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Biomass and carbon stock of mangrove forest in coastal area of Thai Binh province, Vietnam

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Abstract

The quantitative evaluation of biomass and carbon stock in mangroves of Thaibinh province does not only contribute to the protection and development of the coastal forest system, and the biodiversity conservation for Red River delta biosphere reserve, but it is also needed for orientation purposes when participating in the carbon market, raising the importance of mangroves in local socio-economic development. The biomass and carbon stored in mangroves are mainly quantified by the following methods: plot surveys, tree sampling, laboratory analyses for determining biomass and carbon content in the samples and modeling the relationship between tree parameters, biomass and carbon contents. The results show that the mangrove species in the study area are mainly *Sonneratia caseolaris, Bruguiera gymnorohiza*, *Kandelia obovata* and *Aegiceras corniculatum*, planted from a long time ago until present, having an average diameter at breast height of 10.69 cm and an average height of 4.66 m. The most suitable bivariate correlation models are: exponential functions for dry biomass or carbon content - diameter at breast heights; quadratic polynomial function for dry biomass or carbon content - tree heights. The correlation functions representing the relationship between dry biomass or accumulated carbon with both diameters at breast height and height of tree are highly consistent with the anatomy data of the samples, so it could be applicable for the whole study area. The entire mangrove in Thai Binh coastal area is estimated approximately 68,000 tons of dry biomass, 34,000 tons of stored carbon and valuated of US $1,373,000for carbon sequestration. This is a significant value for forest managers, especially for the local habitants managing community forests.

Keywords: ***biomass, mangroves, carbon stock, CO_2absorption, Thaibinh***

1. Introduction

Forests play a critical role in the Earth's climate system, in a number of different way. Most importantly for global climate change, they capture CO_2 from the atmosphere, convert it into living biomass (stems, roots, branches and leaves) through photosynthesis and store large amounts of carbon in forest soils, absorbed through leaf litter, wood debris and roots (Brack, 2019). The estimates of carbon stored in forest ecosystems in the world vary significantly. In 2000, the Intergovernmental Panel on Climate Change (IPCC) estimated the total amount of1,100 gigatons (Gt)(Watson *et al*., 2000), which is 1.3 times greater than the carbon stored in fossil fuels (estimated at 800 Gt) and much larger than carbon released into the atmosphere from human activity since 1870 (about 600 Gt) (Federici *et al.*, 2018). FAO (2010) yielded lower value of about 652 Gt, including 44%, 5%, 6% and 45% in live biomass, dry biomass, garbage and forest soils respectively. Therefore, a large amount of CO_2 will be released into the atmosphere from global deforestation. At the United Nations Climate Change Conference in Indonesia in December 2007, 187 member countries signed the Bali Agreement which outlined the program " Reducing Emissions from Deforestation and Forest Degradation”(REDD), with the aim to limit the destruction of tropical forests.Many countries will meet some of their emission reduction targets through the purchase of carbon credits of developing countries made available by CO_2 absorption by forests (United Nations Framework Convention on Climate Change - UNFCCC, 2007). Thus, the problem posed here is to quantify the amount of CO_2 stored by forest ecosystems in developing countries, including Vietnam. This work, first of all, requires identifying the biomass and carbon accumulated in these forests.

Forest biomass can be estimated bythe correlation functions relating biomass and dimensions of tree or its components (Whittaker and Woodweel, 1968). In recent years, many quantitative methods and models of forest biomass prediction have been applied using the correlation between tree biomass and basic and easily measurable factors such as: diameter at breast height ($D_{1.3}$), tree height (H), trunk circumference, branches, roots, leaves, etc. These models help to calculate biomass faster and more accurately, with less cost. The CO_2 absorption of forest ecosystems is generally determined by following methods: (i) Direct measurement of physiological processes controlling carbon balance in forest ecosystems (Botkin*et al.*, 1970; Woodwell, 1970); (ii) Based oneddy correlation analysis for quantifying net ecosystem exchanges of carbon dioxide (Wofsy*et al.*, 1993); (iii) Based on mathematical equations presenting the relationship between biomass, carbon stock and treedimensions (Grier*et al.*, 1989; Hunter *et al.*, 2013; Ostadhashemi *et al.* 2014); (iv) Use remote sensing data and GIS techniques in combination with basic forest inventory data (Patenaude *et al.*, 2004, 2005; Myeong *et al.*, 2006; Jeyanny *et al.*, 2014; Vicharnakorn *et al.*, 2014; Bindu *et al*., 2018).

In Vietnam, biomass and forest productivity have also been studied for different tree populations such as Rhizophora (Hoang Manh Tri, 1986; Dang Trung Tan, 2001), *Pinus kesiya*(Le Hong Phuc, 1996), *Acacia auriculiformis* (Vu Van Thong, 1998). Since the adoption of Clean Development Mechanism (CDM), there has been new opportunity for the forestry study with an increasing and diverse quantity. Forest biomass was determined by statistic tabular of growth process and biomass (Nguyen Ngoc Lung and Nguyen Tuong Van, 2004), by age and species (Nguyen Tuan Dung, 2005; Vu Tan Phuong, 2006; Vo Dai Hai *et al.*, 2009; Dang Thinh Trieu, 2010), and by mathematical correlation between biomass and surveyed factors in forest stands such as stem diameter, height and age (Vo Dai Hai *et al.*, 2009). Each type of forest and its quality have different carbon sequestration capabilities (Vien Ngoc Nam; 2009; Dao Thi Ngoc Diep, 2015; Nguyen Ha Quoc Tin *et al*.,2015). Carbon sequestration in these studies is based on the relationship between carbon storage and basic parameters such as diameter, height, density, age, etc. The absorbed $CO_2$is also valuated by Hoang Xuan Ty (2004), Pham Tuan Anh (2007).

