Forest Ecology and Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Belowground carbon sequestration in a mature planted mangroves (Northern Viet Nam)

Ha Thi Hien [a], Cyril Marchand [b,c], Joanne Aimé [b,c], Dang Hoai Nhon [d], Phan Nguyen Hong [e], Nguyen Xuan Tung [f], Nguyen Thi Kim Cuc [a,e,*]

[a] Thuyloi University, 175 Tay Son Str., Dong Da Dist., Ha Noi, Viet Nam
[b] IMPMC, Institut de Recherche pour le Développement (IRD), UPMC, CNRS, MNHN, Noumea, New Caledonia, France
[c] Analytical Chemistry Department, University of Sciences of Ho Chi Minh City, 225 Nguyen Van Cu, Ho Chi Minh, Viet Nam
[d] Marine Geo-environment Department, Institute of Marine Environment and Resource, 246 Danang Street, Hai Phong, Viet Nam
[e] Mangrove Ecosystem Research Division (MERD), Centre for Natural Resources and Environmental Studies (CRES), Vietnam National University (VNU), 144 Xuan Thuy, Cau Giay, Ha Noi, Viet Nam
[f] Mangrove Ecosystem Research Centre (MERC), Hanoi National University of Education (HNUE), 136 Xuan Thuy, Cau Giay Dist., Ha Noi, Viet Nam

ARTICLE INFO

Article history:
Received 25 March 2017
Received in revised form 21 June 2017
Accepted 28 June 2017
Available online xxxx

Keywords:
Planted mangroves
Soil
Carbon stocks
Carbon burial rates
Viet Nam

ABSTRACT

Mangroves play a key role in carbon sequestration along tropical and subtropical coastlines, mainly as a result of their high primary productivity and the anoxic character of their soils, in which organic matter decay processes are slow. Unfortunately, these forests are disappearing worldwide, notably due to aquaculture and the need for space on the shoreline. The mangrove area in Viet Nam decreased substantially until late 90's, which was a concern for the Vietnamese government. Then, replantation programs were developed in order to protect the shoreline against the erosion; like in northern Viet Nam, where monospecific stands were planted from the mid 90's. Within this context, our objectives were to determine carbon stocks and carbon burial rates in the soil of a 18 years old *Kandelia obovata* (Sheue, Lui & Yong) mangrove forest. Three plots were set up in the planted mangroves and three in adjacent bare land (without any mangrove) at the mouth of Red River. Three geo-slicers up to 100 cm depth were taken in each plot; and in each core, ten soil samples were collected with a 10 cm depth interval. Later on, dead and live roots were sorted. Carbon contents in soils and in roots were determined using the Walkley-Black method and loss on ignition (LOI) method, respectively. Then, the total belowground carbon sequestration was estimated. There was a depth related distribution of organic carbon in soil with the highest concentrations measured between 20 and 60 cm depth. Accumulated carbon up to depth of 100 cm in soil and roots of the planted *K. obovata* were 146.78 ± 3.87 Mg OC ha^{-1} and 12.67 ± 0.14 Mg OC ha^{-1}, respectively. The value was 87.59 ± 1.08 Mg OC ha^{-1} for the adjacent bare land. Consequently, the mean carbon burial rate for this system was approximately 6.94 Mg OC ha^{-1} yr^{-1}, which is higher than most of the mangroves and may be related to a low export of the net primary productivity or most likely to a high sedimentation rate. These results were compared with previously published results on carbon stocks in younger planted forests of the same species in the same region, a positive and linear relationship was determined between the age of the planted stand and the belowground carbon stocks.

