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ALLOMETRY AND BIOMASS ACCOUNTING FOR MANGROVES *KANDELIA OBOVATA* SHEUE, LIU & YONG AND *SONNERATIA CASEOLARIS* (L.) ENGLER PLANTED IN COASTAL ZONE OF RED RIVER DELTA, VIETNAM

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ABSTRACT

We estimated carbon stock of mangrove *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler planted in coastal zone of Red River Delta, Vietnam. A total of 84 10 x 10 m sample plots consisting of 39 *K. obovata* at 1-13 years old, 33 *S. caseolaris* at 2-7, 8-13 years old and mixed species of *K. bovata* and *S. caseolaris* at 10-13 years old were established. A tree census was carried out in the sample plots. Diameter at 30 cm above widening base of trunk of all trees were measured. Allometric equations $W_{AG} = 0.000318D^{4.19917}$, $W_{BG} = 0.000431D^{3.56175}$ and $W_{TT} = 0.000596D^{4.04876}$ were used to estimate above ground, below ground and total tree biomass for *K. obovata*. Allometric equations $W_{AG} = 0.04975D^{1.94748}$, $W_{BG} = 0.01420D^{2.12146}$ and $W_{TT} = 0.10316D^{1.85845}$ were used to estimate above ground, below ground and total tree biomass for *S. caseolaris*. Those allometric equations were established from meassurements of 101 *K. obovata* trees and 84 *S. caseolaris* trees. The results indicates that above ground, below ground and total standing tree biomass of *K. obovata* and *S. caseolaris* increased with stand. Standing tree biomass of *K. obovata* was consistenly higher than those of *S. caseolaris* or mixture of both species.

INTRODUCTION

Mangrove forest is an important ecosystem in tropical and subtropical coastal regions. However, this ecosystem is being degraded and damaged in an alarmed rate by human activites, e.g. land use change, unsustainable exploitation or population increase (Ong *et al*., 2004; Phan Nguyen Hong *et al*., 1999). Moreover, the values, including carbon accumulation, of mangroves have not deeply and widely understood. *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler are key species and mainly planted in the coastal provinces of Northern Vietnam, e.g. Hai Phong, Nam Dinh, Thai Binh, Ninh Binh. In the natural development and ecological succession of mangroves, this species and others are grown together in natural mangrove forest (Phan Nguyen Hong *et al*., 1999). Therefore understandings of ecological characteristics, especially biomass and carbon accumation, of this species could significantly contribute to sustainable management of this mangroves.

Sicentists have developed a number of methods to estimate biomass (dry weight) of both inland forest and mangrove forests. Those methods are divided into three categories: 1) the harvest method, 2) the mean-tree method and 3) the allometric method. The harvest method cannot be easily used in mature forests because measuring big trees in these forests are time and human power consuming. Moreover, harvest method is not reproducible because all trees must be destructively harvested. The mean-tree method is utilized only in forests with a relative homogeneous tree size distribution. The allometric method uses allometic equations to estimate the whole and partial weight of a tree from measurable tree dimensions, including trunk diameter and height. This method is useful for estimating temporal changes in forest biomass by subsequent measurements (Komiyama *et al*., 2008). However, the allometric equations are site- and species-specific. As we have known that, only few researchs about allometric equations for *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler were published and cited. Our research presented in this paper is one of the first studies in Vietnam on allometric equations for *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler in

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both total and component biomass. In this paper, we also present the results of applying allometric biomass equations for *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler in biomass accouting for mangroves *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler planted in coastal zone of Red River Delta.

MATERIALS AND METHODS

Study site

The present study was carried out on plantation of *Kandelia obovata* Sheue, Liu & Yong and *Sonneratia caseolaris* (L.) Engler in coastal region of Nam Dinh, Thai Bình and Hai Phong provinces. This coast receives sediments from Red River, Thai Binh River and Van Uc River, thus it is relatively flat with a thick layer of alluvial sediments. The study site is also specified by the diurnal tide, sea level 0.1 - 3.9 m, the temperature of 24°C, the rainfall nearly 1500 mm/year, air humidity of about 82% and salinity 18.0 - 28.3‰.

Materials

A total of 84 sample plots consisting of 39 *K. obovata*, 33 *S. caseolaris* and mixed species of *K. bovata* and *S. caseolaris* were established by stratified sampling method. The study sites was divided into different compartments corresponding to the ages of mangrove stands (*K. obovata* 1 - 13 years, *S. caseolaris* 2 - 7, 8 - 13 years and combination of both species 10 - 13 years). Three sample plots (10 x 10 m) within each compartment were surveyed. In each plot, diameter at 30 cm above widening base of trunk was censused and then converted to tree biomass by allometric equations made from measurements of 185 sample trees consisting of 101 *K. obovata* and 84 *S. caseolaris* located in and around the sample plots. Biomass of a sample plot is total biomass of all trees measured within that plot.

