MANAGEMENT OF SUSTAINABLE SEAWEED (*Kappaphycus alvarezii*) AQUACULTURE IN THE CONTEXT OF CLIMATE CHANGE MITIGATION

Erlania# and I Nyoman Radiarta

Center for Aquaculture Research and Development, Jakarta

(*Received 12 February 2014; Accepted 24 April 2014*)

ABSTRACT

Seaweed is an important aquaculture commodity that could contribute on climate change mitigation, related to its ability on absorbing CO_2, as one of the green house gases, through photosynthesis. This study aimed to analyze seaweed potencies on carbon sequestration in the context of climate change mitigation while still resulting optimum production as primary purpose and to analyze the carrying capacity of Gerupuk Bay in order to manage sustainability of seaweed aquaculture. Seaweed, (*Kappaphycus alvarezii*) was cultivated with long-line system in Gerupuk Bay, West Nusa Tenggara, during five months for three cultivation cycles. Samplings were conducted at days-15, 30, and 45 with CO_2 absorption rates as main parameters. Water carrying capacity was calculated to determine the ability of Gerupuk Bay waters for supporting development of sustainable seaweed aquaculture. The results showed that absorption rates of CO_2 by seaweed (*K. alvarezii*) were different at each sampling days of cultivation periods; the highest value was at 10-20 days of cultivation. CO_2 absorption analysis resulted based on sampling days of cultivation period could be applied to formulate the strategies for management of sustainable seaweed aquaculture, with optimal production and positively contributed to the environment. However, waters carrying capacity should also be considered as major aspect in the application of seaweed cultivation management, thus it can run continuously without causing conflicts with other interests.

KEYWORDS: sustainable aquaculture, seaweed, management, CO_2 absorption, carrying capacity, climate change

INTRODUCTION

Seaweed is one of aquaculture commodity that also plays an important role in environmental quality improvement, related to climate change mitigation. Seaweed as photoautotrophic macroalgae has ability to absorb CO_2 that is used in photosynthesis process to form carbohydrate as primary product and oxygen as by-product. CO_2 is a colorless, odorless, faintly acidic, very stable, non-reactive, and non-flammable gas that like other greenhouse gases (GHGs), only present in the atmosphere in tiny quantities; by volume less than 0.04% of all gases in the atmosphere; and the concentration in the atmosphere has reached 382 mg/L by 2007 (Dawson & Spannagle, 2009) and was predicted to rise to 450 mg/L by 2020 if no action is taken (Kraan, 2010). CO_2 is the most important anthropogenic GHG that annual emissions have grown between 1970 and 2004

Corresponding author. Center for Aquaculture Research and Development
Jl. Ragunan 20, Pasar Minggu, Jakarta Selatan 12540, Indonesia. Phone: +62 21 7805052
E-mail: erlania_elleen@yahoo.com

by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (IPCC, 2007). Average global temperatures have increased by 0.76ºC since 1900, and has led to changes in geo-physical and biophysical earth system (Dawson & Spannagle, 2009). In general, mitigation is aimed at reducing the causes of climate change, in particular the emissions of the gases (Houghton, 2004).

In Indonesia, seaweed is the highest production of aquaculture commodity (DJPB, 2012). Seaweeds have been used for human and animal consumption, sources of phycocolloids, as raw material of cosmaceuticals and nutraceuticals, and also can be used as fertilizers, feed-stuff, and biofuels resources (McHugh, 2003). Large-scale open water cultivations of seaweed have been carried out for decades with optimum production as the main purpose. Seaweed has high productivity as shown by growth rates of this marine macroalgae that far exceed those of terrestrial biomass (Kraan, 2010). Nowadays, seaweed aquaculture activity has more important role than production attainment only.

General evolution of seaweed cultivation has been developed from cultivation activity to produce biomass, shifted to cultivation activity as nutrient bioextraction; that is an environmental management strategy by which nutrients are removed from an aquatic ecosystem through the harvest of enhanced biological production, including the aquaculture of marine algae and/or suspension-feeding shellfish (Barrington *et al*., 2009). The cultivation of seaweed can make a beneficial effect in some respects such as nutrient removal and can facilitate polyculture. Seaweed culture is an extensive culture system which relies mostly on a natural nutrient supply (Phillips, 1990; Chopin *et al*., 2001). More importantly, seaweed cultivation activites have also become carbon sequestration system (Grimsditch, 2011; Grimsditch & Chung, 2012). Recent study shows that the rate of carbon sequestration based on harvesting biomass of *Gracilaria gigas* reached up to 90.09 ton C/ha/year, almost 335.79% higher than *K. alvarezii* that was 20.67 ton C/ha/year (Erlania *et al*., 2013a). However, during the cultivation process of seaweed, there was a difference in the absorption rate of CO_2 depending on age of cultivation days. High potency of carbon sequestration of cultured seaweed could be an alternative of sustainable seaweed aquaculture management in context of climate change mitigation. Strategy of seaweed cultivation might be applied based on the highest to the lowest carbon absorption rate of each age of cultivation day. This study aimed to analyze potential of seaweed as carbon sequestration in the context of climate change mitigation while still resulting optimum production as primary purpose and to analyze the carrying capacity of Gerupuk Bay in order to manage sustainability of seaweed aquaculture.

