VNU Journal of Science: Natural Sciences and Technology, Vol. 33, No. 1 (2017) 39-47

Studying and Evaluating the Ability to form Carbon Sinks in Biomass of the Pure *Sonneratia caseolaris* Plantation in the Coastal Area of Tien Lang district, Hai Phong city

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Received 30 November 2016
Revised 13 December 2016; Accepted 23 March 2017

Abstract: An evaluation study on the ability of mangrove *Sonneratia caseolaris* aged 10, 11, and 13 years old in the coastal area of Tien Lang district, Hai Phong city in carbon sequestration in standing biomass following the guidance of IPCC (2006) was conducted to provide a basis for assessing the role of *Sonneratia caseolaris* plantation in greenhouse gas reduction and climate change response as well as to provide a scientific basis and information for international negotiations under programs of greenhouse gas reduction such as REDD and $REDD^+$ program,; the study is based on the total and component (leaves, stems, branches and roots) biomass of 72 *S. caseolaris* sample trees collected from 9 sample plot (each plot has an area of 100 m^2) of *S.caseolaris* plantation aged 10, 11 and 13 years old in 2014 - 2015. The results show that carbon stock in forest biomass reached the highest value in the 13 year-old forest (43.37 tonnes/ha), followed by the 11-year-old forest with 34.77 tonnes/ha; the lower value was seen in the 10-year-old forest at 32.69 tons/ha. The 10-year-old forest accumulated 4.81 tonnes/ha/year (corresponding to 17.65 tonnes of CO_2/ha/ year), the figures for the 11-year-old and 13 year-old forests were 5.18 tonnes/ha/year (equivalent to the amount of CO_2 of 19.01 tons/ha/year) and 5.52 tonnes/ha/year (equivalent to the amount of CO_2 of 20.26 tonnes/ha/year) respectively. The amount of carbon accumulated in forest tree corresponding to the amount of CO_2 sequestered by forest trees is very high, which is of significance to reducing the amount of CO_2 in the atmosphere, contributing to mitigating greenhouse gas emissions, and responding to climate change. The great ability of forests to store carbon is a highly important element for the implementation of REDD, $REDD^+$ programs in Viet Nam.

Keywords: *Sonneratia caseolaris,* accumulated carbon, greenhouse gas, mangroves forest, carbon credit.

1. Introduction

Climate change is one of the great challenges of human beings in the twenty-first century. One of the solutions to minimize climate change is reducing emissions from deforestation in developing countries (REDD) and reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries ($REDD^+$). Viet Nam is among the countries joining REDD, $REDD^+$ programs and required to needs to calculate its forest carbon stocks (Nguyen Quang Tan, 2011) [8].

In 2006, IPCC (Intergovernmental Panel on Climate Change) developed a set of guidelines for nations to carry out an overall inventory of

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greenhouse gas emissions, including the CO_2 emissions from degradation and deforestation. There are five forest carbon pools that are identified: 1) above ground biomass (AGB), 2) below ground biomass (BGB), 3) litter, 4) dead wood) and 5) soil (IPCC, 2006) [5]. Currently in Vietnam, there are limited quantitative studies of mangrove carbon stocks to assess the ability of mangroves to create carbon sinks that follow the approach under the guidance of international organizations such as IPCC (2006) and CIFOR (2012).

Hai Phong is a coastal city; it has about 18,280 ha of forest (natural forests 10,773 ha and planted forests 7,507 ha). Plantations here are mainly *Kandelia obovata*, *Sonneratia caseolaris* (Ministry of Agriculture and Rural Development, 2016) [1].

The present study was carried out to evaluate the role of planted *Sonneratia caseolaris* in the coastal area of Tien Lang district, Hai Phong city in reducing greenhouse gases and to provide scientific basis and information for international negotiations on programs to cut greenhouse gas emissions, such as REDD, REDD$^+$ in Vietnam.