In general, it can be clearly seen that forest biomass and stored carbon have been studied, but incomprehensively for all typical ecosystems in Vietnam. Most of the studies focused on forest ecosystems in hilly and mountainous areas or mangroves in the coastal plain of southern Vietnam. Determining biomass and carbon stocks in mangrove ecosystem of Thai Binh province, belonging to the coastal zone of the Red River Delta, not only fulfills study for lacking area but also contributes to the protection and development of this ecosystem, orienting to participate into the carbon market,increasing the importance of mangroves in local socio-economic development, thereby raising awareness of mangrove protection in the strategy dealing with climate change, simultaneously contributes to biodiversity conservation for the Red River Delta Biosphere Reserve.

2. Study area

The coastal area of Thai Binh province is located in Thai Thuy and Tien Hai districts (Figure 1), considered one of the areas rich in biodiversity and strongly affected by climate change. Its population is estimated approximately 458,700 people with a density of 917 perkm^2 (Thai Binh Statistical Office, 2016).

The climate in this area is a tropical monsoon with annual average temperature about 22-24ºC. July is the hottest month with the mean of 29.1ºC and January is the coldest with value 16.7ºC. The precipitation of 1,658 mm/year unevenly distributes among the months of the year. Rainy season, from May to September, accounts for 70 - 80% of annual total. The rest time, from October to April, usually has average monthly rainfall below 100 mm, resulting in water shortage. From May to November, especially in August, the area is hit by typhoons and depressions, coming from the East Sea (South China Sea) with an average frequency of 2.1 times/year.

Four major rivers (Thai Binh, Diem Ho, Tra Ly and Red rivers), flowing through the study area to the sea, have complicated hydrological regime due to the influence of both Red and Thai Binh river systems. In general, there are two distinct seasons: the flood season, from June to October, accounts for 75 - 80% of the total annual flow; the dry, from November to May, accounts for 20-25% of the total.

The wave regime, controlled by prevailing wind, has the directions: northeast in offshore area and northeast, east or southeast in coastal area for the winter; south in off shore area and southeast or south in coastal area for the summer. On the coast, winter waves can reach 0.4 - 0.9 m height in average and 3.0 m maximum; the summer waves are 0.7 to 1.2 m of average height and 6 m highest. Influenced by storms and tropical cyclones, the large waves in winter are more frequent than in summer. The diurnal tide with a high amplitude in relief of gentle slope creates a considerably large tidal flats with a width of 4-5 km, even 7-8 km in Thai Binh estuary, favoring mangrove development for the study area.

Developed on Holocene unconsolidated sands, silts and clays, the relief of study area is relatively flat and low. The river-sea interaction produces following landforms: river channels and floodplains, delta plains, ancient sandy dunes, high and low tidal flats, mouth bars. Among them, high and low tidal flats are the terrain suitable for mangrove development. Statistically, there are 13 soil types of sandy, saline, acid sulfate and alluvial groups in the area. Among them, the high, medium and low saline and tidal flat soils, related to mangrove forest, occupy 22,058.47 ha accounting for 37.23% of the total natural area of Tien Hai and Thai Thuy districts (Luu The Anh, 2016).