MATERIALS AND METHODS

Seaweed Cultivation

The study was conducted in Gerupuk Bay, Central Lombok, West Nusa Tenggara from July-November 2012 (Figure 1). Seaweed (*K. alvarezii*) was cultivated with long-line system for wide area of 2,500 m^2. The long-line systems consist of primary line that were designed to be square shaped, equipped with anchors and buoys at each corner. Secondary line stretched between the primary line; the seeds were bunched with plastic rope to secondary line. The *K. alvarezii* seeds were obtained from National Seaweed Center, Gerupuk, Central Lombok, West Nusa Tenggara. Duration of cultivation was 135 days with harvesting time every 45 days. The yield from the first period of culture (45 days) was replanted for the next cultivation cycle (second and third periods). CO_2 absorption rates by *K. alvarezii* were analysed on days 15, 30, and 45 for each cultivation cycle.

Estimation of CO_2 Absorption Rate and Seaweed Aquaculture Productivity

CO_2 absorption (ton CO_2/ha/year) by seaweed could be estimated based on carbon absorption calculation which is multiplied with CO_2 conversion factor. Estimation of carbon absorption by cultivated seaweed calculated based on formulation by Muraoka (2004):

$$\text{C absorption} = \text{Total area (ha)} \times \text{Standing stock} \times \text{P-B ratio} \times \text{Carbon content (\%)}$$

Productivity of seaweed aquaculture was calculated based on total yield every period of culture (45 days) that was considered to be one cycle of cultivation. Yield from every cultivation cycle was converted to seaweed farming wide area.

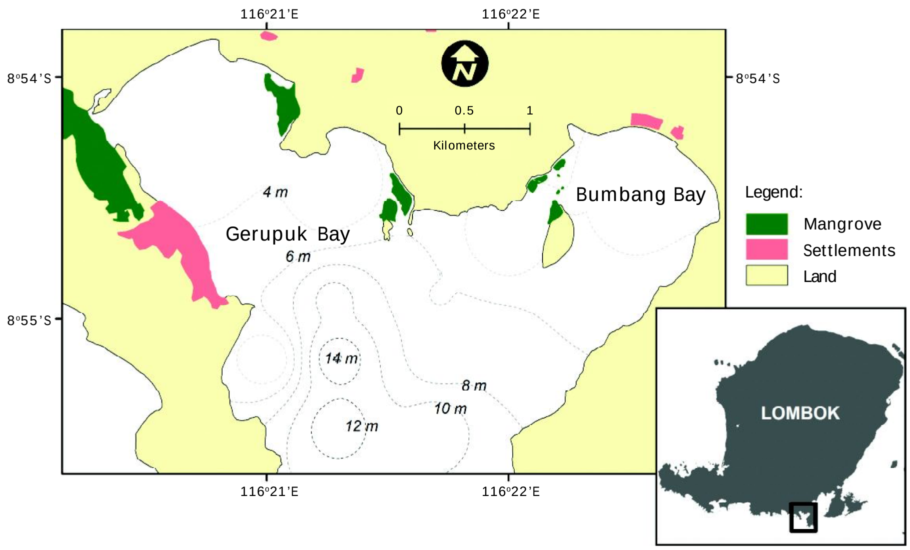

Figure 1. Research site at Gerupuk Bay, Central Lombok, West Nusa Tenggara

Waters Carrying Capacity

Waters capacity for seaweed aquaculture was defined as an area of water that can be used for seaweed cultivation activities continually, but socially and ecologically will not cause conflicts and coastal ecosystems damage. Calculation of waters capacity for seaweed cultivation with long-line system considered wide area that occupied by long-line unit including space between the units for water circulation. Waters capacity was calculated as follows (Azis, 2011):

$$\text{Water capacity (\%)} = \frac{L_2P_2 - L_1P_1}{L_2P_2} \times 100\%$$

where:

L_1 = Width of a unit long-line
L_2 = Suitable width of a unit long-line
P_1 = Length of a unit long-line
P_2 = Suitable length of a unit long-line