2. Materials and methods

2.1. Study objects, sites and time

The study was conducted from 2014 to 2016 in a planted *Sonneratia caseolaris* on mud flats grown in 2000 (13 year old forest - R13T), 2002 (11 year old forest - R11T), and 2003 (10 year old forest - R10T) in Dong Hung commune, Tien Lang district, Hai Phong city (figure 1). The total area is about 132 ha. The 10-year-old stand has an average density of 1570 trees/ha, 11-year-old forest 1460 trees/ha, and 13-year-old forest 1490 trees/ha.

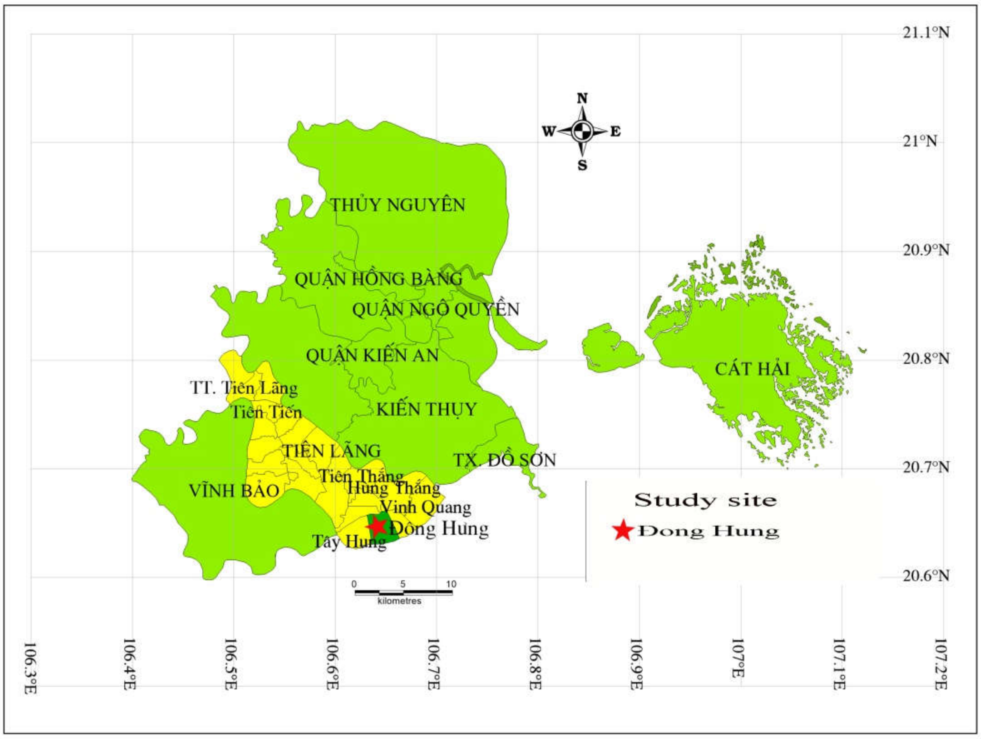

Figure 1. Study site.

2.2. Study method

2.2.1. Setting sample plots

The 09 sample plots were set up from the dykes seaward, perpendicular to the seadykes; being close to the seadyke was the 13 year old mangrove stand; next come the 11 year old stand followed by the 10 year old stand. In the forest of each age, 3 sample plots were established, 100 m^2 (10m x 10m) in size each; the average distance between plots is 100m (figure 2).

