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Mainstreaming Mangroves

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Estimation of CO2 Fixation Capacity and Growth Potential on Mangrove Forest in South East Asia

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ABSTRACT

Carbon stocks of mangrove forest have estimated by using allometric equations, although UNFCCC approves the only 10 equations for AR-CDM. The allometric method is laborious and time consuming to develop, so alternative methodologies which more accurate and simple to use are required. We have challenged to develop such alternative methods on the monoculture mangrove forest. As a result of that, both analysis methods of gas exchange and growth curve were proposed (Okimoto et al., 2007, 2008). The former method estimates CO_2 balance of photosynthetic absorption and respiratory emission of CO_2, which are based on measurements of photosynthesis in leaf and respiration in leaf, branch and trunk. While, the latter is derived by variations of the tree biomass at some tree ages, and which estimates potential of maximum tree biomass and variations of annual biomass increment with derivative value of the growth curve. Our results of the gas exchange estimations shows that above-ground biomass increment were 66.0 and 34.3 ton ha^{-1} yr^{-1} for 7 and 10 year-old Kandelia candel forest in Nam Dinh and Thanh Hoa, Vietnam (21° and 19° N North latitude) and 76.3 ton ha^{-1} yr^{-1} for 9 year-old Rhizophora apiculata forest in Trat, Thailand (12° N), respectively. Meanwhile, the growth curve estimations in the both sites of Vietnam show that potential of the maximum growth of 265 and 305 ton ha^{-1} was estimated, respectively. Consequently, it is appeared that the mangrove monoculture forests in approx. 20° N (the North Vietnam) have potential to growth up to around 300 ton/ha. In addition to the results shown above, some data for 8-10 year-old R. apiculata forest in Sungai Asam, Indonesia (2° S) are under analysis. All analyzed data will be combined to figure out variations of growth potential of the mangrove monoculture forest in different latitudinal areas.

Introduction

Forests, which function as carbon sinks, are expected to sequester a great amount of the greenhouse gas carbon dioxide (CO_2). Efforts at reducing emissions from deforestation and forest degradation (REDD) in developing countries that include conservation, sustainable management and enhancement of forest carbon stocks by afforestation and reforestation (REDD+) have been a controversial issue in the climate change debate.

Carbon pools of mangrove forests are among the highest of tropical forest types (Bouillon et al., 2008). Of great interest is the mangroves' potential value in carbon mitigation programs such as REDD+ and other financial incentives for its conservation of standing forests (Kauffman and Donato, 2012). Mangroves are currently being advanced as an essential component of climate change strategies such as REDD+ and blue carbon (Alongi, 2012). However, distribution of mangrove trees has decreased to the half in the last five decades due to land conversion for urbanization, agriculture, and aquaculture, especially shrimp farms. They are planted to recover its distribution and rehabilitate the coastal ecosystems.

To account for mangrove biomass, only ten allometric methods are approved by UNFCCC (United Nations Framework Convention on Climate Change) so far (Putz and Chan 1986, Day et al. 1987, Clough and Scott 1989, Chave et al. 2005, Smith and Whelan 2006). The allometric method relies on some empirical relationships between growth factors such as diameter at breast height (1.3 m from the ground), tree height and tree biomass. Although these factors are periodically measured in the field, it requires laborious and time-consuming work to correlate the growth relationships.

Alternative methodologies are required to ensure estimation accuracy and make it simple to use. We have conducted studies on mangroves of *Rhizophora stylosa* in Ishigaki, Japan (24° North latitude), and *Kandelia candel* in Thanh Hoa, Vietnam (21° N) to propose alternative methods, which increase the accuracy of estimations of the carbon fixation capacity of mangrove trees.

Our previous study has proposed two analysis methods of gas exchange and growth curve (Okimoto et al. 2007 and 2008). The former estimates photosynthetic CO_2 absorption, respiratory CO_2 emission and the balance of net CO_2 fixation. It has overcome traditional gas exchange method which had weaknesses to estimate the CO_2 emission due to the difficulty. As a result, it is appeared that accuracy in measuring CO_2 fixation of the forest can be enhanced by temperature modification, i.e. correcting CO_2 values of photosynthetic absorption and respiratory emission with a diurnal change model of temperature in each month. The latter method shows variations in the biomass of planted mangrove trees and derives annual biomass increments with the derivative values throughout mangrove forest maturity up to 23 to 28 years (Gong and Ong, 1995).

