost 300% carbon sequestration rate was higher than *K. alvarezii* which was cultured in Gerupuk Bay with the same method of cultivation [10].

Muraoka [13] also reported that several important genera of seaweed along the coasts of Japan included *Laminaria, Ecklonia, Sargassum, Gelidium,* and others indicated different carbon sequestration rate: 1156, 562, 346, 17, 103 thousand ton C/year, respectively.

The trend of carbon sequestration was also different between cultivation periods. *K. alvarezii* var. Maumere had close connection trend with *E. denticulatum* at the first and second periods (Fig. 3 (a); (c)), likewise *K. alvarezii* var. Tambalang and *K. striatum* (Fig. 3 (b); (d)). However, different trends occur only at the third cultivation period for every seaweed variant (Fig. 3). Statistical analysis caused significant difference ($P < 0.05$) on trend of carbon sequestration between cultivation periods. The first and second periods showed higher carbon sequestration rate than the third period (Table 2). Study on seaweeds growth which cultured in Gerupuk Bay, showed that the first and second periods (July–August and September–October, 2013) were categorized as the productive period for seaweed cultivation, but the third (November–December) was non-productive period [15]. This could be indicated that seaweeds capability on carbon sequestration rate is correlated to cultivation productivity.

Generally, *K. alvareii* var. Maumere and *E. denticulatum* showed the same decreasing trend of carbon sequestration pattern during cultivation. It was at a high rate at the beginning (day-15) then decrease at the end of cultivation (day-45) on every cultivation period (Fig. 3 (a); (c)). The first cultivation period of *K. alvarezii* var. Tambalang and *K. striatum* also had the same tendency with *K. alvareii* var. Maumere and *E. denticulatum*, but at the second period they showed different patterns, lower rate at day-15, and increase at day-30 then decrease again at day-45 (Fig. 3 (b); (d)). ANOVA and Duncan Test indicated significant differences ($P < 0.05$) of carbon sequestration pattern between seaweed age at day-15, 30 and 45 of culture (Table 2). Erlania and Radiarta [12] reported that seaweed *K. alvarezii*var. Maumere caused the highest carbon sequestration rate at the beginning of culture about the first 15 days on each cultivation period. Similar trend was also found for *K. alvarezii* var. Maumere in this study (Fig. 3a). Whereas, *K. alvarezii* var. Tambalang and *K. striatum* showed different tendencies at the second cultivation period and the highest carbon sequestration rate was found at day-30 of culture (Fig. 3 (b); (d)).

3.2 Climate Change Mitigation through Seaweed Aquaculture Activity

Seaweed cultivation can positively contribute to reducing CO_2 from the atmosphere regarding to the role of ocean ecosystem on blue carbon context [10, 17]. Marine and Fisheries Industrialization Program was launched by Ministry of Marine Affair and Fisheries, Indonesia for national production enhancement including seaweed from aquaculture. Development of seaweeds aquaculture not only can increase national production, but also enhance economic level of coastal people and improve environmental conditions through its carbon sequestration capability. It is interesting to note that 3.5 tons of algae production utilizes 1.27 tons of carbon and about 0.22 tons of nitrogen and 0.03 tons of phosphorus [18].

Carbon sequestration capability positively correlated with seaweed aquaculture productivity [12]. The main aspect that very important in influencing of seaweed aquaculture productivity is seasonal cultivation period. Moreover, seasonal aspect will differentiate physical and chemical conditions of water quality parameters, the physical and chemical factors affecting the growth of these plants [19]. The quantity of seaweeds production is in line with carbon sequestration volume by seaweed aquaculture [10]. Other important aspects are selection of seaweed species/variants which are suitable for different specific locations with different environmental conditions. Evaluation of seaweed growth is very important for species suitability selection based on location and planting period [14]. Age of seaweed also influences its performance during cultivation process. *K. alvarezii* and *Gracilaria gigas* showed the highest daily growth rate at the beginning of cultivation [10, 12].

Much consideration is needed to arrange a strategy for developing of seaweeds aquaculture in order to make this activity become efficient both economically and environmentally. Implementation strategy for climate change mitigation has to consider at least these three important aspects on seaweeds aquaculture development scheme. Seasonal cultivation periods will be different between different areas; different seaweed variants could not always be suitable in any different cultivation areas; and different age of seaweed will be different on carbon sequestration rate.

Indonesia has great potential areas to develop seaweed aquaculture activity for coastal people economic enhancement. Optimal utilization of the potential area for seaweed aquaculture could reduce a great quantity of CO_2 from the atmosphere and help to mitigate global climate change process. Planning and implementation processes of policy and management of coastal carbon ecosystems for climate change mitigation require that stakeholders and community engaged in both climate change mitigation and coastal activities [20]. Therefore, government should play a significant role in managing and regulating a way to combine seaweed aquaculture activity as one of coastal community livelihood with awareness of people to do this activity not only for economic interests, but also for environmental concern.

4. Conclusions

Seaweed capability on carbon sequestration could be influenced by seaweeds variants, cultivation periods, and seaweed age (day of culture). *E. denticulatum* had the highest carbon sequestration rate and *K. striatum* had the lowest. Seasonal cultivation periods were also influence capabilities of seaweed on carbon sequestration. These were caused by variabilities conditions of environmental factors between different cultivation periods. Implementation strategy for climate change mitigation has to consider at least three important aspects on seaweeds aquaculture development scheme. Seasonal cultivation periods will be different in any areas; different seaweed variants could not always grow well in any different cultivation area; and different age of seaweed would have different capability on carbon sequestration.

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