The sample trees were cut down and dug roots in the 2008, 2009 and 2013 to measure the diameter, total and component (above ground, below ground and total) dry weight. Before felling sample trees, we measured and recorded the diameter at 30 cm above widening base of trunk. The sample trees were cut, separated and weight fresh above ground component including stems, branches and leaves, and roots. About 5-10 g samples of each component was subsampled and weighed for its exact fresh weight. The subsamples then were taken to the laboratory and dried to constant weight. The ratio of the fresh weight and dry weight of each subsample was used to calculate the dry weight of each component. Total dry weight of stems, branches and leaves is bove ground biomass. Total biomass of a tree is the sum of the total dry weight of all above ground components and roots.

RESULTS AND DISSUSSIONS

Biomass allometry

Table 1 presents the allometric regressions obtained for total, above ground and below ground biomass of *S. caseolaris* and *K. obovata*. The coefficient of determination (R^2) for both equations are greater than 0.85 indicating that a large proportion (over 85%) of the total biomass could be explained by the diameter at 0.3 m height. However, the errors of estimates (*SE* and *bias*) shows that the equation of *S. caseolaris* fits the data better than the equation of *K. obovata*. Moreover, the regressions fitting the actual data shown in Figure 2 also indicate that the fit was better with *S. caseolaris* than with *K. obovata*. For the trees with diameters less than 5 cm two equations overestimate actual biomass. For the trees with diameters greater than 10 cm *K. obovata* equation also overestimates the actual biomass, but *S. caseolaris* equation results in the better estimates. *K. obovata* equations has coefficient of determination (R^2) of around 79% indicating that about 79% of the trunk biomass could be explained by the diameter.

Table 1. Total (TT), above ground (AG) and below ground (BG) biomass allometriy

Species	Equation	D (cm)	N	R^2	*SSE*	*bias*
S. caseolaris	$W_{TT} = 0.000596D^{4.04876}$	0 – 18	84	0.96	14.34	0.86
	$W_{AG} = 0.000318D^{4.19917}$	0 - 18	84	0.95	11.88	0.90
	$W_{BG} = 0.000431D^{3.56175}$	0 – 18	84	0.97	0.38	0.05
K. obovata	$W_{TT} = 0.10316D^{1.85845}$	0 – 14	101	0.86	113.43	-0.07
	$W_{AG} = 0.04975D^{1.94748}$	0 - 14	101	0.79	71.85	-0.06
	$W_{BG} = 0.01420D^{2.12146}$	0 - 14	101	0.73	19.34	-0.01

Table 2. Total stand biomass of *K. obovata* at different stand age

Age	Diameter (cm)	Tree height (m)	Biomass (tons/ha)		
			Above ground	Below ground	Total
1	1.25 ± 0.25	0.60 ± 0.18	1.69 ± 0.52	0.46 ± 0.56	2.15 ± 1.15
2	2.15 ± 0.09	1.10 ± 0.12	15.11 ± 1.95	7.31 ± 0.86	22.42 ± 1.80
3	4.52 ± 0.07	1.32 ± 0.22	39.43 ± 3.08	12.75 ± 0.85	52.18 ± 2.70
4	4.89 ± 0.58	1.61 ± 0.78	44.78 ± 2.57	15.04 ± 1.03	59.82 ± 2.79
5	6.25 ± 0.55	2.57 ± 0.42	45.85 ± 1.75	11.73 ± 0.55	57.58 ± 1.62
6	5.82 ± 0.75	2.08 ± 0.87	54.40 ± 2.30	15.72 ± 1.31	70.13 ± 2.59
7	6.38 ± 0.96	2.89 ± 0.56	51.92 ± 1.78	13.90 ± 0.69	65.82 ± 1.98
8	6.56 ± 0.45	3.12 ± 0.69	57.46 ± 1.86	14.61 ± 0.85	72.32 ± 2.15
9	6.81 ± 0.25	3.35 ± 0.67	63.70 ± 1.05	18.56 ± 0.25	82.26 ± 1.96
10	6.99 ± 0.12	3.48 ± 0.55	67.92 ± 2.41	13.32 ± 0.34	81.25 ± 2.41
11	7.56 ± 0.35	3.99 ± 0.75	77.59 ± 1.61	14.22 ± 0.55	91.80 ± 1.69
12	8.12 ± 0.62	4.02 ± 0.55	97.19 ± 1.55	16.03 ± 0.48	113.22 ± 1.63
13	9.67 ± 0.88	4.19 ± 0.75	122.88 ± 3.85	15.38 ± 0.47	138.27 ± 3.88

However, about 95% of *S. caseolaris* trunk biomass could be explained by the diameter. *SSE* and *bias* also show that *S. caseolaris* equation fits the actual data better than the *K. obovata* equations because *SSE* and *bias* for the *S. caseolaris* equation are 11.88 and 0.90, while the values for *K. obovata* equation are 71.85 and -0.06 respectively. The graphs of trunk biomass against diameter of actual and two fitted models (Figure 2) also supports above observations.