The method used to calculated waters carrying capacity for seaweed aquaculture was based on the analysis of land suitability (Azis, 2011). Calculation of carrying capacity in Gerupuk Bay involved total suitable wide area for seaweed aquaculture based on feasibility study which was done by Radiarta & Rasidi (2012). The carrying capacity for seaweed aquaculture was calculated using the formula (Azis, 2011):

$$\text{Carrying capacity (ha)} = Wa \times Wc$$

where:

Wa = Suitable wide area (ha)
Wc = Water capacity (%)

Generally, size of long-line units that was used in Gerupuk Bay was 2,500 m^2 (50 m x 50 m). Distance between long-line unit is ideally around 10 m (Azis, 2011), which is twice of maximum width of the boat width weight-counterbalancing. So, the wide area required for a long-line unit is ideally 4,900 m^2 (70 m x 70 m). Determination of maximum number of cultivation units with long line system which can be supported by the waters capacity can be calculated using the formula (Azis, 2011):

$$\text{Number of long-line unit} = \frac{C}{A}$$

where:

C = Carrying capacity (ha)
A = Ideal wide area for a long-line unit (ha/unit)

Data Analysis

The data collected was analyzed using simple statistical methods of descriptive statistics (mean and standard deviation) and the result showed in tables and graphs. The relationship between amount of CO_2 absorbed with seaweed aquaculture productivity was calculated with linier regression method.

RESULTS AND DISCUSSION

Carbon (CO_2) Sequestration for Management of Seaweed Aquaculture Development

CO_2 absorption rate by seaweed (*K. alvarezii*) aquaculture was different at each age of cultivation day (Figure 2). Generally, the highest rate of CO_2 absorption was found in the age of 15 days; further decreased at day-30, then increased again at the age of 45 days, thus continued from the first period to the second periods of culture. While in the third periods of culture, the rate of CO_2 absorption at day-45 remained decreased (Figure 2).

Table 1 shows the large amounts of CO_2 absorbed by seaweed proportional to the productivity of seaweed aquaculture. The productivity of the first and second periods of seaweed cultivation was relatively higher compared to the third period of culture. Likewise, the rate of CO_2 absorption was also higher in the first and second periods compared to the third period. Model of the relationship between the rate of CO_2 absorption and seaweed aquaculture productivity following the equation y = 0.0202 x + 0,006. R^2 value of the model was 0.9225 which showed strong relationship between the rate of carbon absorption and seaweed farming productivity.

The differences in productivity of seaweed aquaculture at different periods of cultivation could also indicate that there were differences in the environmental and climate conditions of each period of cultivation (Radiarta *et al*., 2013). Thus, it could be estimated that the environmental conditions in Gerupuk Bay were relatively suitable to support cultivation of seaweed *K. alvarezii* in the first and the second periods of culture which was shown by

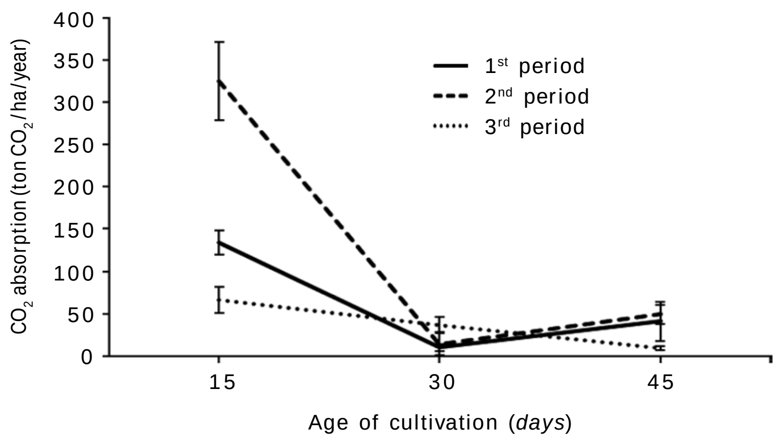

Figure 2. Different levels of CO_2 sequestration rate (ton CO_2/ha/year) by seaweed at different age of cultivation days in Gerupuk Bay, Central Lombok

Table 1. The amount of CO_2 absorbed by seaweed aquaculture in Gerupuk Bay, Central Lombok

Periods of culture	CO_2 absorbed (ton CO_2/ton yield)	Seaweed aquaculture productivity (ton/ha/year)
1st period	1.32	56.64
2nd period	1.76	89.60
3rd period	0.70	39.68
Model :	y = 0.0202x + 0.006	
R^2:	0.9225	

high seaweed productivity. In the third period of cultivation, the quality of marine environment in the location was not optimum condition for seaweed *K. alvarezii* cultivation, so that productivity was relatively lower than the previous periods of culture (Table 1).