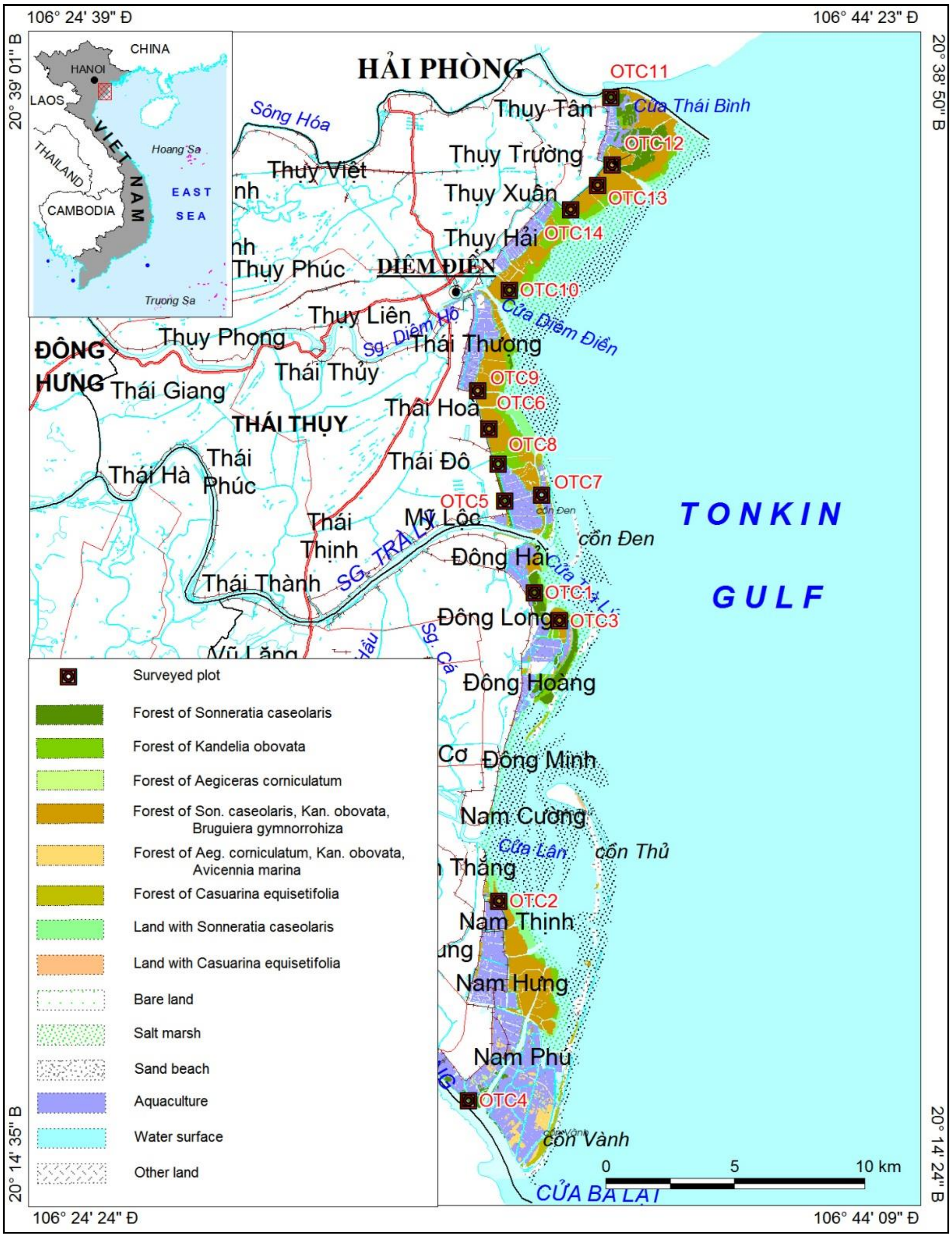

Fig. 1 Study area and surveyed plots

The total coastal forest of Thai Binh province occupies 3,899.1 ha, including 3,709.1 ha mangroves, in 10 communes and towns of the two districts Thai Thuy and Tien Hai(Thai Binh Department of Agriculture and Rural Development - TBDARD, 2015). Mangroves are mainly pure or mixed planted forests: *Sonneratia caseolaris, Kandelia obovata,Aegiceras corniculatum, Son. Caseolaris - Kan. Obovata - Bruguiera gymnorohiza, Aeg. Corniculatum - Kan. Obovata - Avicennia marina*(Figure 1). Communities of*Avicennia marina* and *Kandelia obovata*are commonly distributed in the outermost area with high salinity and deep water. *Sonneratia caseolaris*, *Kandelia obovata*, and*Aegiceras corniculatum* are situated in moderately submerged area. The community with dominance of *Sonneratia caseolaris*and underbrush*Acanthus ilicifolius*is mainly found in the estuarine area (Tran Van Thuy *et al.*, 2016). In Thai Thuy district, there are more than 2000 hectares of mangroves concentrated in 5 communes: Thuy Truong, Thuy Xuan, Thuy Hai, Thai Phuong and Thai Do. An inventory in Thuy Truong shows that there are 38 plant families including 111 species in which 12 species are true mangroves and 30 others are mangrove associates (Nguyen Thi Kim Cuc and Dao Van Tan, 2004). In Tien Hai district, mangroves are distributed mainly in five communes: Nam Thinh, Nam Hung, Nam Phu, Dong Long and Dong Hoang, in which the first three belong to Tien Hai Wetland Nature Reserve occupying an area of 1450 ha. This Reserve has: 11 species of true mangroves, including 1 of ferns and 10 of angiosperms; and 37 species of mangrove associates, including 17 of monocotyledons and 20 of dicotyledons of angiosperms (Mai Sy Tuan *et al.*, 2008). Outside the reserve such as in Dong Long, the flora has quite high diversity with 66 species of 33 families, whose 8 species are true mangroves and 19 others are mangrove associates (Doan Dinh Tam, 2013). For whole coastal zone of Thai Binh, there are 14 species of true mangrove in the communities of natural forest, planted forest, aquaculture ponds and new-land pioneer as follows(Tran Thi Thuy Van *et al.*, 2017):

- 01 species of fern: *Acrostichum aureum* L.

- 12 species of dicotyledons belonging to angiosperms:*Acathus ebracteatus* Vahl, *Acathus ilicifolus* L., *Sensuvium portulacastrum* L, *Avicennia marina* (Forsk) Veirh), *Lumnitzera racemosa* (Gaud.) Presl., *Derris trifoliata* (Benth) Barker, *Excoecaria agallaocha* L, *Aegiceras corniculatum* (L.) Blanco, *Bruguiera gymnorohiza* (L), *Kandelia obovata* Sheue Liu & Yong,*Rhizophora stylosa* Griff.and *Sonneratia caseolaris* (L.) Engl.

- 01 species of monocotyledons belongs to angiosperms: *Cyperus stoloniferus* Retz.

3. Data and methods

3.1. Field survey

The key plotsare selected on the basis of topographic features and current status of mangroves in the study area (Figure 1). These plots must meet the requirements such as representatives for the forests which are surveyed on (dominant) mangrove species, distribution area, status, structure and density of trees. In the study area, 14 plots are selected with sizes of 100 m^2 (10m x 10m), 500 m^2 (25m x 20m) or 2,500 m^2 (50m x 50m) depending on the present status of mangrove.

In each plot, survey work was conducted: statistics of the number of trees, measurement of Diameter at Breast Height (DBH), i.e. at 1.3m, and height of all trees, species identification(Vietnamese name and scientific name), abnormal characteristics of trees (banyan tree, buttress tree, diameter of buttress, buttress height, etc.) and measurement of fresh biomass of sampled tree.

The selected sample trees are representative for key plots. A total of 31 trees are sampled for laboratory analysis. However, *in situ* identification of sampled trees is carried out and precise measurements are also done for their fresh biomass, diameter at the stump (position 0.0 m), DBH, stem length (from the stump to the highest), height below the branches (from the position 0.0 m to the main branching point of the tree), trunk length from the base (position 0.0 m) to the point of10 cm diameter; buttress height and diameter, etc. After all, the sampled trees are separated into their parts such asthe trunk, branches, leaves, roots and buttress (if present), which are then weighted for biomass estimation.

After the fresh weighting, samples for laboratory analysis are taken immediately with4 samples representing stem, branch, leaf and root for each tree. Stem is sampled by taking 2 - 3 cutting boards or radial cutting boards (if the tree is large) with a mass accounting for 0.2% of fresh stem. Branch sample is takenwith 4 small cutting boards, weighted of 0.5 - 1.0 kg in total. All samples are packed in plastic bags and tied tightly to prevent evaporation.

3.2. Carbon analysis in tree samples

Samples taken from roots, stems, branches and leaves of mangroves are dried at 70^oC for estimating dry mass and moisture content. These dry samplesare grinded to the size through 0.2mm sieve for analysis. The organic carbon content is determined by Walkley Black method specified in Vietnam Standards (TCVN 9294: 2012).

