THINNING PRACTICES IN REHABILITATED MANGROVES: OPPORTUNITY TO SYNERGIZE CLIMATE CHANGE MITIGATION AND ADAPTATION

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ABSTRACT: Mangrove trees act important roles in the coastal ecosystems, protecting community against high-tide and storms, controlling land erosion and providing fish breeding ground. In the last few decades, the massive area has devastated due to commercial shrimp and fish ponds development. To rehabilitate the coastal ecosystems, some mangrove has been planted with spacing distances of 1x1 m with minimal forest management. Those dense-spaced stands enhanced light competitions and inhibit growth. These poor quality and immature stands that reach an early climax in 10-15 years were observed in two adjacent sites near Nam Dinh and Thanh Hoa in northern Vietnam, where *Kandelia candel* were planted. To cultivate the resurgent stands and increase their growth, thinning mangrove is essential. Stand densities of the mangrove trees with and without the thinning practice were 17,800 and 5,200 trees ha^{-1}, respectively. Their potential of the maximum above-ground biomass were 303 and 239 Mg ha^{-1}, respectively. However, quality of the single tree was largely different whether or not thinning practice is conducted, as the thinned one of 46 kg tree^{-1} was about three times higher than the non-thinned of 17 kg tree^{-1}. The thinning practice enhances stand biomass growth with improved growth condition in the forest, which advances carbon sequestration for the climate change mitigation. The cultivated trees also ensure the climate change adaptation of coastal protection, fishery products and bio-diversity. Synergizing mitigation and adaptation strategies with the mangrove thinning would enhance the benefits for coastal communities most vulnerable to climate change.

Keywords: Mangrove plantation, biomass and coastal ecosystem rehabilitation.

INTRODUCTION

Mangroves provide firewood, charcoal and livelihoods of fisheries to the local community. Also, they have significant multi-ecological services such as prevention of high tide (tsunami) and controlling land erosion, water management and biodiversity. Communities of the coastal area depend their livelihood and well-being on the mangroves. However, due to land use change by expansion of shrimp and fish culture, coastal development and illegal cuttings, mangrove areas had decreased to the half in the last five decades. The degradation leads urgent matter to secure the coastal livelihood and management.

Carbon pools of mangrove forests are among the highest of tropical forest types (Bouillon et al., 2008; Donato et al., 2011; Adame et al., 2013). Of great interest is the mangroves' potential value of carbon mitigation programs, such as REDD+ and blue carbon (Alongi, 2012; Kauffman and Donato, 2012; Nellemann et al. 2009). The mangroves also contribute to climate change adaptation, which strongly influence the community structure of fish on neighboring coral reefs in the Caribbean (Mumby *et al.*, 2004). Organic matter derived from mangrove trees is brought in by the tides from adjacent marine environments (Kristensen et al., 2008).

In the last few decades, mangroves have started to be replanted or afforested and they are conserved. Owing to that, a part of the area has recovered and such extent contributes to rehabilitate the coastal ecosystems. However, almost of the planted areas of mangroves in the Southeast Asia are abandoned due to lack of any forest management. This may be short of consideration for its requirement of management and voluntary resources for the activity. At the beginning of the plantation, propagules are applied in 1.0 to 1.5 m intervals. After around 5 year-old when tree height reaches to 2 to 3 m, canopy leaves are overlapped and light competition is occurring that affects their own growth. Under the condition, the planted trees get poor and immaturity. It is less expected for such immature trees to act multi-ecological services in the coastal area.

Mangrove plantation should be managed by an appropriate forest management with thinning practice that reducing tree numbers along their growth. In Matang mangrove reserve, Malaysia, mangrove timbers

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are produced for charcoal production and firewood in the concession. Systematic management has conducted there for over a hundred years. Intermediate felling has conducted with thinning practice, over the term 'stick method', which is one of the best and easiest ways practiced in Matang mangrove reserve in Malaysia (Inoue et al., 1999). The first thinning was conducted in between 15^{th} to 20^{th} year, and the second one is in between 20^{th} to 24^{th} year, where the final felling is at 30^{th} year, but they have improved for effective production that the first be brought forward as early as the 12^{th} year, the second at between 15^{th} and 17^{th} year, and the final at 25^{th} year (Dato, 2003).

The purpose of this paper is to identify several tree biomass of rehabilitated *Kandelia candel* in the adjacent areas of Vietnam and their annual biomass increment. It is proposed to stress necessary for tree number control by thinning, and which may also promote to synergize climate change mitigation and adaptation.