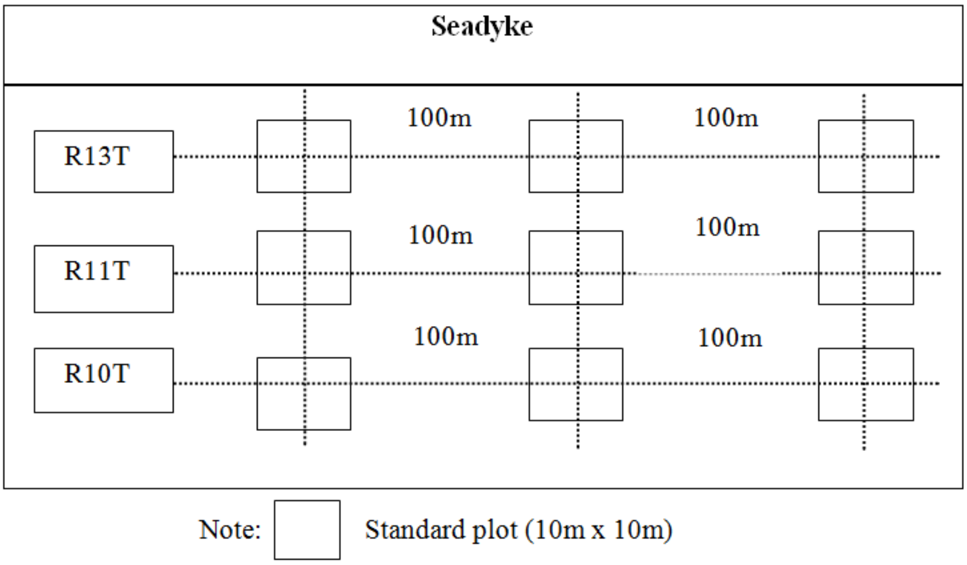

Figure 2. Experimental setting for sampling.

2.2.2. Biomass sampling and analyzing

Research on tree biomass is the basis for determining the carbon content of the trees. Tree biomass includes above ground biomass (leaves, stems, branches ...) and below-ground biomass (roots) [4, 9].

A total of 4 tree biomass samplings were taken in 2 years (2014-2016). For each sampling, two trees of medium size in each sample plot were cut; all the roots were also digged out. A total number of sample trees is 72.

Each sample tree was divided into parts: stems, branches, leaves and roots. Fresh weight of each tree part was scaled, based on which the fresh weight of the tree was calculated. For each tree part, 100 g of fresh sample was taken, and dried at 105^0C for stems and branches and at 85^0C for the other parts until the constant dry weight.

Tree biomass is the total dry weight of tree parts of individual trees; mangrove stand biomass is the individual tree's biomass multiply stand tree density.

2.2.3. Analysis and calculation of carbon content

Carbon content (%) in the tree was determined by Chiurin method. The total number of samples for carbon content analysis is 72 sample trees * 4 tree parts (leaves, stems, branches and roots)/sample tree = 288 samples

Carbon accumulated in each part of plant was determined by the carbon content (%) and dry weight of each part of the tree. The total carbon accumulated in a tree is determined by total carbon content of above-ground parts (leaves, stems, branches...) and below-ground part (roots) of the tree.

The carbon stock of a mangrove stand was determined based on average carbon content of individual trees and tree density.

The carbon stock in biomass helped infer the corresponding CO_2 absorbed by standing trees generating which is calculated by carbon accumulated in trees (ton/ha) x 3.67 (3.67 is the constant applied to all types of forests) (Nguyen Hoang Tri, 2006) [10], (Kaffman JB, et al.) [6].

2.2.3. Statistical analysis and data processing

All data collected were processed by mathematical statistical method such as determination of mean value, standard deviation, and errors within the confidence interval.

3. Results and discussion

3.1. Amount of carbon in above, below ground and total biomass of Sonneratia caseolaris trees aged 10, 11, and 13 years old

Plant/tree biomass is the content of organic matters that are accumulated in plant tissues, such as stems, branches, leaves, roots ..., through photosynthesis process [4]. Biomass is also called as the content of organic carbon accumulated in trees/plants. From the results of our research on biomass, we can identify amount of carbon accumulated in tree biomass.

Amount of carbon accumulated in above-ground biomass (leaves, branches, stems), below-ground biomass (roots) and the total biomass of the trees increased with tree age; amount of carbon accumulated in biomass was the highest in the 13 year old forest followed by the 11 year old forest and then 10 year old forest (table 1).