The results indicates that a rather small proportion of about 73% of root biomass of *K. obovata* and about 97% of root biomass of *S. caseolaris* could be explained by diameter (coefficient of determination (R^2) for *K. obovata* and *S. caseolaris* equations are 0.73 and 0.97 respectively). Errors of estimate (*SSE* and *bias*) (Table 1) and graphs of below-ground biomass against diameter of actual and two fitted models (Figure 2) show that the *K. obovata* equation does not fit the actual data better than the *S. caseolaris* equation.

Table 3. Total stand biomass of *S. caseolaris* at different stand age

Age	Diameter (cm)	Tree height (m)	Biomass (tons/ha)		
			Above ground	Below ground	Total
2	6.21 ± 0.39	2.71 ± 0.18	5.59 ± 0.54	2.22 ± 0.66	7.81 ± 0.99
3	7.74 ± 0.37	3.47 ± 0.15	12.37 ± 0.45	4.58 ± 0.43	16.95 0.53
4	9.21 ± 0.39	3.81 ± 0.12	19.37 ± 0.72	8.30 ± 0.23	27.67 ± 0.69
5	11.30 ± 0.37	4.09 ± 0.06	36.61 ± 1.51	10.49 ± 0.76	47.10± 1.55
6	11.82 ± 0.53	4.86 ± 0.23	38.70 ± 1.08	12.05 ± 0.94	50.75 ± 1.37
7	12.83 ± 0.61	5.64 ± 0.22	54.75 ± 2.14	14.67 ± 0.63	69.42 ± 2.28
9	14.84 ± 0.29	5.93 ± 0.02	50.37 ± 0.66	12.90 ± 0.43	63.27 ± 0.69
10	15.38 ± 0.16	6.02 ± 0.09	50.40 ± 1.81	11.57 ± 0.70	61.97 ± 2.00
11	15.89 ± 0.25	6.15 ± 0.12	58.77 ± 2.73	13.08 ± 0.75	71.86 ± 2.99
12	15.79 ± 0.28	6.21 ± 0.15	68.09 ± 1.49	13.94 ± 0.46	82.03 ± 1.74
13	16.72 ± 0.24	6.30 ± 0.22	71,17 ± 2.25	14.48 ± 0.96	85.65 ± 2.78

Table 4. Total stand biomass of mixed species of *K. obovata* and *S. caseolaris* at different stand age

Age	Species	Diameter (cm)	Tree height (m)	Biomass (tons/ha)		
				Above ground	Below ground	Total
10	*K. obovata*	5.42 ± 1.08	1.54 ± 0.55	26.34 ± 0.54	6.64 ± 0.26	50.79 ± 3.68
	S. caseolaris	12.89 ± 0.86	3.86 ± 0.42	15.37 ± 0.43	2.44 ± 0.22	
11	*K. obovata*	5.75 ± 0.80	1.65 ± 0.86	25.53 ± 0.84	5.83 ± 0.17	38.29 ± 3.80
	S. caseolaris	15.43 ± 0.55	4.45 ± 0.62	6.00 ± 0.25	0.92 ± 0.04	
12	*K. obovata*	6.12 ± 0.46	2.05 ± 0.48	48.97 ± 0.15	10.38 ± 0.12	73.92 ± 4.09
	S. caseolaris	18.24 ± 0.29	4.49 ± 1.02	12.62 ± 0.19	1.95 ± 0.15	
13	*K. obovata*	6.56 ± 0.16	3.59 ± 0.25	63.36 ± 2.27	13.06 ± 0.84	93.84 ± 5.33
	S. caseolaris	23.11 ± 12	4.53 ± 0.15	14.69 ± 0.08	2.22 ± 0.12	