MATERIALS AND METHODS

Study Site

Study sites are located in Thanh Hoa (20°12'N, 160°32'E) and Nam Dinh (21°17'N, 106°33'E) in the mouth of River Len flowing into Tonkin Golf, where approximately 100 km from the capital Hanoi city to the south-east away. These regions are adjacent and have similar climate, as they are characterized by subtropical climate with dry seasons (May–October) and rainy seasons (December–February) and annual mean temperature was 32.4°C at maximum and 17.8°C at minimum, annual precipitation is 1,600 mm, and the average humidity is 85.7% (period 1997–2001).

Dominant mangrove species is *Kandelia candel*, planted by Red Cross of Japan and Vietnam, while *Rhizophora stylosa* and *Sonneratia alba* were scattered. Field research was carried out for representative single tree of 5, 10 and 15 year-old in Thanh Hoa and that of 2, 5, 7 and 10 year-old in Nam Dinh, respectively. This specie is familiar in the northern limit of mangrove distribution in the Southeast Asia. Tree density of *K. candel* trees are 64.5, 89.0 and 52.0 trees 100 m^{-2} in Thanh Hoa where thinning is conducted as a result of some local utilization (thinned area). While those are 108, 108, 226 and 178 trees 100 m^{-2} in Nam Dinh, as they are abandoned after the plantation (non-thinned area). Tree height of each tree were 1.6, 3.1 and 7.1 m in Thanh Hoa and 1.7, 2.1, 2.8 and 4.8 m in Nam Dinh, respectively.

Measurement of Above-Ground Tree Biomass

Biomass of branch and trunk in each tree was measured based on dry weight. The branch was divided into four offshoot groups, following the same method described in the previous study (Okimoto et al., 2008)—primary offshoots attached to the trunk, those branching from the first offshoots, those branching from the second offshoots, and other twigs. The divided branches were also separated into lignified brown and non-lignified green parts, based on the degree of lignification and color of the branch surface. Roots were carefully collected by excavation with a pump engine (SEG-25E, Koshin Ltd.). They were divided into four groups: main root and first and second lateral roots and the lateral roots were separated into two groups, brown and white, based on the color of the root surface. These biomass samples were partly dried at 115°C for more than a week, and the dry weights were measured. In addition, water content and wood density (weight per unit volume) of the samples were calculated.

Estimation of Annual Biomass Increment Using Growth Curve Analysis Methods

In the growth curve analysis method, single tree biomass at different tree ages in the monoculture mangrove forest was measured. A growth curve was calculated based on some tree biomass and a given maximum dry weight of the tree, based on the following formula described the details in the previous paper (Okimoto et al., 2008):

$$Y = \frac{D}{1 + E \cdot \exp^{-F \cdot t}} \quad (1)$$

where Y is the tree biomass (kg dry weight/tree) at the age of t, t is the tree age (years), D is the maximum tree biomass, E is an integration constant, and F is the growth coefficient showing the maximum value of annual biomass accumulation. The value of E can be calculated by both D and an initial value of Y_0 with the following equation:

$$E = \frac{D - Y_0}{Y_0} \quad (2)$$

A derivative value of the growth curve ($\Delta Y / \Delta T$) was calculated by the following formula, and annual biomass increment (net CO_2 fixation) along the tree growth was estimated by this value:

$$\frac{\Delta Y}{\Delta T} = \frac{D \cdot E \cdot F \cdot \exp^{-F \cdot t}}{(1 + E \cdot F \cdot \exp^{-F \cdot t})^2} \quad (3)$$

RESULTS

Stand Biomass in Each Site

In Thanh Hoa, most of the parts in above-ground *K. candel* tree was composed of lignified brown trunk and first branches (Fig. 1). Dry weight of leaves belonging to 10 and 15 year-old tree was almost the same. They were 2.3 times higher than those of the 5 year-old tree. Above-ground tree biomass was 1.86, 9.39 and 15.4 kg tree^{-1}, respectively (Table 1). The total dry weight of the 5, 10, and 15 year-old *K. candel* tree was 4.48, 11.5, and 31.3 kg tree^{-1}, respectively. Their total dry weight per hectare was 28.9, 102 and 163 Mg ha^{-1}, respectively. Root biomass was mainly composed of the main roots. The ratio of dry weights of the main roots was about 43, 36, and 58%, respectively. Their T/R ratios were 0.71, 4.46 and 0.97, respectively.

In Nam Dinh, most of the parts in above-ground *K. candel* tree were also composed of lignified brown trunk and first and second branches (Fig. 2). Above-ground biomass of 2, 5, 7 and 10 year-old *K. candel* tree was 0.48, 2.48, 3.86 and 9.74 kg tree^{-1}, respectively (Table 2). Root biomass of the single tree was 0.44, 1.57, 1.73 and 2.34 kg tree^{-1}, respectively. Dry weight of the above-ground biomass per unit hectare was 5.18, 26.8, 87.2 and 173 Mg ha^{-1} and those of the root were 4.75, 17.0, 39.1 and 41.6 Mg ha^{-1}, respectively. Their T/R ratios were 1.09, 1.58, 2.24 and 4.17, respectively.