Table 1. The amount of carbon accumulated in parts of *Sonneratia caseolaris* trees aged 10, 11, and 13 years old

Tree age	Planting year	Leaves (kg/tree)		Stems (kg/tree)		Branches (kg/tree)		Root (kg/tree)		Carbon accumulated in trees (kg/tree)
		Biomass	Carbon content	Biomass	Carbon content	Biomass	Carbon content	Biomass	Carbon content	
10	2003	0.54	0.29	19.81	9.93	14.32	6.97	7.23	3.63	20.82
11	2002	0.63	0.33	23.42	11.68	15.98	7.83	7.87	3.98	23.82
13	2000	2.86	1.46	27.64	13.58	19.05	9.38	8.76	4.41	29.10

The average amount of carbon in the 10-year-old tree was 20.82 kg/tree, followed by the 11-year-old trees with 23.82 kg/tree and the highest was seen in 13-year-old trees with 29.10 kg/tree. The study results are consistent with the rules of growth and development of plants, i.e. tree biomass increases with tree age.

Amount of carbon in biomass of above ground parts and below ground part was not even. For above-ground parts of trees, the carbon was mainly accumulated in tree stems (9.93 to 13.58 kg/tree), followed by that of branches (6.97 to 9.38 kg/tree), the figure for leaves was 0.29 to 1.46 kg/tree. Amount of carbon in root biomass did not vary much among different tree ages.

In general, amount of carbon in above-ground biomass of trees was higher than in below-ground biomass. The present results are similar to those of my previous study on the content of carbon accumulated in trees of *K. obovata* aged 10, 11, and 13 years old and planted along the coast of Tien Hai district, Thai Binh province (Nguyen Thi Hong Hanh, 2015) [3]; the conclusion was also that carbon accumulation in tree biomass increased with the forest ages and the content of accumulated carbon was higher in above-ground biomass than in below ground biomass of trees.

3.2. Carbon stock in above-ground, below-ground and total biomass of S. caseolaris stands aged of 10, 11, and 13 years old

It can be seen that similar to the carbon accumulation in tree, amount of carbon in above-ground and below-ground biomass of *S.caseolaris* stands generally increased with stand age (table 2).

Table 2. The content of carbon accumulated in above-ground and below-ground biomass and total biomass of *S.caseolaris* forest (ton/ha)

Stand age	Density (trees/ha)	Above ground		Below ground		Total	
		Biomass	Carbon content	Biomass	Carbon content	Biomass	Carbon content
10 year	1570	54.43 ± 2.24	26.99 ± 1.03	11.35 ± 0.59	5.70 ± 0.31	65.78 ± 2.62	32.69 ± 1.18
11 year	1460	58.44 ± 2.56	28.96 ± 1.19	11.49 ± 0.51	5.81 ± 0.27	69.94 ± 2.85	34.77 ± 1.30
13 year	1490	73.99 ± 2.92	36.80 ± 1.43	13.06 ± 0.60	6.57 ± 0.27	87.05 ± 3.15	43.37 ± 1.51

Table 2 shows that the cumulative amount of carbon in above-ground biomass of the 10 year old stand was the lowest, followed by the 11-year-old stand and the highest was observed in the 13-year-old stand, being 26.99 tons/ha; 28.96 tons/ha and 36.80 tons/ha respectively.

The carbon accumulated in below-ground biomass of the *S.caseolaris* stand aged 13 years was the highest at 6.57 tons/ha, followed by the 11-year-old forest with 5.81 tons/ha; the lowest was seen in the 10-year-old forest with 5.70 tons/ha.

Overall, the cumulative carbon in below ground biomass in the mangrove stands changed insignificantly, from 0.11 ton/ha to 0.76 ton/ha. However, the carbon accumulated in above-ground biomass of the population has increased markedly, from 1.96 tons/ha to 7.84 tons/ha. This proves that when the trees aged from 10 to 13 years old, they grew mostly in biomass of leaves, branches and stems. On the other hand, the 10-year-old trees had closed canopy of 95%, prioritizing the development of leaf biomass, increasing the biomass of the CO_2 assimilation organs. As for 11 and 13 years old forests that have completely closed canopies, natural thinning has occurred intensively; and there have been fewer branches and leaves; the trees have grown strongly in height due to competition in natural light.