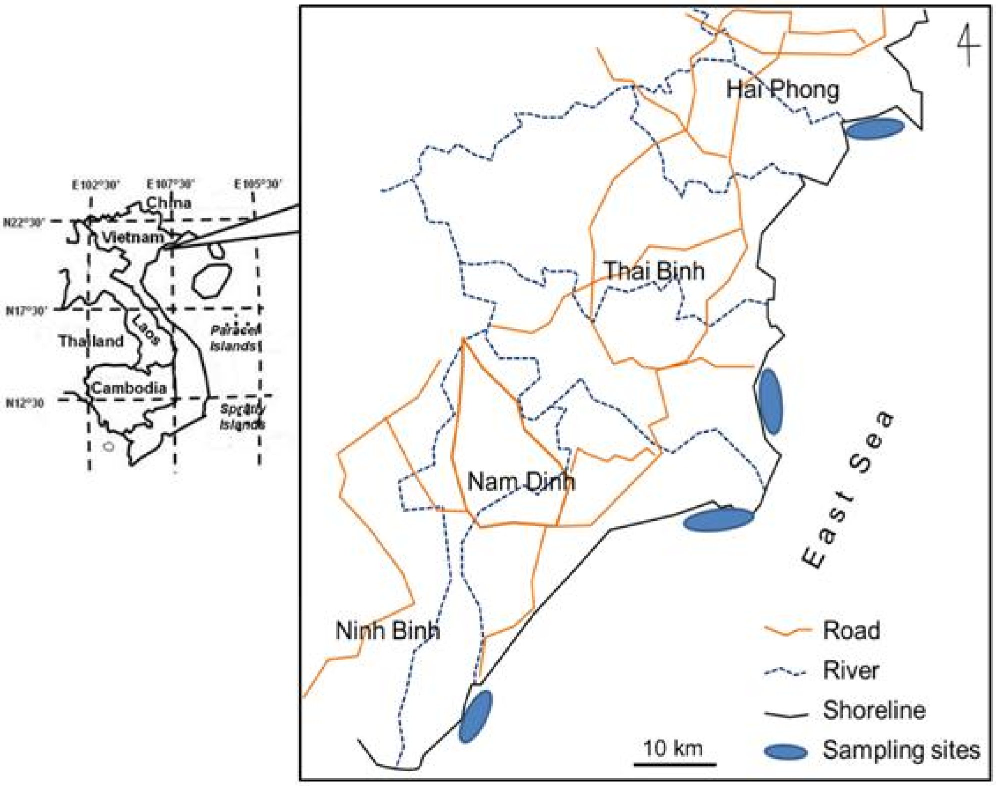

Figure 1. Location and map of study site

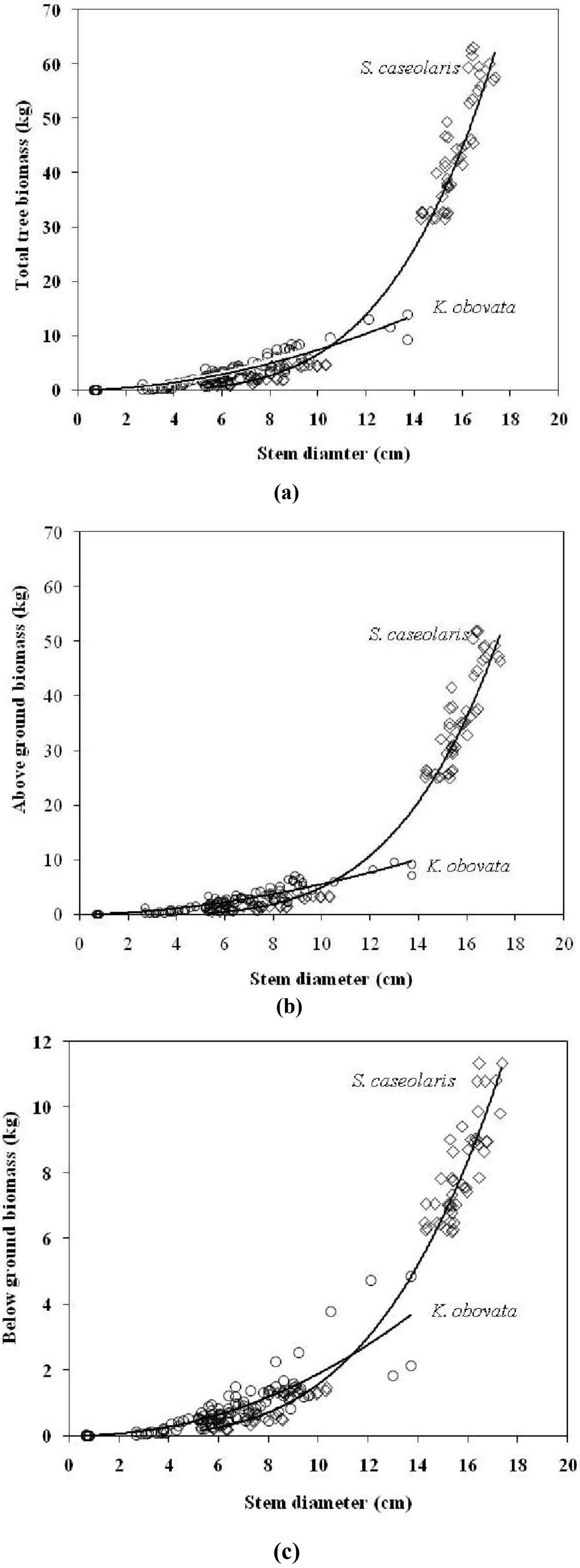

Figure 2. Total (a), above ground (b) and below ground (c) biomass against diameter of actual and fitted models

The coefficients of determination (R^2) for the allometric equations developed for *K. obovata* and *S. caseolaris* of about 0.73 - 0.97 and small errors of estimate (bias $\leq$ 0.86) for all of obtained equations confirmed the earlier observations that power curve or allometric function ($y = bx^k$) can accurately describes the relationships between biomass and stem diameter (Whittaker and Marks, 1975) and those relationships can be used to correctly estimate the biomass of trees from stem diameter in the mangrove species (Ong *et al*. 1995; Putz and Chan, 1986).

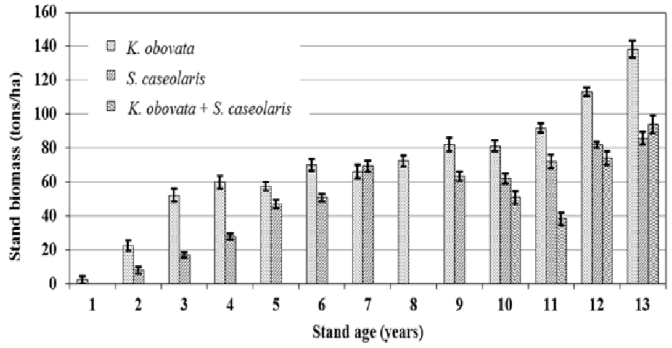

Figure 3. Total stand biomass of mangrove plantations by species and age

However, it is noticed that regression models vary between species, different localities and depending on site-specific factors such as tree density, management practices and whether it is a monoculture or mixed forest. The regression equations derived in this study for the mangrove plantations may not be appropriate for open natural mangroves. This study also confirmed that the allometric constants (b and k) of allometric equations for mangroves could be directly determined by using statistical software (e.g. JUMPIN). The allometric equations directly developed by non-transformation with a statistical software could also fit the actual data better than the log-transformed equations. Baskervilles (1972) and Whittaker and Marks (1975) explained the inefficiency of log-transformation approach. They concluded that the logarithmic transformation requires input data to be converted from arithmetic form to logarithmic form, and the input data convertion generates errors. The amount of errors is proportional to the magnitude of converted values.