Over the field surveys in the three different sites for the last decade, several data of biomass of the monoculture mangrove trees were collected and those of CO_2 fixation capacity were estimated. This paper shows growth curve estimations in the three research site, and which leads to estimate growth potential of biomass in the monoculture forest in South-east Asia.

Material And Methods

1) Study site

Study sites are located in Trat, Thailand (12°11'N, 102°34'E) and the both of Thanh Hoa (20°12'N, 160°32'E) and Nam Dinh (21°17'N, 106°33'E) in Vietnam. These regions are all sub-tropical areas. Field research was carried out for monoculture mangrove trees of 3, 4, 5 and 9 year-old *R. apiculata* in Trat, 5, 10 and 15 year-old *Kandelia candel* in Thanh Hoa, and 2, 5, 7 and 10 year-old *Kandelia candel* in Nam Dinh, respectively. These species are all familiar in Southeast Asia. Tree density of *R. apiculata* trees in Trat was 100, 66.7, 50.0 and 25.0 trees 100 m^{-2}, *K. candel* trees in Thanh Hoa 64.5, 89.0, and 52.0 trees 100 m^{-2} and *K. candel* trees in Nam Dinh 108, 108, 226 and 178 trees 100 m^{-2}, respectively.

2) Measurement of above- and below-ground biomass

Biomass of branch and trunk in each tree was measured based on dry weight (surface area and volume for *R. apiculata* in Trat, because they are preserved trees.). 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 colour of the branch surface. Roots were carefully collected by excavation with an engine pump (SEG-25E, Koshin Ltd.). They were divided into four groups: main root and first, second and third lateral roots. The main root was separated into four parts—upper, upper middle, middle lower and lower—and the lateral roots were separated into two groups, brown and white, based on the colour of the root surface. These biomass samples were used for RCER measurement. After the measurements, the samples were 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.

3) Estimation of net CO_2 fixation capacity using gas exchange and growth curve analysis methods

Net CO_2 fixation capacity of the monoculture mangrove trees in South-east Asia was estimated using both analysis methods, gas exchange and growth curve (described in Okimoto et al. 2008).

In the gas exchange analysis, the response of the photosynthetic CO_2 exchange rate (PCER) to light and temperature was measured in the leaves of upper and lower layers in the canopy. Light extinction and distribution of the leaves in the canopy were measured to calculate the canopy's CO_2 absorption capacity. Respiratory CO_2 emission was estimated by multiplying the respiratory CO_2 exchange rate (RCER) measured in selected organs by the total amount of each organ in the above-ground tree. Monthly average based on whole-day absorption and emission of CO_2 was corrected based on the diurnal values of light intensity and air temperature. An annual CO_2 fixation capacity was estimated by integrating CO_2 balance (absorption and emission) each month. The details can be referred to Okimoto et al. (2008).

In the growth curve analysis method, single tree biomass of 3, 4, 5 and 9 year-old *R. apiculata* trees was measured based on both surface area and volume using non-destructive methods. A growth curve was calculated based on the volumes at different tree ages and the given maximum dry weight of the tree, based on a formulation described in Okimoto et al. (2008):

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

where Y is the tree biomass (kg dry weight/tree) at the age of t, t is the tree age (in 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:

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

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

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

4) Estimation of annual biomass accumulation using growth curve analysis

In drawing a growth curve of the single tree biomass, it is necessary to have actual tree biomass in different growth stages and maximum tree biomass in a mature period. A shape of the growth curve is determined by these data on the tree biomass and an initial tree biomass (propagule). An annual biomass increment was calculated based on derivative values of the growth curve. A growth curve was drawn by using the above-ground biomass of each tree based on Equation 1 above.