The most effective ways to reduce CO_2 emissions are to improve energy efficiency of each economic sector and to lessen destruction of tropical and temperate forests around the world (Ritschard, 1992). However, this option may not be fully achieved technically and economically, because of the presence of various barriers both social and political. Ritschard (1992) also stated that the most practical of the innovations is to increase CO_2 sinks through photosynthesis, including increased C storage in standing tree biomass, substitution of fossil fuels with biofuels, increased soil C sequestration, and increased ocean primary productivity. However, from each of these methods there are still remained unanswered questions about the technical and economic feasibility, as well as the environment consequences that may be resulted.

Through seaweed aquaculture activity, technical, and economic feasibility could be achieved. Seaweed aquaculture could contribute not only as a source of livelihood for coastal communities but also plays an important role to control environment quality, especially in decreasing of CO_2 concentration from the atmosphere (Muraoka, 2004; Kaladharan *et al*., 2009). The differences of CO_2 absorption rates in different age of seaweed cultivation day, can be used as an alternative in determining the strategy of sustainable seaweed aquaculture management. The highest rate of CO_2 absorption in the age of 15 days, may also indicate the highest growth rate of seaweed at this age of cultivation. This condition can be applied in the management of seaweed aquaculture, particularly to develop seaweed nurseries. At the age interval we can make rejuvenation from the cultivated seaweed, by cutting the secondary thallus to be replanted for seed production then be used as seed supplier for growing stage. Thus, seaweed aquaculture activities can be more effective in absorbing CO_2 from the environment, and can play even greater role in the process of climate change mitigation (Erlania *et al*., 2013b). Many factors could influence the success of seaweed aquaculture, not only land suitability and cultivation technology, but also sufficiency, quality, and continuity of seed supply (Parenrengi, 2011). Therefore, seaweed nursery is an important factor for seaweed aquaculture sustainability development. Seaweed nurseries development as a part of seaweed aquaculture process will contribute to decrease CO_2 from the environment.

CO_2 absorption rate tended to decrease until the lowest rate at the age of 30 days, and then to increase again at the age of 45 days for the first and second periods of cultivation (Erlania & Radiarta, 2014). The environmental conditions during these periods were relatively close to the optimum for seaweed cultivation (Erlania & Radiarta, 2014; Radiarta *et al*., 2013), thus it could be considered as the natural cycle of the species *K. alvarezii* cultivated in coastal waters with long line system. This cycle was in accordance with the cultivation practice by seaweed farmers that determined the duration of *K. alvarezii* cultivation for one cycle, i.e. one cycle is conducted for 45 days. At day 45, cultivated seaweed were harvested and partly replanted. Vegetative regeneration is an effective means for propagation of *K. alvarezii*. Increasing of the CO_2 absorption rate on day-45 also indicated increasing of seaweed growth rate at the same time.

Waters Carrying Capacity for Sustainable Seaweed Aquaculture

Carrying capacity of area indicated the maximum capacity of wide area to support farming activities continuously without causing degradation, both social and biophysical environment (Azis, 2011). Carrying capacity is an important factor for maintaining sustainability of seaweed aquaculture activities as well as other food production systems (Zamroni & Yamao, 2011). Feasibility study by Radiarta & Rasidi (2012) reported that available area of Gerupuk Bay suitable for seaweed aquaculture was 322 ha (Table 2). Carrying capacity for seaweed aquaculture activities in Gerupuk Bay using water capacity approach was 157.71 ha, and the number of long-line units which can be supported for seaweed aquaculture activities were 321 units (Table 2).

Water quality is also an important factor which determines the success of seaweed cultivation. Water quality is one of main parameters in the analysis of site suitability for seaweed cultivation, in addition to socio-economic, institutional, and infrastructure availabil-

Table 2. Characteristic of Gerupuk Bay, Central Lombok to support sustainable seaweed aquaculture

Characters	Units	Values
Suitable wide area (Radiarta & Rasidi, 2012)	ha	322.00
Ideal wide area for a long line unit	ha	0.49
Waters capacity	%	48.98
Carrying capacity	ha	157.71
Number of long line units	Units	321.00

ity factors. Furthermore, the results of site suitability analysis used as a basis for determining the water carrying capacity for seaweed aquaculture (Azis, 2011). If seaweed cultivation activities are conducted beyond the waters carrying capacity, the seaweed aquaculture will not be sustained. Moreover, the expected positive contribution to the environment, especially carbon and nutrient absorption from the water will become inefficient.