Growth Curve Analysis of *K. candel* Trees

Tree biomass variations of *K. candel* for the both sites as a function of time were shown in the growth curve (Fig. 3). Growth curves corresponded well to the dry weights of the tree biomass measured at different ages. Although they have similar climate in the adjacent areas of the northern Vietnam, potential values of the maximum above-ground biomass in Nam Dinh and Thanh Hoa were 17.3 and 45.8 kg tree^{-1} as shown in Fig. 3, respectively. The tree biomass in Thanh Hoa was approximately 2.6 times larger than that in Nam Dinh. The forest biomass per hectare was 303 and 239 Mg ha^{-1}, which was calculated by multiplying the maximum tree biomass obtained in the growth curves by the tree density, respectively. Tree biomass in Thanh Hoa reaches its growth climax in 20-25 years, while relatively poor quality and immature trees in Nam Dinh reach an early climax period in 10-15 years (Fig. 3).

Annual growth rates, which are the derivative values described in Eq. 3, can be substituted for actual biomass accumulations of the tree (net CO_2 fixation capacity) in each growth stage. Those values of total tree biomass for 2, 5, 7 and 10 year-old tree in Nam Dinh were 4.99, 14.9, 50.6 and 37.2 Mg ha^{-1} yr^{-1}, respectively (Table 3). Meanwhile, those values for 5, 10 and 15 year-old tree in Thanh Hoa were 6.45, 34.0 and 22.8 Mg ha^{-1} yr^{-1}, respectively. In the comparison, the annual biomass increment in Nam Dinh was larger than those in Thanh Hoa.

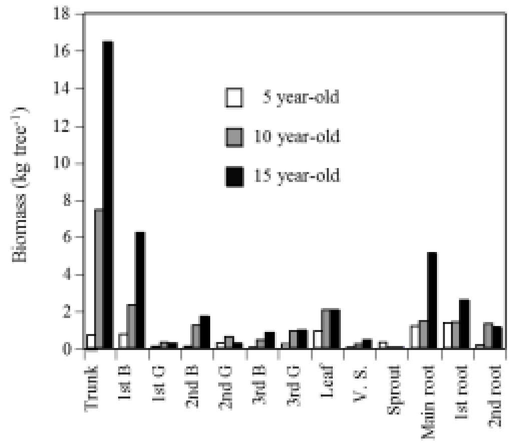

Fig.1. Biomass of each organ in 5, 10 and 15 year-old *Kandelia candel* tree in Thanh Hoa, Vietnam. In X-axis, B shows brown part of the branch, G shows green parts of the branch, and V.S. shows viviparous seed.

Table 1. Tree biomass (kg tree^{-1}) of 5, 10 and 15 year-old *K. candel* in Thanh Hoa, Vietnam. Top (T) to Root (R) ratio is shown in the table.

Tree age (yr)	5	10	15
Above-ground	1.86	9.39	15.4
Below-ground	2.62	2.11	15.9
Total	4.48	11.5	31.3
T/R	0.71	4.46	0.97

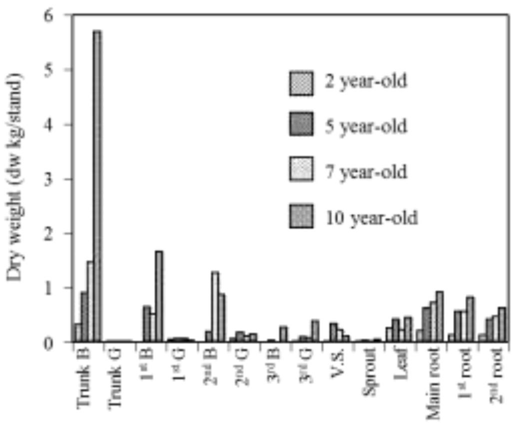

Fig. 2. Biomass of each organ in four kinds of tree ages of *Kandelia candel* in Nam Dinh, Vietnam. B shows brown part of the branch, G shows green parts of the branch and V.S. shows viviparous seed.

Table 2. Tree biomass (kg $tree^{-1}$) of 2, 5, 7 and 10 year-old *K. candel* in Nam Dinh, Vietnam. Top (T) to Root (R) ratio is shown in the table.