3.3.Mathematical modeling

Based on the anatomical data of tree samples, the mathematical modelsare used to quantify the relationship between tree parameters such as diameter at breast height (D) and height (H) on the one hand, tree biomass (M) or carbon stored in tree (C) on the other hand. Two-dimensional models showing the correlation between biomass or carbon with one of the two parameters of a tree, diameter or height, are usually expressed as functions such as exponential ($y = Ae^{Bx}$), linear ($y = Ax + B$), logarithms ($y = A\ln x + B$), quadratic polynomials ($y = Ax^2 + Bx + C$) and powers ($y = Ax^B$). The three-dimensional model shows the correlation between biomass or carbon and both tree parameters (diameter and height) as two-variable function: $y = Ax_1 + Bx_2 + C$. The model suitability is assessed by coefficient of determination R^2.

$$R^2 = 1 - \frac{SSres}{SStot} = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Where, SSres is residual sum of squares; SStot is total sum of squares; y_i is the measured value; $\bar{y}$ is the mean of y_i; f_i is mathematically calculated value.

R^2 ranges from 0 to 1; It is closer to 1, the model is more suitablefor the data, normally $R^2$the model is acceptable if $R^2 \geq 0.5$.

4. Results and discussion

4.1.Results of plot survey

Detailed surveys are conducted on all 14 plots occupying 10600 m^2 in the study area (Table 1). 700 trees counted in these plots have mean values of 10.69 cm and 4.66 m for DBH and height respectively. Plot 11, *Sonneratia caseolaris* forest in Thuy Truong commune (Thai Thuy district, is the largest mean DBH (19.19 cm). The smallest mean DBH with value of 5.88 cm is Plot 7, a recently planted forest of *Sonneratia caseolaris* - *Kandelia obovata* - *Bruguiera gymnorohiza*in Con Den (Tien Hai district). In terms of average height for each plot, Plot 6 is the highest (9.11m)and Plot10 is the lowest (3.11m). The highest density is Plot 3 (7600 trees per ha) and the lowest is Plot 12 (100 trees per ha). In general, the older forests have mean DHB and height higher than the overall average because they have long time for growing their dimensions. The high densityis statistically related to forests having mean DHB and height lower than the overall average. These forests may be planted on a large scale recently.

Table 1. Survey results in key plots

Plot	**Dominant trees**	**Length x Width** (m)	**Area** (m^2)	**Tree Quantity**	**Mean Diameter**(cm)	**Mean Height**(m)	**Density** (trees/ha)
1	*Son.*	25 x 20	500	92	10.45	5.65	1840
2	*Son.,Kan.,Bru.*	25 x 20	500	40	11.24	4.79	800
3	*Son., Kan.,Bru.*	10 x 10	100	76	7.92	3.74	7,600
4	*Son.*	25 x 20	500	82	15.62	5.88	1,640
5	*Son.*	25 x 20	500	103	8.27	3.83	2,060
6	*Son., Kan.,Bru.*	10 x 10	100	9	14.85	9.11	900
7	*Son., Kan.,Bru.*	10 x 10	100	67	5.88	3.90	6,700
8	*Kan.*	10 x 10	100	21	9.02	4.71	2,100
9	*Son., Kan.,Bru.*	50 x 50	2,500	32	11.31	3.96	128
10	*Son., Kan.,Bru.*	10 x 10	100	54	7.96	3.11	5,400
11	*Son.*	10 x 10	100	14	19.19	8.64	1,400
12	*Son., Kan.,Bru.*	50 x 50	2,500	25	16.42	5.72	100
13	*Son., Kan.,Bru.*	50 x 50	2,500	36	14.66	5.00	144
14	*Son., Kan.,Bru.*	25 x 20	500	49	12.65	4.29	980
	Overall		**10,600**	**700**	**10.69**	**4.66**	**660**

Note:*Son.* - *Sonneratia caseolaris*; *Kan.* - *Kandelia obovata*;*Bru.* – *Bruguiera gymnorohiza*

4.2. Biomass and carbon stocks in mangrove trees

Biomass and carbon storage are determined for 31 sample trees with DBH from 5.41 cm to14.01 cm and height from 1.5 m to 5.5m (Table 2). The analytical results show that the dry biomass of sample trees ranges from 4.34 kg to 43.65 kg, the carbon accumulated in tree ranges from 2.18 kg - 21.83 kg. In general, biomass and accumulated carbon increase with the growth of tree, i.e. the increase of DHB and height. The smallest tree (tree 8 inTable 2) has lowest dry biomass and carbon content; and vice versa, the trees with largest size (trees 29, 31 inTable 2) are also the ones with the highest dry biomass and carbon content.