The maximum tree biomass at climax period was assumed based on the largest tree biomass in each site. Hence, they were 9 year-old tree for *R. apiculata* in Trat, 15 year-old tree for *K. candel* n Thanh Hoa and 10 year-old tree for *K. candel* in Nam Dinh, respectively. For example in Trat, the maximum tree biomass was arbitrarily assumed to be about 1.5, 2.0 and 2.5 times larger than that of the 9 year-old tree—i.e., 15, 20 and 25 × 10^{-2} m^3 $tree^{-1}$, respectively. Meanwhile in Nam Dinh, the maximum tree biomass was assumed by the following three steps; the first ones for a whole tree, above- and below-ground biomass were 12.5, 10.0 and 2.5 kg DW $tree^{-1}$, which is similar to the 10 year-old biomass (12.1, 9.7 and 2.3 kg DW $tree^{-1}$), respectively. The second one was 17.2, 13.9 and 3.3 kg DW $tree^{-1}$, respectively. These are calculated by referring to above-ground biomass of mature *R. apiculata* forest 246.7 ton ha^{-1} (Alongi et al., 2000), and which was calculated by multiplying T/R (top/root) ratio of 4.16 by the tree density (178 trees 100 m^{-2}), the both are obtained in the 10 year-old tree. The third one was 14.6, 11.8 and 2.8 kg DW $tree^{-1}$, the middle values of the two maximum tree biomasses as shown above. Those three kinds of maximum biomass are 223, 260 and 306 ton ha^{-1}, respectively. Assumptions of the maximum tree biomass for *K. candel* in Thanh Hoa were described in Okimoto et al. (2008).

It is reported that mangroves reach their climax in 23 to 28 years (Gong and Ong, 1995); thus, the growth curves were drawn based on the assumption that the tree biomass would reach its maximum at 25 years.

Results

In Trat, total surface area in a single tree of 3, 4, 5 and 9 year-old *R. apiculata* was 0.136, 0.584, 1.95 and 19.8 m^2 and the total volume was 0.0520, 0.147, 0.608 and 10.3×10^{-2} m^3, respectively. To calculate dry weight of the tree biomass of different ages, wood density obtained from a part of samples in 4 year-old tree (0.510 and 0.488 g cm^{-3} for trunk and branch, respectively) was multiplied by the calculated value of tree biomass in volume. The calculated tree biomass of 3, 4, 5 and 9 year-old in dry weight was 0.254, 0.720, 2.97 and 50.2 kg DW $tree^{-1}$, respectively. Above-ground tree biomass in hectare was 2.54, 4.80, 14.9 and 126 ton DW ha^{-1}, calculated by multiplying the single tree biomass in dry weight by tree density, respectively. Root biomass of the 4 year-old *R. apiculata* tree was 5.82 m^2 in surface area and 1.91×10^{-2} m^3 in volume. Both of them were 10 times higher than those of above-ground biomass. Root biomass of 4 year-old tree in dry weight was 6.30 kg DW $tree^{-1}$, which was calculated by using the wood density of root (0.329 g cm^{-3}). T/R ratio (the ratio of total weight of above-ground biomass to dry weight of the root) was 0.114.

In Thanh Hoa, total dry weight of the 5, 10, and 15 year-old *K. candel* tree was 4.48, 11.5, and 31.3 kg DW $tree^{-1}$, respectively. Their total dry weight per hectare was 28.9, 102, and 163 ton DW ha^{-1}, respectively. Most of the parts in above-ground tree were composed of lignified brown trunk and first branches. 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. 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 1.45, 3.85, and 2.54, respectively.

In Nam Dinh, 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 DW $tree^{-1}$, respectively. Root biomass of the single tree was 0.44, 1.57, 1.73 and 2.34 kg DW $tree^{-1}$, respectively. Dry weight of the above-ground biomass per unit hectare was 5.18, 26.8, 87.2 and 173 ton ha^{-1} and those of the root were 4.75, 17.0, 39.1 and 41.6 ton ha^{-1}, respectively. Their T/R ratios were 1.09, 1.58, 2.23 and 4.16, respectively.

Volume accumulations of *R. apiculata* trees in Trat as a function of time in growth curve analysis method were shown in Fig. 1. Three kinds of growth curves with different values of the maximum tree biomass corresponded well to the single tree volumes obtained from the four different ages. As indicated in the growth curves, it can be predicated that single tree biomass attain their peaks at around 13 year-old. Meanwhile, annual increment of tree biomass in volume reached their maximum value at 8 or 9 year-old, which were 5.26-9.43×10^{-2} m^3 $tree^{-1}$ yr^{-1}. In the growth curve with the maximum tree biomass of 20×10^{-2} m^3 $tree^{-1}$, annual increments of the tree volume in 3, 4, 5 and 9 year-old tree was 0.0742, 0.203, 0.611 and 5.81×10^{-2} m^3 $tree^{-1}$ yr^{-1}, respectively, which was calculated from derivative values of the growth curve. These values in volume can be converted into those in dry weight by multiplying the calculated values by the wood density obtained from the samples of 4 year-old tree (0.486 g cm^{-3}). The calculated values of annual dry weight accumulation in above-ground of 3, 4, 5 and 9 year-old forests were 3.32, 6.69, 15.0 and 71.2 ton ha^{-1} yr^{-1}, respectively (Table 1). Also from the growth curves with the maximum tree biomass of 15 and 25×10^{-2} m^3 $tree^{-1}$, the annual values of dry matter accumulation were 2.85-53.1 ton ha^{-1} yr^{-1} and 3.77-88.1 ton ha^{-1} yr^{-1}, respectively (Table 1).