The result also indicated that the amount of cumulative carbon in above-ground biomass was higher than that in below-ground biomass (Figure 3). Amount of carbon in above-ground biomass of *S.caseolaris* stands aged 10, 11, and 13 years was 4 to 5 times higher than that in below-ground biomass of the forest. The amount of carbon in above-ground biomass of the forest aged 13 years was 36.80 tons/ha while it was only 6.57 tons/ha in below ground biomass.

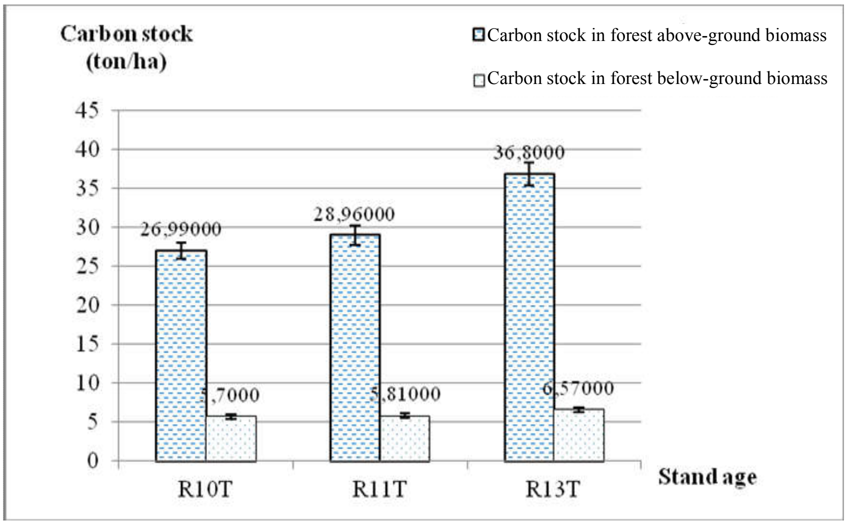

Figure 3. Amount of carbon in above-ground and below-ground biomass of *S. caseolaris* mangroves aged 10, 11, and 13 years.

The comparison of the amount of carbon accumulated in total biomass of *S. caseolaris* stands with that of mixed species stands of *K. obovata* and *S. caseolaris* [3] indicates that at the same age of 10,11 and 13 years, the amount of carbon accumulated in biomass of *S.caseolaris* plantations was higher. The carbon accumulated in biomass of the mixed plantation aged 10 years was 22.36 tons/ha while the plantation of *S.caseolaris* aged 10 years was 32.69 tons/ha. Nguyen Hoang Tri (1996) also concluded that at the same age, *S. caseolaris* trees have much greater biomass than *K. obovata* trees [9]; therefore, although the density of mixed spesies stands aged 10 years old (8784 trees/ha, including 8400 *K.obovata* trees and 384 *S. caseolaris* trees) was higher than that of the *S.caseolaris* stand aged 10 years old (1570 trees/ha), the number of *S. caseolaris* trees in the mixed species stand was less than in the *S.caseolaris* stands. Thus, the carbon content in biomass of *S.caseolaris* was higher than that of mixed species mangroves.

From the evidence above, it can be remarked that the amount of carbon accumulated in mangroves depends on tree species, age, and planted tree density. The carbon accumulated in biomass of *S. caseolaris* mangroves was higher than that of mixed species mangroves consisting of *K. obovata* and *S. caseolaris*; this demonstrates the role of *S. caseolaris* mangroves in carbon accumulation, contributing to reducing greenhouse gas emissions.

3.3. Ability of S. caseolaris mangroves to form biomass carbon sinks

To assess the ability of mangrove forests to create biomass carbon sinks, we evaluated changes in carbon stocks by following equation (IPCC, 2006) [5].

$$\Delta B = \frac{\Delta t_2 - \Delta t_1}{t_2 - t_2}$$

Where: ΔB: carbon credits for a period of time

Δt_1: carbon stock measured at time t_1

Δt_2: carbon stock measured at time t_2

From the results of the study in 2014 and 2015 on the carbon stock in tree and stand biomass of *S.caseolaris* mangroves aged 10, 11 and 13 years old, we evaluated their ability to create carbon sinks with the results are shown in table 4.