Table 2. Dry biomass and accumulated carbon of sampled trees

Tree	Parameters		Dry biomass (kg)					Accumulated carbon (kg)				
	D (cm)	**H** (m)	**Trunk**	**Branch**	**Leaf**	**Root**	**Total**	**Trunk**	**Branch**	**Leaf**	**Root**	**Total**
1	10.98	3.9	9.50	11.03	3.74	1.89	26.16	4.75	5.52	1.87	0.95	13.09
2	11.14	4.2	13.82	10.8	4.5	1.85	30.97	6.91	5.4	2.25	0.93	15.49
3	5.57	1.5	2.93	1.89	1.08	0.95	6.85	1.47	0.95	0.54	0.48	3.44
4	10.98	4.5	15.26	4.32	3.15	1.4	24.13	7.63	2.16	1.58	0.7	12.07
5	8.59	3.0	4.55	7.34	2.93	1.53	16.35	2.28	3.67	1.47	0.77	8.19
6	6.68	1.8	3.56	4.19	3.02	1.44	12.21	1.78	2.1	1.51	0.72	6.11
7	5.57	1.6	3.24	1.04	0.59	0.5	5.37	1.62	0.52	0.3	0.25	2.69
8	5.41	1.5	2.93	0.68	0.5	0.23	4.34	1.47	0.34	0.25	0.12	2.18
9	10.03	3.5	9.00	10.35	3.6	1.67	24.62	4.5	5.18	1.8	0.84	12.32
10	11.94	4.1	13.95	11.25	4.95	2.03	32.18	6.98	5.63	2.48	1.02	16.11
11	7.96	2.5	5.85	3.6	1.8	0.77	12.02	2.93	1.8	0.9	0.39	6.02
12	11.62	4.5	15.30	4.5	3.6	1.58	24.98	7.65	2.25	1.8	0.79	12.49
13	8.91	2.9	4.95	7.65	3.15	1.53	17.28	2.48	3.83	1.58	0.77	8.66
14	7.00	2.0	4.05	4.5	3.15	1.49	13.19	2.03	2.25	1.58	0.75	6.61
15	6.05	1.9	3.24	1.04	1.04	0.59	5.91	1.62	0.52	0.52	0.3	2.96
16	11.94	4.5	15.98	5.18	3.38	1.62	26.16	7.99	2.59	1.69	0.81	13.08
17	9.87	4.0	9.90	10.8	3.15	1.53	25.38	4.95	5.4	1.58	0.77	12.7
18	12.73	4.2	15.30	11.25	4.05	2.12	32.72	7.65	5.63	2.03	1.06	16.37
19	6.37	2.0	3.15	2.25	1.35	0.54	7.29	1.58	1.13	0.68	0.27	3.66
20	10.19	3.7	13.95	3.15	2.25	1.08	20.43	6.98	1.58	1.13	0.54	10.23
21	10.50	3.4	9.00	7.2	4.95	2.16	23.31	4.5	3.6	2.48	1.08	11.66
22	6.37	1.7	3.56	4.19	3.02	1.49	12.26	1.78	2.1	1.51	0.75	6.14
23	6.68	2.1	4.05	2.25	1.35	0.77	8.42	2.03	1.13	0.68	0.39	4.23
24	10.66	4.6	14.63	11.7	4.5	2.12	32.95	7.32	5.85	2.25	1.06	16.48
25	11.94	4.4	11.25	12.6	4.5	2.07	30.42	5.63	6.3	2.25	1.04	15.22
26	12.57	4.1	13.05	10.35	4.05	1.89	29.34	6.53	5.18	2.03	0.95	14.69
27	8.28	2.6	5.85	3.83	2.25	1.04	12.97	2.93	1.92	1.13	0.52	6.5
28	11.46	4.8	16.16	5.22	4.05	2.03	27.46	8.08	2.61	2.03	1.02	13.74
29	14.01	5.1	9.90	14.85	5.85	2.12	32.72	4.95	7.43	2.93	1.06	16.37
30	9.87	3.8	7.11	8.37	6.03	2.16	23.67	3.56	4.19	3.02	1.08	11.85
31	13.69	5.5	13.5	4.14	23.4	2.61	43.65	6.75	2.07	11.7	1.31	21.83

4.3 Correlation between biomass and tree dimension

Anatomical analysis data of 31 sample trees on diameter at breast height (D), height (H) and dry biomass (M) (Table 2) allow to establish quantitative relations between them according to different mathematical models: exponential, linear, logarithmic, polynomial and power (Figure 2). These functions all show an increase of M as D or H increases but in different degrees.

Linear and quadratic polynomial functions have similar forms; power functions and especially exponential functions usually increase more slowly at first and then increase faster than linear functions; where as logarithmic functions usually increase faster at first and then increase more slowly than linear functions. The important thing here is to choose the model best fitting the anatomical data. This is solved by comparing their coefficient of determination R^2.

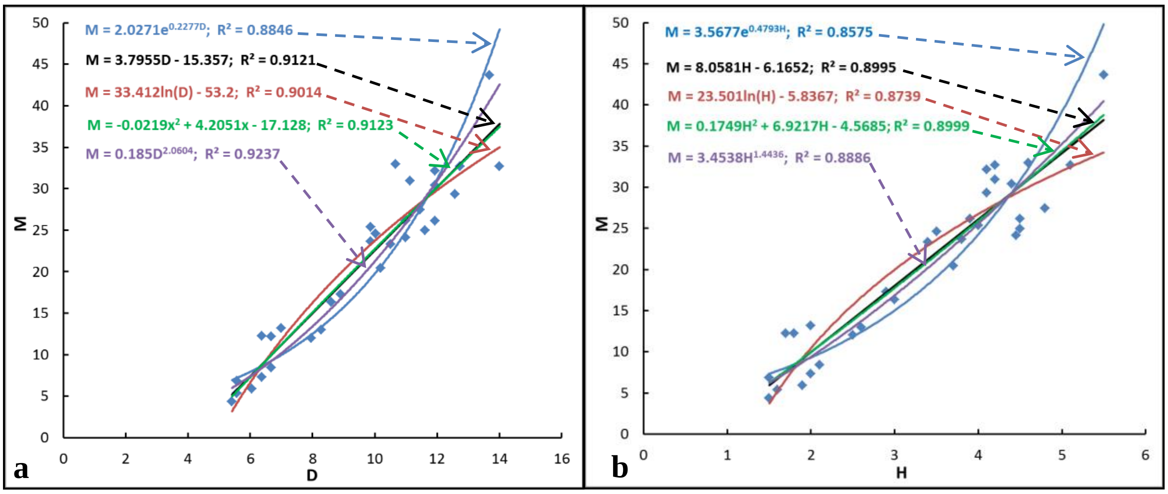

Fig.2 Regressions correlating biomass (M) with: a- DBH(D) or b- height (H)

In terms of M - D relationship, all five given models, expressing in exponential, linear, logarithmic, polynomial or power functions, are acceptable because of relatively high R^2, from 0.88 to 0.92(Figure 2a). Among them, the power function, $M = 0.185D^{2.0604}$, has the highest determination coefficient (R^2 = 0.92), so it is most suitable for the analytical data. This means that the tree biomass increases slowly at first, then increases rapidly as the DBH increases.

The five models, including exponential, linear, logarithmic, polynomial and power functions, expressing M - H correlation, are all acceptable because of relatively high R^2, ranging from 0.86 to 0.90 (Figure 2b). However, comparing to the M - D models, the suitability of these M - H models is slightly lower. The quadratic polynomial model, $M = 0.17949H^2 + 6.99217H – 4.5685$, with highest coefficient of determination (R^2 = 0.8999), is the most suitable for presenting M - H relationship. This means that growth rate of biomass has a relative stability as the tree's height increases.