Tree age (yr)	2	5	7	10
Above-ground	0.48	2.48	3.86	9.74
Below-ground	0.44	1.57	1.73	2.34
Total	0.92	4.05	5.59	12.1
T/R	1.09	1.58	2.24	4.17

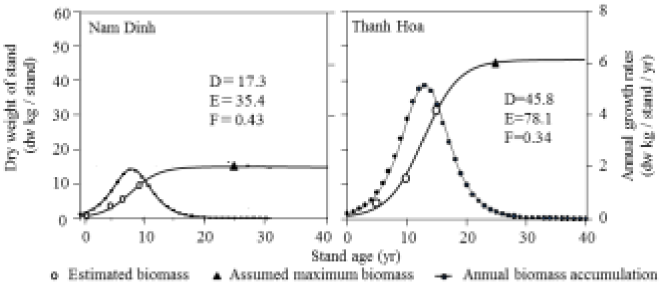

Fig.3. Comparison of the growth curve for whole tree biomass of *Kandelia candel* in both sites of Thanh Hoa and Nam Dinh Vietnam. The values of A, B and K show the parameters of growth curve equation of $Y=D/(1+E \cdot exp^{-F \cdot t})$, where A is an assumed maximum stand biomass, $E=(D-Y_0)/Y_0$, where Y_0 is an initial value of stand biomass, t is a stand age and F is a growth coefficient.

Table 3. Annual biomass increment (Mg ha^{-1} yr^{-1}) for each growth stage of *K. candel* trees in Nam Dinh and Thanh Hoa, Vietnam.

Tree age (yr)	2	5	7	10	15
Nam Dinh	3.44	13.1	50.8	39.5	--
Thanh Hoa	--	6.45	--	34.0	22.8

DISCUSSION

In the adjacent areas where similar climate in Vietnam, tree biomass of *K. candel* in different growth stages and their annual biomass increment was measured and compared them by using growth curve analysis method.

Potential values of the maximum above-ground biomass in Thanh Hoa and Nam Dinh were 303 and 239 Mg ha^{-1}, respectively. It is expected that the rehabilitated mangrove trees show sufficient potential of their growth and biomass exceeding 200 Mg ha^{-1}. However, quality of the single tree was largely different in the cases whether thinning practice is conducted or not, where tree numbers were 17,800 and 5,200 trees ha^{-1}, respectively. The thinned one of 46 kg $tree^{-1}$ in Thanh Hoa was about 2.6 times larger than the non-thinned of 17 kg $tree^{-1}$ in Nam Dinh (Fig. 3, Table 3). It is considered that insufficient growth of the stands in Nam Dinh is mainly caused by dense tree numbers, which leads light completion in the canopy. Decreasing tree numbers with thinning practice is the most tasks to avoid the light competition.

Annual biomass increment for total tree biomass obtained in this study (3.44-50.8 Mg^{-1} yr^{-1}; Table 3), converted into 1.38 to 20.3 MgC ha^{-1} yr^{-1}, were similar to those values of 7 to 18 MgC ha^{-1} yr^{-1} (Ong, 1993) and 17±5 MgC ha^{-1} yr^{-1} (Ong et al., 1995) both for 20 year-old *R. apiculata* forest in Malaysia and those of 14 to 35 MgC ha^{-1} yr^{-1} for 6 to 14 year-old *R. apiculata* forest in Thailand (Christensen, 1978). These reported values were all estimated by the allometric method. It was clear that the growth curve analysis method was equally able to estimate the net CO_2 fixation capacity to the allometric method.

Single trees in the thinned area showed almost double growth of the one in the non-thinned area (Fig. 3). By contrast, biomass accumulation in a hectare was larger in the non-thinned area than that of the thinned area (Table 3). In considering the management of the rehabilitated mangrove with appropriate thinning practice, such larger CO_2 fixation in the non-thinned area suggests to have potency as an intensive mitigation strategy by the first period of thinning practice. After that, some trees are supposed to be cut by the thinning and can be utilized for a local resource for firewood and charcoal. These are one of the main drivers of deforestation of those illegal cuttings. As a strategic countermeasure for REDD+, their local utilization could be arranged in appropriate forest management with well-arranged thinning practice.

It is considered that poor and immature trees as we observe in the non-thinned forest cannot serve sufficient ecosystem services and well-being, such as coastal protection, erosion control, fishery products and bio-diversity. These ecological functions are highly expecting for the mangrove rehabilitation. However, the effects of the thinning practice with aspects of environment, livelihood and economy are not sufficiently quantified yet, although mangroves provide habitat for fishery nursery (Mumby et al., 2004) and economic values of the mangroves for storm protection and erosion control worth at USD 12,392 ha^{-1} (UNEP, 2009). It is not clear yet that how much carbon additionally sequestrated in the remaining trees or leaked out with the thinned materials for local uses, neither.

Synergizing adaptation and mitigation strategies would enhance the benefits for communities most vulnerable to climate change (Murdiyarso et al., 2012). Modeling tools including thinning need to be developed to simulate with various aspects and feasibility of the models was determined through financial analysis. The thinning system employed has to be easy to execute and also easy to monitor. A complicated system may get out of control and cause damage to the forest stands.

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