Table 4. Changes of carbon stocks in above, below ground and total biomass of pure *S. caseolaris* mangroves aged 10, 11, and 13 years

Carbon stock	Change of carbon stock	13 year-old stand		11 year-old stand		10 year-old stand	
		Cumulative carbon	Equivalent CO_2	Cumulative carbon	Equivalent CO_2	Cumulative carbon	Equivalent CO_2
Carbon in above-ground biomass	2014	34.14	125.29	26.54	97.40	24.96	91.60
	2015	39.42	144.67	31.39	115.20	29.01	106.47
	Carbon accumulated after one year (ton/ha/year)	5.28	19.38	4.85	17.80	4.05	14.86
Carbon in below-ground biomass	2014	6.44	23.63	5.64	20.70	5.32	19.52
	2015	6.70	24.59	5.97	21.91	6.07	22.28
	Carbon accumulated after one year (ton/ha/year)	0.26	0.95	0.33	1.21	0.75	2.75
Carbon in total forest biomass	2014	40.61	149.04	32.18	118.10	30.28	111.13
	2015	46.13	169.30	37.36	137.11	35.09	128.78
	Carbon accumulated after one year (ton/ha/year)	5.52	20.26	5.18	19.01	4.81	17.65

Table 4 shows that the amount of carbon in above-ground biomass increased significantly after 1 year; this is of significance in creating carbon credits; the figures for the 10, 11 and 13-year-old stands were 4.05 tons/ha/year (corresponding to the amount of CO_2 of 14.86 tons/ha/year absorbed by trees), 4.85 tons/ha/year (equivalent to 17.80 tons/ha/year of CO_2), and 5.28 tons/ha/year (equivalent to 19.38 tons/ha/year of CO_2) respectively.

Similarly, the amount of carbon in below-ground biomass also increased by a certain amount after one year; the figure for the 10 year old stand was 0.75 tons/ha/year (equivalent to 2.75 tons of CO_2/ha/year), 11-year-old stand 0.33 tons/ha/year (equivalent to 1.21 tons of CO_2/ha/year), the 13-year-old stand 0.26 tons/ha/year (equivalent to 0.95 tons of CO_2/ha/year). Therefore, the 10-year-old stand had a higher content of carbon in below-ground biomass than the 11 and 13 year-old stands; this could be explained that the 10-year-old trees are in the stage of growth and development. The 13-year-old trees started showing signs of slower growth, so the carbon content in root biomass was lower than that of trees aged 10 and 11 years.

Every year, *S.caseolaris* mangroves accumulated additional quantities of carbon in tree biomass, which is significant in generating carbon credits to participate in $REDD^+$ program; the 10 years old stand sequestered an additional amount of 4.81 tons/ha/year (equivalent to the amount of CO_2 of 17.65 tons/ha/year), the stand aged 11 years old accumulated an additional amount of 5.18 tons/ha/year (equivalent to 19.01 tons/ha/ year of CO_2), and the stand aged 13 years old an additional amount of 5.52 tons/ha/year (equivalent to the amount of CO_2 of 20.26 tons/ha/year).

The amount of carbon stored in mangrove trees is corresponding to a large amount of CO_2 absorbed by trees; this can significantly reduce the amount of CO_2 in the atmosphere, contributing to reducing greenhouse gas emissions and climate change response [2, 7, 10]. The great ability of mangroves to accumulate carbon is an important element for the implementation of REDD, and $REDD^+$ programs in Viet Nam.

4. Conclusions

In the present condition, carbon stock in biomass of *S.caseolaris* mangroves increased with increasing stand age, reaching the highest value in the 13-year-old stand with 43.37 tons/ha (the accumulated carbon in above-ground and below-biomass of the forest was 36.80 tons/ha and 6.57 tons/ha respectively. Next came the 10-year-old stand with 32.69 tons/ha (content of carbon accumuled in above-ground and below-ground biomass of the forest was 26.99 tons/ha and 5.70 tons/ha respectively) and the 11-year-old stand with 34.77 tons/ha (content of carbon accumuled in above-ground and below-ground biomass of the forest was 28.96 tons/ha and 5.81 tons/ha respectively).