The relationship among M - D - H is expressed by function of two independent variables: M = 2.31061D + 3.285976H - 12.2 (Figure 3). This model has a high coefficient of determination, R^2 = 0.92, so it is acceptable.

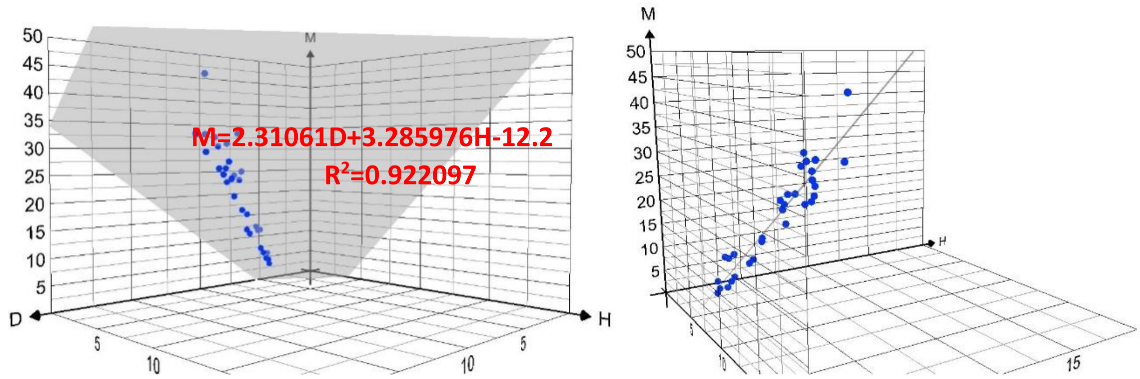

Fig. 3 Relationship among dry biomass (M), DBH (D) and height (H)

Thus, the most suitable mathematical models show that biomass increases as the tree grows, it increases sharply with the growth of DBH (power model) and more or less stably with the growth of height (quadratic polynomial model). In terms of determination coefficients, the power model showingM-D relationship with the largest value (R^2 = 0.9237) is the most suitable. The model of two independent variables has slightly lower coefficient (R^2 = 0.9221), but it expresses relationship between M with both DBH and H. Therefore, it is reasonable to use this two-variable model for estimating biomass:

$$M = 2.31061D + 3.285976H-12.2 \quad (1)$$

Where,M isDry biomass (kg); D is DBH (cm), i.e.tree diameter at 1.3m from the ground; H is Height of tree (m).

4.3. Correlation between accumulated carbon and tree dimension

Data of DBH (D), height (H) and accumulated carbon (C) of 31 sample trees (Table 2) allow to establish their quantitative relationships by exponential, linear, logarithmic, polynomial and power regressions (Fig. 4). All these models show the increase in carbon C as the diameter D or height H increase, but in different degrees. Linear and quadratic polynomial models have similar forms; power and especially exponential models carbon usually increase slower at first and then increase faster than linear models; whereas logarithmic function increase faster at first and then slower than linear. To select the appropriate model, it is necessary to evaluate the coefficient of determination R^2 for each model.

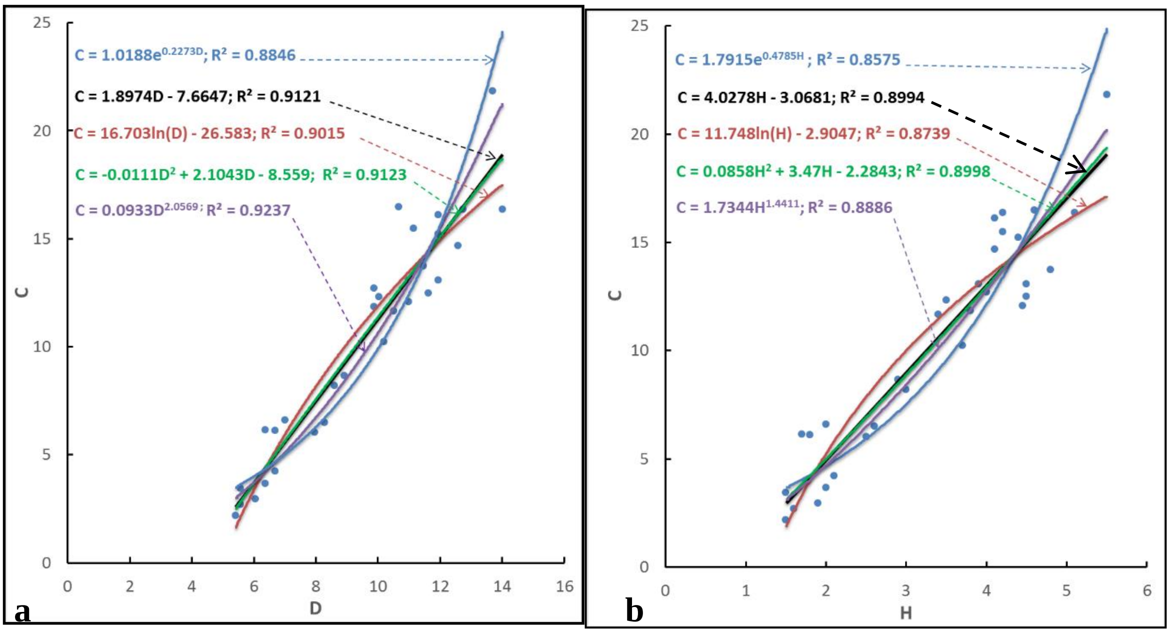

Fig.4 Regressions correlating accumulated carbon (C) with: a-DBH (D) or b- height (H)

In terms of expressing C - D relationship, all five given models, exponential, linear, logarithmic, polynomial and power functions, are acceptable because of their high R^2 from 0.88 to 0.92 (Fig. 4a). Among them, the power function $C = 0.0933D^{2.0569}$ has the highest coefficient of determination ($R^2 = 0.9237$), so it is most suitable for the anatomical results. This means that the carbon storage in tree increases slowly at first and then it speeds up as the DBH increases.