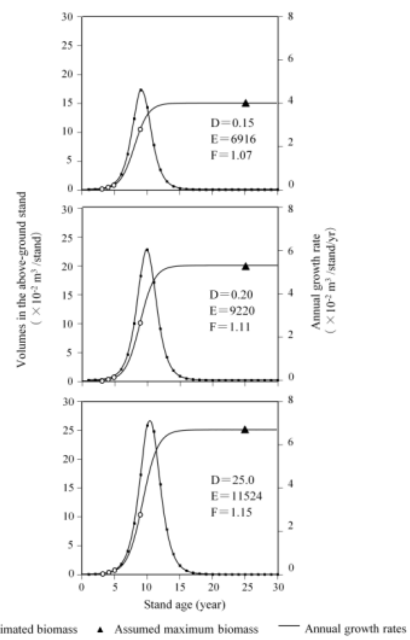

Fig. 1. Growth curves made using the estimated data of above-ground biomass in four kinds of stand ages in Trat, Thailand. Maximum stand biomass was assumed in three levels, details referred in Materials & Methods. Values of D, E and F show the parameters of growth curve equation of $Y=D/(1+E \cdot \exp^{-F \cdot t})$, where D 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 1. Annual biomass increment (ton ha^{-1} yr^{-1}) in the forests of Rhizophora apiculata in Trat, Thailand, estimated by growth curve analysis method.

Stand age (yr)	Growth Curve Estimation (ton ha^{-1} yr^{-1}) Assumed maximum stand biomass (X10^{-2} m^3/stand)		
	15	20	25
3	2.85	3.32	3.77
4	5.53	6.69	7.86
5	11.9	15.0	18.2
9	53.1	71.2	88.1

Dry weight accumulation of *K. candel* trees in Thanh Hoa in the growth curve analysis was shown in Fig. 2, which is previously reported Okimoto et al. (2008). All the growth curves corresponded well to the dry weights of the single tree measured at different three ages. Annual growth rates of the total tree biomass of 5, 10, and 15 year-old tree calculated by derivative values of the growth curve were 1.00, 3.82, and 4.39 kg DW $tree^{-1}$ yr^{-1}, in which the maximum value of the total tree biomass was postulated at 45.8 kg DW $tree^{-1}$. The net CO_2 fixation capacity of 5, 10, and 15 year-old canopy estimated by growth curve analysis was 6.45, 34.0, and 22.8 ton ha^{-1} yr^{-1} (Table 2), which was calculated by multiplying the annual growth rates of single tree by the tree density (64.5, 89.0, and 52.0 trees 100 m^{-2}), respectively. The derivative values described in Eq. 3 can be substituted for the actual biomass accumulations of the tree in each growth stages.

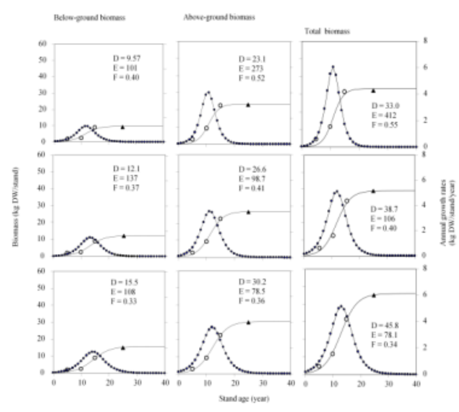

Fig. 2. Growth curves made with both estimated stand biomass, above- and below-ground biomass and total stand biomass in three kinds of stand age in Thanh Hoa, Vietnam. Maximum stand biomass was assumed in three levels, details referred in Materials & Methods. Values of D, E, and F show the parameters of growth curve equation of $Y=D/(1+E \cdot \exp^{-F \cdot s})$, where D is an assumed maximum stand biomass, $E=(D-Y_0)/Y_0$ where Y_0 is an

initial value of stand biomass, s is a stand age, and F is a growth coefficient.