Seaweed Aquaculture in Context of Climate Change Mitigation

Great potency of seaweed on carbon sequestration makes the seaweed aquaculture becomes a very important activity that should be more developed. Figure 3 shows the CO_2 sequestration rate by several seaweed species under different conditions: natural and farming. Some natural seaweed species could absorb 3.26-118.73 ton CO_2/ha/year (Muraoka, 2004), but the cultured species showed higher; 75.79-330.32 ton CO_2/ha/year (Erlania *et al*., 2013a). *K. alvarezii* that was used in this study could absorb 27.35-158.40 ton CO_2/ha/year, that were different at each culture periods (Figure 3). Carbon sequestration capability of each seaweed species could become a consideration for developing seaweed aquaculture activity. *Gracilaria gigas* and *Kappaphycus alvarezii* are two potential species that have been cultivated not only with high economic value, but also with high capability in carbon sequestration (Erlania *et al*., 2013a).

Indonesia has a total of about 1.38 million ha potency of seaweed aquaculture area (MMAF-JICA, 2011). If the potential areas were used based on the carrying capacity (48.98%),

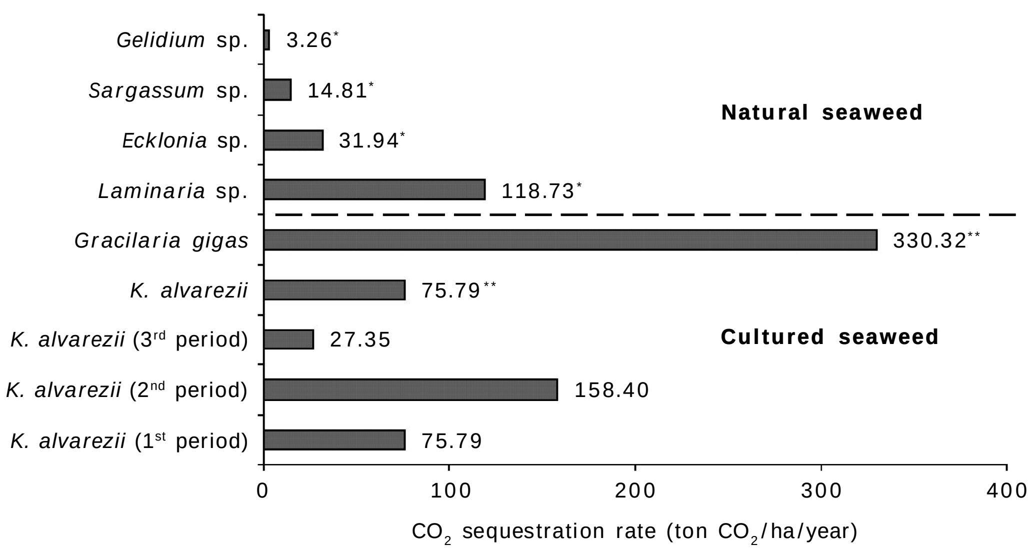

Figure 3. CO_2 sequestration rate by different seaweed species under natural and cultured condition (* Muraoka, 2004; ** Erlania *et al*., 2013a)

then nationally seaweed aquaculture could contribute in climate change mitigation through carbon sequestration attained to 675.92 ton CO_2/year. Developing sustainable seaweed aquaculture in Indonesia could be conducted not only in line with increasing national seaweed production, but also to improve environmental condition. The more extensive seaweed cultivation area, the greater the carbon that can be absorbed, thus it could give positive impact to the climate change mitigation.

CONCLUSIONS

The total yield of seaweed aquaculture could simply describe the amount of CO_2 absorbed by seaweed cultivation. CO_2 absorption analysis resulted based on cultivation periods could be applied to compose an alternative strategy for management of sustainable seaweed aquaculture, even with optimal production and positive contribution to the environment. Gerupuk Bay could support 321 units of long-line for sustainable seaweed cultivation based on its 157.71 ha of carrying capacity. Waters carrying capacity should remain as a major consideration to manage seaweed aquaculture, thus it can run continuously without causing conflicts with other interests. Cultured seaweed shows high capability in carbon sequestration from the environment. Thus, sustainable seaweed aquaculture activity will be more efficient for production and environmental quality improvement, including climate change mitigation.

ACKNOWLEDGEMENT

We acknowledge the National Seaweed Center, Gerupuk, Central Lombok, West Nusa Tenggara. We greatly appreciate the field assistance by Rasidi, Buntaran, Rusman, and Seme. This project was financed by the Goverment of Indonesia through DIPA 2012.

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