All five models, including exponential, linear, logarithmic, polynomial and power functions, expressing the C -H relationship, are also acceptable because of their high R^2, ranging from 0.86 - 0.90 (Figure 4b). However, comparing to C - D models, their suitability is slightly lower. The quadratic polynomial model, $C = 0.0858H^2 + 3.47H - 2.2843$, with highest coefficient of determination ($R^2 = 0.8998$) is the most suitable model presenting C - H correlation. This means that accumulatedcarbon increases stably with the growth of height.

The model with two independent variables, C = 1.1578D + 1.63657704H - 6.1, expressing relationship amongC - D - H, is also acceptable due to its high coefficient of determination, $R^2 = 0.92$ (Fig. 5).

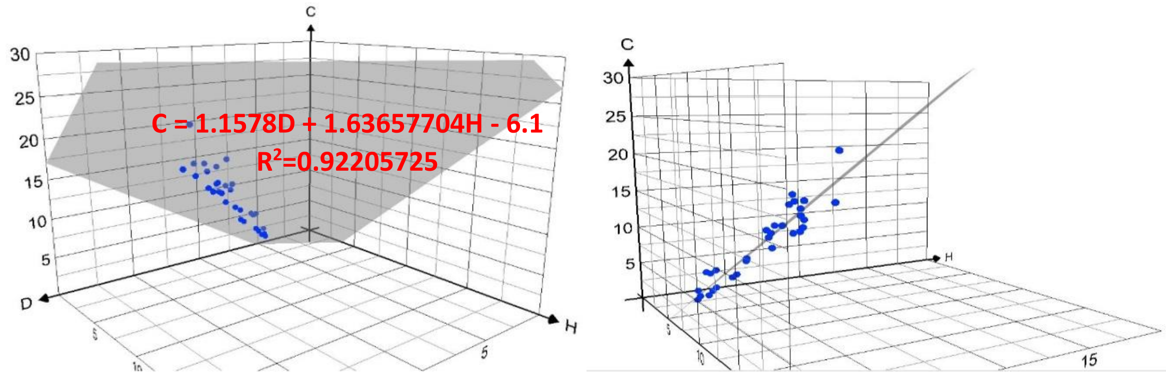

Fig. 5 Relationship among accumulated carbon (C), DBH (D) and tree height (H)

Thus, the most suitable mathematical models show that accumulatedcarbon increases withthe tree growth, it increases sharply with the increase of DBH (powermodel) and more or less stably with the increase of height (quadratic polynomial model). The power model shows best correlation between accumulated carbon and DBHbecause of having largest coefficient of determination (R^2 = 0.9237). The model of two independent variables has slightly lower coefficient (R^2 = 0.9221) but it expresses relationship between accumulated carbon with both DBH and height of tree. Therefore, it is reasonable to use this two-variable model for estimating accumulated carbon.

$$C = 1.1578D + 1.63657704H - 6.1 \qquad (2)$$

Where, C is carbon accumulated in the tree (kg); D is DBH (cm), i.e.tree diameter at 1.3mfrom the ground; H is height of tree (m).

4.5 Biomass and carbon accumulated in mangroves

Dry biomass as well as carbon stored in forest depend heavily on the species, age and density of trees. In Giao Lac commune (Nam Dinh province), the amount of carbon accumulated in *Kandelia obovate* forests of 1, 5, 6, 8 and 9 years increases with the ages(Nguyen Thị Hong Hanh, 2009). In mixed forests of *Kandelia obovate* and *Sonneratia caseolaris*with 10, 11 and 13 years of Nam Phu commune (Thai Binh province), accumulated carbon in also increases with the age andit in *Kandelia obovate*(1.60 - 2.39 kg per tree) is much lower than in*Sonneratia caseolaris* (23.22 - 37.23 kg per tree); however, due to the tree density, carbon productivity in *Kandelia obovate* (49.31-124.56 t/ha) is higher than in *Sonneratia caseolaris*(12.51 - 32.74 tons ha^{-1})(Nguyen Thi Hong Hanh, 2015).

For the study area, total dry biomass and carbon in each key plot are estimated by quantity of trees and dry biomass (Function 1) or accumulated carbon (Function 2) of a tree having mean DHB and height in that plot (Table 1). The results show that total dry biomass in plots ranges from 469 kg (Plot 6) to 3,544 kg (Plot 4) and accumulated carbon in plots changes from 234 kg (Plot 6) to

1772 kg (Plot 4) (Table 3). Their variations in sample plots are similar, the plots with high biomass also have high carbon accumulation and vice versa, the dry biomass is more or less twice the carbon. In term of productivity, biomasses of Plot 9 and Plot 12 (*Sonneratia caseolaris+Kandelia obovata +Bruguiera gymnorohiza*) are estimated respectively 3.5tonsha^{-1} and 4.5 tons per ha and the carbon amounts of these two plots are respectively 1.73 tons per ha and 2.23 tons per ha, the lowest values due to the low tree densities. Plot 3 has largest productivity of biomass and accumulated carbon with approximate values of 140 tons per ha and 70 tons per ha respectively due to its highest density (7,600 trees per ha), although tree size here is not large, below the overall mean (Table 1). Plot 7 and 10 with recently planted small trees but in high densityand Plot 11 with sparse but long time and large trees also have relatively high productivities of biomass (85 - 95 tons per ha) and accumulated carbon (42 - 47 tons per ha) (Table 3).