1. Introduction

Mangroves are saline or brackish wetland environments, mainly anoxic due to waterlogging (Kristensen et al., 2008; Kauffman et al., 2011). This unique condition, combined with their high productivity (218 ± 72 Tg C y^{-1}; Bouillon et al., 2008), induces a high ability of this ecosystem in fixing and storing CO_2, one of the greenhouse gases that contribute to global warming. Carbon is assimilated and stored, both in aboveground and belowground biomass (stems, branches, leaves and roots) but also in their soils, with up to 90% of carbon stocks stored as soil organic matter (Donato et al., 2011; Stringer et al., 2015). Breithaupt et al. (2012) suggested that up to 15% of mangrove productivity can be buried, the remaining being decomposed or exported towards adjacent ecosystems through tidal flushing or tidal pumping (Maher et al., 2013; Leopold et al., 2015, 2016). Although

* Corresponding author at: 175 Tay Son Str., Dong Da Dist., Ha Noi City, Viet Nam.
E-mail addresses: nguyencucvn@gmail.com, nguyencuc@tlu.edu.vn (T.K.C. Nguyen).

http://dx.doi.org/10.1016/j.foreco.2017.06.057
0378-1127/

mangroves occupy only ~0.5% of global coastal ocean area (Giri et al., 2011), they account for approximately 10–15% of the total carbon sequestration of this area (Alongi, 2014). As a consequence, mangrove environments are sites for intense carbon processing with potential high impact on the global carbon cycle (Alongi, 2009).

In Viet Nam, mangrove forest area was estimated at more than 400,000 hectares in 1943 (Maurand, 1943). However, their area dropped sharply over the past 70 years to 131,520 hectares in 2016 (Ministry of Agriculture and Rural Development, 2016) due to the aftermath of the destructive war and the excessive exploitation of forests. In the northern parts of Viet Nam, 17,094 hectares of mangroves had been lost throughout the period of 1964–1997. Particularly, in the Red River Delta, 4640 hectares of mangroves were lost from 1975 to 1991 then followed by a decrease of 7430 hectares in 1993 (Mcnally et al., 2010), which was an alarming problem for the local population. Since 1994, over 5600 hectares of mangrove forests have been planted in the Red River Mouth (including Thai Binh and Nam Dinh Provinces) by the Viet Nam Red Cross with the support of the Danish and the Japanese Red Cross through International Federation of Red Cross and Red Crescent Societies (IFRC, 2010). These planted forests are currently growing well and serve as a "green wall" against sea waves, reducing the risk of a sea dike break and providing substitute livelihoods as well as increasing available aquatic resources for fishing. Besides those effective benefits, mangroves are now regarded not only as sinks for sediments and nutrients, but also as a sink for CO_2.

Studies on carbon accumulation in mangroves in northern Viet Nam were carried out in young mangrove plantations, <10 years old (Ha et al., 2004; Cuc et al., 2009). However, there is a lack of data concerning stocks and burial rates for mature planted mangroves. The objectives of this study were, thus, to determine the carbon stocks in the substrate of a mature planted *Kandelia obovata*[1] (Sheue, Lui & Yong) forest of 18 years old, both in the roots and in the soil, and to compare with the results obtained for the younger mangroves (Ha et al., 2004; Cuc et al., 2009). Our hypothesis is that carbon stocks in soils will increase with the age of the forest as observed for young planted mangroves (Ha et al., 2004; Cuc et al., 2009) and for mature monospecific pristine mangroves in French Guiana (Marchand, 2017). Marchand (2017) showed that even if the productivity of mature forests asymptotes, organic carbon continues to accumulate in soils over time. To reach our goal, the study was conducted in both monospecific mangrove forest and in the adjacent bare land.

2. Material and methods

2.1. Study site

The study site (20°13′37.6″N and 106°31′42.0″E) was set up in the buffer zone of Xuan Thuy National Park (XTNP), which is located on the south bank of Red River (Ba Lat Mouth) in Gulf of Tonkin, Nam Dinh Province, northern Viet Nam (Fig. 1). Mangroves in Xuan Thuy cover over 15,000 hectares (Tinh and Tuan, 2015) and are a mix of planted and natural ones with three main species: *Kandelia obovata, Sonneratia caseolaris* and *Rhizophora apiculata*. Most of mangroves in the buffer zone of XTNP were planted from 1996 to date and dominated by *K. obovata*. The studied site in mangrove forest (*K. obovata*) was planted in 1998.