Table 2. Annual biomass accumulation of K. candel trees in Thanh Hoa in growth curve analysis (ton ha^{-1} yr^{-1} in the forest, kg $stand^{-1}$ yr^{-1} in one tree). In table, "Whole" shows the summed value of above- and below-ground biomass.

Growth curve analysis					
	Forest			Tree	
Tree age	Above ground	Root	Whole	Above ground	Whole
15	5.00	1.50	6.50	0.77	1.01
10	26.6	8.50	34.0	2.99	3.82
15	13.6	8.60	22.8	2.62	4.38

Dry weight accumulation of *K. candel* trees in Nam Dinh as a function of time in growth curve analysis was shown in Fig. 3. All the growth curves corresponded well to the dry weights of the single tree measured at different five ages (2, 5, 7 and 10 year-old). Forest biomass per hectare was 265-308 ton ha^{-1}, which was calculated by multiplying the maximum single tree biomass obtained in the growth curves (14.9-17.3 kg DW $tree^{-1}$) by the tree density. Maximum values of annual biomass increment in above-, below-ground and the total tree were 2.23-2.26 kg DW $tree^{-1}$ yr^{-1} at 8 year-old, 0.18-0.19 kg DW $tree^{-1}$ yr^{-1} at 6-11 year-old and 2.51-2.84 kg DW $tree^{-1}$ yr^{-1} at 7-9 year-old, respectively. These values resulted in the maximum value of annual biomass increment per hectare of 54.7±3.51 ton ha^{-1} yr^{-1}. In the growth curve analysis method, averaged values of annual biomass increment at 2, 5, 7 and 10 year-old were 3.44, 13.1, 50.8 and 39.5 ton ha^{-1} yr^{-1}, respectively (Table 3).

By using gas exchange analysis method, net CO_2 fixation capacity was estimated with CO_2 balance between photosynthetic absorption and respiratory emission of CO_2. Although results of the gas exchange estimations are not sufficiently described in this paper, the above-ground values for 3, 4, 5 and 9 year-old *R. apiculata* tree in Trat were 6.33, 36.9, 50.5 and 76.3 ton CH_2O ha^{-1} yr^{-1}, respectively (Fig. 4). Those for 5, 10 and 15 year-old *K. candel* in Thanh Hoa were 71.2, 34.3 and 3.64 ton CH_2O ha^{-1} yr^{-1} and for 2, 5, 7 and 10 year-old *K. candel* tree in Nam Dinh were 35.0, 32.0. 66.0 and 28.6 ton CH_2O ha^{-1} yr^{-1}, respectively.

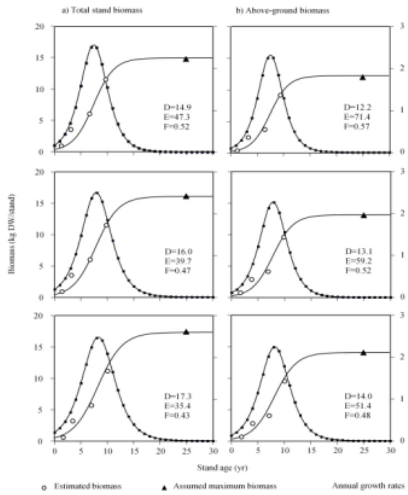

Fig. 3. Growth curves made with both estimated stand biomass, above- and below-ground biomass and total stand biomass in four kind of stand ages of *Kandelia candel* in Nam Dinh, Vietnam. Maximum stand biomass was assumed in three levels, details referred in Materials & Methods. Values of D, E, and F show the parameters of growth curve equation of $Y=D/(1+E \cdot exp^{-F \cdot t})$, where D 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. Comparison of annual biomass accumulation estimated with the growth curves (ton ha^{-1} yr^{-1}) which were drawn using the four kinds of the estimated stand biomass (2, 5, 7 and 10 year-old) of Kandelia candel in Nam Dinh, Vietnam. "D" in the title is the assumed maximum stand biomass (kg DW $tree^{-1}$).

Tree age	Assumed maximum value (D)			
	14.9	16.0	17.3	Average
2	4.62	2.8	2.89	3.4
5	17.0	11.4	11.0	13.1
7	56.6	48.9	47.0	50.8
10	27.6	43.5	47.3	39.5

Discussions

To estimate CO_2 fixation capacity of the monoculture mangrove trees, two analysis methods of gas exchange and growth curve have conducted to develop. Through collecting the data and comparison of the both estimations, the two methodologies have proposed (Okimoto et al. 2007, 2008). This paper shows mainly results of the growth curve estimations, which leads to estimate growth potentials of the monoculture mangrove trees.