Standing tree biomass

Biomass values for the different components of the mangrove stands by species and their age are presented in Table 2-4. The results indicates that total and component standing tree biomass of *K. obovata* and *S. caseolaris* increased with stand age. This age-dependent increase in total and component standing tree biomass has also been observed in mixed species of *K. obovata* and *S. caseolaris* although the measurements were limmited in 10, 11, 12 and 13 year old stands. The results in Table 2-3 also indicated that the proportion of above ground biomass in *K. obovata* and *S. caseolaris* stands increased with stand age. As compared with the study of Hoque *et al*. (2010), above ground biomass of *K. obovata* in Northern Vietnam was greater than that in Mako Wetland (Okinawa, Japan) for 13 year old stands. The opposite result was found for below ground biomass. Our results of above ground and below ground biomass were 138.27 tons/ha, 122.88 tons/ha and 15.38 tons/ha respectively while Hoque *et al*. (2010) reported that above ground and below ground biomass were 109.28 tons/ha, 51.08 tons/ha respectively. The comparison of biomass of different species stands indicated that stand biomass of *K. obovata* was consistenly higher than those of *S. caseolaris* or conbination of both species. At about 7 year old, plantations of *K. obovata* and *S. caseolaris* had almost same biomass level, 65.82 tons/ha and 69.42 tons/ha respectively. After that biomass of *K. obovata* increased significantly while biomass of S. caseolaris slowly changed age by age (Figure 3). Although differences in growth rate among *K. obovata, S. caselaris* and mixed species may be the main criterion for selecting species for production mangroves in a particular area, the results shown in Figure 3 provide information that might be useful in selecting the species for mangrove plantation.

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