Table 3. Dry biomass, accumulated carbon and CO_2 value

Plot	**Area** (m^2)	**Treequan tity**	**D** (cm)	**H** (m)	**Mplot(** kg)	**Biomass product.**(t/ ha)	**Cplot** (kg)	**Carbon product. (**t/ha)	**CO_2 product. (**ton/ha)	**CO_2 value** (US$/ha)
1	500	92	10.45	5.65	2807	56.14	1402	28.04	102.83	1131.10
2	500	40	11.24	4.79	1181	23.62	590	11.81	43.29	476.18
3	100	76	7.92	3.74	1398	139.85	699	69.87	256.20	2818.20
4	500	82	15.62	5.88	3544	70.87	1772	35.43	129.91	1429.06
5	500	103	8.27	3.83	2008	40.17	1004	20.07	73.59	809.52
6	100	9	14.85	9.11	469	46.85	234	23.40	85.81	943.88
7	100	67	5.88	3.90	950	95.00	474	47.41	173.84	1912.29
8	100	21	9.02	4.71	507	50.67	253	25.31	92.81	1020.93
9	2,500	32	11.31	3.96	863	3.45	431	1.73	6.33	69.59
10	100	54	7.96	3.11	887	88.72	443	44.35	162.61	1788.75
11	100	14	19.19	8.64	848	84.75	424	42.36	155.31	1708.42
12	2,500	25	16.42	5.72	1114	4.45	557	2.23	8.17	89.84
13	2,500	36	14.66	5.00	1372	5.49	686	2.74	10.06	110.65
14	500	49	12.65	4.29	1525	30.50	763	15.25	55.93	615.19
Overview	**10,600**	**700**	**10.69**	**4.66**	**19472**	**18.37**	**9731**	**9.18**	**33.66**	**370.28**

Note:D is mean DBH; H is the mean height of the tree; Mplot is dry biomass estimated in plot; Cplot is carbon storage estimated in plot; Conversion: CO_2 = 3,667 x C; CO_2 price of US$11 per ton

Generally, for whole 10600 m^2 of 14 plots, the total dry biomassis estimated nearly 19.47 tons, i.e. 18.37tons per ha, The total amount of carbon is approximately 9.73 tons, i.e. 9.18 tons/ha (Table 3). Based on this result, given the mangrove occupying 3,709.1 ha in the coastal zone of Thai Binh province (TBDARD, 2015), the total biomass amount is estimated of 68,136 tons and the accumulated carbon is about 34,050tons. This valuable resource is not only participating in coastal protection but also a basis for bringing mangrove forests in Thai Binh province into the promising carbon market.

4.6CO_2 valuation of mangrove through carbon market participation

The carbon market is seen as the main tool to reduce CO_2 emissions, one of the four green house gases. The carbon market activity is supported by four main mechanisms outlined in the Kyoto Protocol, including emissions trading mechanism, CDM, joint implementation (JI) and REDD (Höhne *et al.*, 2015). So far, the carbon trading market has been divided into two types: the regulatory compliance and the voluntary markets. The regulatory compliance is the market in which carbon trading is based on the commitment of states in the UNFCCC to achieve the goal of reducing green house gases.It is regulated by mandatory, mainly for CDM or JI projects. The voluntary carbon market, outside the Kyoto Protocol framework, is based on bilateral or multilateral cooperation agreements between organizations, companies or countries.In Vietnam, it exists a numerous limitations impeding investments in carbon trade with in framework of Kyoto Protocol,such as: inadequacies in approval process, lack of openness and transparency in mechanisms of financial allocation, etc.Vietnam currently has several projects towards carbon market (Nguyen Ngoc Lung and Nguyen Tuong Van, 2004), Hoang Xuan Ty, 2004).Given the CO_2 price fromUS$5/tonto US$10/ton, the carbon stored in production forests is valuated from US$2,640.7ha^{-1} (restored forest) to US$5,150.8ha^{-1} (rich forest) for Southern Vietnam,US$2,164.5-5,238.1ha^{-1} for the CentralandUS$1,991.3-4,328.6ha^{-1} for the northern Vietnam (Vietnamese Academy of Forest Sciences, 2013).

Based on the CO_2 price of US$11/tonand the CO_2 absorption converted from carbon stored in mangroves, economic efficiency in providing service and trade environment is estimated for each surveyed plot (Table 3).The highest CO_2 value belongs to Plot 3(US$ 2,800ha^{-1}), followed byPlot 7, 10and 11 with values ranging from US$ 1,700ha^{-1} to US$ 1,900ha^{-1}, the lowest is Plot 9 and 12 with CO_2 values below US$ 100ha^{-1}. Overall estimation of 14 plots, CO_2 value is approximately US$ 370.28ha^{-1} (Table 3).Given the mangrove area of 3,709.1 ha (TBDARD, 2015), the total CO_2 absorbed in mangroves of Thai Binh province is valuated at US$1,373,406. This is a significant value for forest managers, especially forlocal habitants managing the community forests in Tien Hai and Thai Thuy coastal districts of Thai Binh province in Vietnam.

5. Conclusions

The main mangroves in coastal areas of Thai Binh are *Sonneratia caseolaris*, *Kandelia obovate*, *Bruguiera gymnorohiza*and *Aegiceras corniculatum* which have been grown for a long time upto now. On an area of 10,600 m^{2}of 14 plots, there are 700 trees with a mean DBH of 10.69 cm mean height of 4.66m.

Forests with DBH larger than overall average often have the height above overall average due to longtime plantation. Dense forests are often associated with small trees, recently planted on a large scale.Dry biomass increases with tree growth. The power function is the most suitable model expressing correlation between dry biomass and DBH, biomass increases slowly at first then rapidly with the augmentation of DBH. The quadratic polynomial function is the best for presenting the relationship between dry biomass and height of tree, the biomass keeps relatively stable growth rate with the increase of the height.

Accumulated carbon also increases with tree growth.The power function is the best model fitting accumulated carbon - DBH relationship, carbon content increasesat first slowly, then accelerates with the growth of DBH. The quadratic polynomial function is the most suitable correlating accumulated carbon and tree height, the rate of carbon accumulation is relative stable with increasing tree's height.The functions that represent the relationship between dry biomass and carbon accumulation with both stem diameter and plant height, are highly consistent with the model anatomy data, which can be used to calculate biomass and carbon accumulation for the entire study area. Generally for entire study area, productivities of dry biomass and carbon storage are estimated approximately 18.37 $tonsha^{-1}$ and 9.18 tons/ha respectively. Biomass and carbon vary similarly and biomass is approximately twice the carbon. The plots with long time and large mangroves often have low biomass and carbon because of low density.The plots with recently planted trees having small size but high density often give high biomass and carbon content.

The entire mangrove of coastal area in Thai Binh province is estimated approximately 68,000 tons of dry biomass, 34,000 tons of accumulated carbon.Converting to CO_2 value, this mangrove would be worth about US$1,373,000,a great significance for local forest management.

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