Annually, *S.caseolaris* mangroves accumulated an additional amount of carbon in trees biomass, which is significant in generating carbon credits; the 10-year-old stand added an cumulative amount of 4.81 tons of carbon/ha/year (corresponding to the amount of CO_2 of 17.65 tons/ha/year); the mangroves aged 11 years accumulated additional 5.18 tons of carbon/ha/year (equivalent to the amount of CO_2 of 19.01 tons/ha/year), and the mangroves aged 13 years 5.52 tons of carbon/ha/year (equivalent to the CO_2 amount of 20.26 tons/ha/year).

The carbon accumulated in mangrove trees was corresponding to the great amount of CO_2 absorbed by trees; this is of significance in reducing the amount of CO_2 in the atmosphere, contributing to mitigating greenhouse gas emissions and climate change response. The high ability of mangroves to accumulate carbon is an important element for the implementation of REDD, $REDD^+$ programs in Viet Nam.

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Nghiên cứu, đánh giá khả năng tạo bể chứa Cacbon trong sinh khối của Rừng ngập mặn trồng thuần loài bần chua (*Sonneratia caseolaris)* ven biển huyện Tiên Lãng, thành phố Hải Phòng

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Tóm tắt: Để có cơ sở đánh giá vai trò của rừng ngập mặn trồng thuần loài bần chua (*Sonneratia caseolaris*) 10, 11, 13 tuổi ven biển huyện Tiên Lãng, thành phố Hải Phòng trong việc giảm khí nhà kính, ứng phó với biến đổi khí hậu, đồng thời cung cấp cơ sở khoa học cho việc đàm phán quốc tế trong các chương trình thực hiện cắt giảm khí nhà kính như REDD; $REDD^+$, chúng tôi nghiên cứu; đánh giá khả năng tạo bể chứa cacbon trong sinh khối của rừng theo hướng dẫn của IPCC (2006), dựa trên số liệu sinh khối của 72 cây bần chua được thu thập tại 9 ô tiêu chuẩn (mỗi ô tiêu chuẩn có diện tích là 100 m^2) của rừng 10 tuổi, 11 tuổi và 13 tuổi (24 cây/rừng) và phân tích hàm lượng cacbon trong các bộ phận lá, thân, cành, rễ của 72 cây (tương ứng với 288 mẫu) trong hai năm từ 2014 - 2015. Kết quả nghiên cứu cho thấy, lượng cacbon tích lũy trong sinh khối của rừng đạt giá trị cao nhất là rừng 13 tuổi với 43,37 tấn/ha, tiếp theo là rừng 11 tuổi với 34,77 tấn/ha, thấp nhất là rừng 10 tuổi với 32,69 tấn/ha. Hàng năm, rừng trồng thuần loài bần chua tích lũy thêm một lượng cacbon trong sinh khối cây và rừng, điều này có ý nghĩa quan trọng trong việc tạo tín chỉ cacbon, rừng 10 tuổi tích lũy 4,81 tấn/ha/năm (tương ứng với lượng CO_2 là 17,65 tấn/ha/năm), rừng 11 tuổi tích lũy 5,18 tấn/ha/năm (tương ứng với lượng CO_2 là 19,01 tấn/ha/năm), rừng 13 tuổi tích lũy 5,52 tấn/ha/năm (tương ứng với lượng CO_2 là 20,26 tấn/ha/năm). Lượng cacbon tích lũy trong cây rừng tương ứng với lượng CO_2 do cây rừng hấp thụ là rất lớn, điều này có ý nghĩa làm giảm lượng CO_2 trong bầu khí quyển, góp phần giảm khí thải nhà kính, ứng phó với biến đổi khí hậu. Khả năng tích lũy cacbon cao của rừng là yếu tố quan trọng để thực hiện các chương trình REDD, $REDD^+$ tại Việt Nam.

Từ khóa: *Sonneratia caseolaris,* cacbon tích lũy, khí nhà kính, rừng ngập mặn, tín chỉ cacbon.