Located in northern Viet Nam, the study area has a typical monsoonal tropical climate with high humidity (80–85% on average). The average annual temperature ranges from 23.4 to 24.5 °C. The coldest months are December and January, with average temperatures ranging from 16.0 to 17.1 °C and the hottest month being July, with mean temperatures over 29.4 °C. The average annual rainfall is between 1750 and 1800 mm, and the two distinct seasons are: wet season from May to October, and dry season from November to April (Nam Dinh Province Statistics Office, 2016). Tidal regime in this area is irregular diurnal, with large amplitude, maximum at 3.54 m and minimum at 0.37 m (Centre for Oceanography, 2016).

2.2. Sampling methodology

The field work was conducted during the dry season in April 2016. Three plots were set up in mangroves that were planted in 1998 and the other three were on adjacent bare land (with no mangrove coverage). A non-contaminated core sampler (Geo-slice NM4; Miyagi and Baba, 2002) was used to collect the soil samples up to 100 cm depth. Three geo-slicers were taken randomly in each plot of the planted mangroves (MR1, MR2, MR3) as well as in the bare land (without mangrove; BL1, BL2, BL3). In each core, ten soil samples of known volume were collected at 10 cm depth intervals. Each soil sample was divided into two parts: one half for root determination and the other for soil analyses.

To collect the root samples, dead and live roots were sorted by diluting the soil samples in water and then filtered through 1-mm diameter sieve *in situ*. Dead and live roots were eyes sorted. The condition of root surfaces or section were carefully judged to separate dead and live roots in term of its color, firmness and freshness (Komiyama et al., 2000). Sorted roots had diameters ranging from >1 mm to ~16 mm. Dead and live roots were stored separately in closed plastic bags and placed in ice box before being sent to the laboratory.

The soil samples were also placed in closed plastic bags and transported to the laboratory for processing. In total, 180 soil samples were used to determine the soil carbon accumulation and 180 other samples for the determination of the organic accumulation in roots (live and dead roots).

2.3. Sample treatment and measurement

In the laboratory, live and dead roots were weighed before and after being dried in oven at 60 °C for 48 h. Carbon content (CC%) in roots was analyzed by the L.O.I method (L.O.I – Loss On Ignition; Rosenmeier, 2005). In this method, organic matter was oxidized to carbon dioxide, water and ash at 550 °C during 4 h. Weight losses associated with water and carbon dioxide evolutions were easily quantified by recording sample weights before and after controlled heating.

Root biomass (organic carbon - OC in Mg OC ha^{-1}) was calculated using the following equation (Ha et al., 2004):

$$\text{Belowground biomass(Mg OC ha}^{-1}) = \text{dry root weight(g)/wet soil volume(cm}^3) \times \text{CC(\%)} \times \text{depth interval(cm)} \quad (1)$$

For the soil, all wet samples were weighed and air-dried at room temperature, then dried in oven at 60 °C for 24 h to determine the dry bulk density (BD) for each interval. The BD was obtained by the ratio of dry mass per volume of wet sample (known from corer's manual).

$$\text{Bulk density(BD in g cm}^{-3}) = [\text{dry mass(g)}]/[\text{wet sample volume(cm}^3)] \quad (2)$$

Then, dry samples were grounded by hand using mortar and pestle, then sieved (2-mm mesh) before being analyzed. Carbon

[1] *Kandelia* (*sp*. Rhizophoraceae) has long been regarded as a monotypic mangrove genus. Recent studies of Sheue et al. (2003) have recognized as two distinct species. From that study, the one that had known as *Kandelia candel* (L.) and planted in the northern part of Viet Nam is *Kandelia obovata* (Sheue, Liu & Yong).

Please cite this article in press as: Ha, T.H., et al. Belowground carbon sequestration in a mature planted mangroves (Northern Viet Nam). Forest Ecol. Manage. (2017), http://dx.doi.org/10.1016/j.foreco.2017.06.057