Annual biomass increments of this study (Table 1, 2 and 3) were partly higher than the above-ground estimates for *Rhizophora* of 26.7 ton ha^{-1} yr^{-1} in Thailand (Christensen, 1978), 23.6 ton ha^{-1} yr^{-1} in Malaysia (Ong et al., 1995) and 22.9 ton ha^{-1} yr^{-1} in Indonesia (Sukardjo and Yamada 1992). As Komiyama et al. (2007) indicates, the variation in net primary productivity of mangrove species may be related to the geographical location (Clough, 1992), species, stand density and growing season (Aksornkoae, 1993), as well as stand age (Ong et al., 1995).

However, it is appeared in this study that the mangrove monoculture forests in approx. 20° N (the North Vietnam) have growth potential up to around 300 ton ha^{-1} (Fig. 2 and 3). Our study shows growth potential of the monoculture mangrove trees which exceeds that of tropical forest. This suggests that mangrove plantation in the south-east Asia could be a strategic countermeasure of climate change mitigation, and which enforce continuous mangrove plantation activity there.

The T/R ratios obtained in this study were similar with those of the mangrove forest of *Xylocarpus granatum* in Thai, showing 0.95–2.14 (Pongparn et al. 2002) and those of mangrove forests varied between 1.1 (a *Ceriops tagal* stand in Thailand) and 4.4 (a *Sonneratia* stand in Indonesia), and generally was between 2.0 and 3.0 (Komiyama et al., 2007). The above-ground biomass to below-ground biomass (T/R) ratio of mangrove forests was significantly lower than that of upland forests (Komiyama et al., 2007) and mangroves might allocate a great deal of biomass to their roots. It is determined by IPCC (International Panel for Climate Change) methodology of AR-AMS0003, description of root biomass is determined with a default value of 0.1 of the above-ground biomass. Therefore, study of the below-ground root is important for precise estimation by avoiding underestimation of the root biomass of mangrove trees.

Our results of the gas exchange estimations shows that above-ground biomass increment were 66.0 and 34.3 ton ha^{-1} yr^{-1} for 7 and 10 year-old *K. candel* forest in Nam Dinh and Thanh Hoa, Vietnam (21° and 19° N North latitude) and 76.3 ton ha^{-1} yr^{-1} for 9 year-old *R. apiculata* forest in Trat, Thailand (12° N), respectively (Fig. 4). The CO_2 fixation capacity of 34.3 tons ha^{-1} yr^{-1} (13.7 ton C ha^{-1} yr^{-1}) for 10-year-old *K. candel* trees in Vietnam was similar to those of 27 ton ha^{-1} yr^{-1} for 15-year-old *R. apiculata* trees in Thailand (Christensen, 1978) and 14.0 ton C ha^{-1} yr^{-1} for 10-year-old *R. apiculata* trees in Malaysia (Ong, 1993), both of which were calculated by the allometric method. These correspondences show the validity of our developing methodologies and indicate the possibility that our methods could supersede traditional methods of measuring the CO_2 fixation capacity of mangrove trees.

Growth curve estimations can be used as a reference value of net CO_2 fixation capacity estimated by the gas exchange estimations. Okimoto et al. (2008) reported the comparisons of estimated values for *K. candel* tree in Thanh Hoa and indicated some remaining challenges to develop the methodologies as found in the difference of the comparison. In regards to the gas exchange analysis method, for example, it is necessary to involve respiratory CO_2 emission from the below-ground root. As for the growth curve, assumed values of the maximum tree biomass can be replaced to actual value, if some mature tree could be collected, and which improve the growth curve analysis method.

In the current study, these developing methods of estimating CO_2 fixation capacity were applied to the well-managed monoculture forest to test their applicability to various mangrove species grown in Southeast Asia and to enhance their accuracy. Precise evaluation of carbon standing stock in mangrove forests is essential to quantify carbon credits generated by "carbon sink" enhancement forestation projects using CDM and REDD+. In addition to the results shown above, some data for 8-10 year-old *R. apiculata* forest in Sungai Asam, Indonesia (2° S) are under analysis. All analyzed data will be combined to figure out variations of growth potential of the mangrove monoculture forest in different latitudinal areas.

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