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Carbon storage of a tropical mangrove forest in Mui Ca Mau National Park, Vietnam

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ABSTRACT

Mangrove forests constitute the most important sink of carbon (C) in the tropics, the conservation of which is an essential mean in offsetting C emissions and climate change. Mangrove forests are therefore suggested to be an important component of reducing emissions from deforestation and degradation (REDD+) schemes, which require scrupulous quantification of ecosystem C storage in order to monitor temporal C sequestration and emissions. Despite this, proportionally less is known about ecosystem C storage of mangrove forests in Vietnam, where these systems constitute a large proportion of its coastline. In this study, ecosystem C storage of a tropical mangrove forest in Mui Ca Mau National Park, Vietnam (CMNP) was quantified by measuring biomass of trees, roots, and downed woody debris, and sediment organic C and overall depth. Results showed that above- and below-ground C stock ranged from 90.2 ± 15.8 to 115.2 ± 19.3 and from 629.0 ± 32.5 to 687.0 ± 29.2 MgC ha^{-1}, respectively. The combination of the above- and below-ground C stocks resulted in a high ecosystem C storage, which ranged from 719.2 ± 38.0 to 802.1 ± 12.3 MgC ha^{-1}, and slightly increased from fringe toward interior forest. The 13,400 ha of mangrove forests in the CMNP were estimated to store 10.3 (±0.8) × 10^6 Mg of C, which is equivalent to 38.0 (±3.0) × 10^6 Mg of CO_2e. The present results suggest that the conservation of mangrove forest is needed to increase ecosystem C storage and to offset C emissions at the regional scale.

1. Introduction

Mangrove forests can store up to 1023 MgC ha^{-1}, ranking among the most important carbon (C) sinks in the tropics (Donato et al., 2011). Recent studies have indicated that C storage by mangrove forests is two to three times higher than that of terrestrial forests (Adame et al., 2013; Donato et al., 2011; Kauffman et al., 2011). The C storage of mangrove forests therefore represents an important component in modeling regional and global C budgets. Mangrove forests also provide a wide range of ecological services such as maintenance of biodiversity, nursery and breeding grounds for fish and invertebrates, and mitigation of disasters (e.g., typhoon, flood, and tsunami) (Alongi, 2011). As a result, mangrove forests have been recognized as a crucial component in climate change mitigation strategies (Alongi, 2011; Donato et al., 2011; Kauffman et al., 2011) and reducing emissions from deforestation and degradation (REDD+) schemes (Siikamäki et al., 2012). Ironically, mangrove forests are among the most threatened ecosystems in the tropics (Valiela et al., 2001), and rapidly deforested by land conversion and natural disasters (Alongi, 2002). In which, aquaculture development is a major cause of mangrove degradation (Seto and Fragkias, 2007), and is a critical issue in many developing countries (Valiela et al., 2001). Mangrove forests have been reduced by at least 35% of their total area from 1980 to 2000 in Africa, Asia, and the Americas (Valiela et al., 2001), and the global mangrove deforestation rate is estimated to be between 1 and 2% per year (FAO, 2007). The loss of mangrove forests will lead to critical consequences such as loss in biodiversity, ecosystem stability, ecosystem services, and the sequestration of C. Moreover, the loss of above-ground biomass may exacerbate the decomposition rate of C-rich sediments in mangrove forests, eventually emitting greenhouse gases (GHGs) to the atmosphere (Donato et al., 2011; Lovelock et al., 2011). Thus, conservation programs (e.g., REDD+) would benefit the protection of mangrove forests and biodiversity in developing countries (Donato et al., 2011; Siikamäki et al., 2012).

The requirements of the REDD+ schemes include a scrupulous monitoring of ecosystem C storage (MgC ha^{-1}), emissions of GHGs, and emission factors associated with land use change (Holly et al., 2007; Lydia et al., 2008). Although ecosystem C storage has been thoroughly quantified for mangrove forests in Asia-Pacific (Donato et al., 2011), oceanic islands (Kauffman et al., 2011), and Caribbean (Adame et al., 2013) regions, yet the assessment of C storage has not been conducted for mangrove forests of Vietnam where these systems constitute

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a large proportion of its coastlines. Thus, quantification of ecosystem C storage of mangrove forests is a prerequisite for future development of climate change mitigation strategies and the REDD+ schemes in Vietnam, and will represent a crucial part of the puzzle when extrapolating C sinks at the regional and global scales (Donato et al., 2011).

The mangrove forest area in Mui Ca Mau National Park, Vietnam (CMNP) is 13,400 ha, accounting for the largest proportion (~37%) of mangrove forests in the Mekong Delta, South Vietnam (Sam and Hong, 2003). Since the 1990s the mangrove forest has exhibited extensive levels of deforestation by massive construction of shrimp ponds (Clough et al., 2002), and this had an observable impact on marine production-based catch (de Graaf and Xuan, 1998), major changes in hydrological processes and soil acidification (Blasco et al., 2001), and may be an unforeseen driving force for the emissions of the GHGs (Lovelock et al., 2011). Despite these observations, the quantification of the C storage of mangrove forests from the region has not been performed. Information and baseline data on C storage would benefit the development of more accurate models and mitigation strategies for climate change, and the development of effective REDD+ schemes. In the present study, we hypothesized that the below-ground C stock accounts for the largest proportion of ecosystem C storage, and that ecosystem C storage of the CMNP's mangrove forest is comparable to that from the Asia-Pacific region. We quantified the C storage of mangrove forest in the CMNP by measuring the biomass of trees, roots, downed woody debris, and sediment organic C and overall depth.

2. Materials and methods

2.1. Study area

The present study was conducted in an estuarine mangrove forest of the CMNP in the Mekong Delta. The CMNP is located between 08°32′–08°41′N and 104°44′–104°55′E in the southernmost tip of the Mekong Delta (Fig. 1). The mangrove forest is dominated by *Avicennia alba*, *Avicennia officinalis*, *Excoecaria agallocha*, *Thespesia populnea*, *Xylocarpus moluccensis*, *Bruguiera parviflora*, *Bruguiera sexangula*, *Ceriops tagal*, *Rhizophora apiculata*, and *Sonneratia caseolaris* with tree heights ranging from 6.3 to 12.1 m (Tinh et al., 2009). The mangrove forest provides many ecological functions and services, being an important habitat for critically endangered species of four-toed terrapin *Batagur baska*, hairy nosed otter *Lutra sumatrana*, and black-faced spoonbill *Platalea minor*, and it is an important stopover and wintering habitat for a large number of migratory birds (http://www.ramsar.org), and nursery grounds for many species of fish and invertebrates (Hong and San, 1993). Additionally, mangrove forest is thought to play a critical role in supporting the coastal fisheries of the Mekong Delta region, in which each hectare of mangrove forest has been estimated to support a marine catch of 450 kg year^{-1} (de Graaf and Xuan, 1998). The CMNP was declared as a Ramsar Site (http://www.ramsar.org) in 2006 and a UNESCO Biosphere Reserve (http://www.unesco.org) in 2009.

The CMNP is located within a tropical monsoon climate zone with a rainy season from May to November and a dry season from December to April. The rainfall averages 2400 mm per year with the highest precipitation level recorded in October (Tinh et al., 2009). The mean monthly temperature of the region ranges from 25.9 to 29 °C with an annual mean of 27.6 °C (Tinh et al., 2009). Tides are mixed diurnal and semi-diurnal regimes with a range of tidal amplitude between 0.5 and 1.5 m. The salinity of the Cua Lon River ranged from 22.9 to 26.9‰ during the sampling campaign (*unpublished data*).

2.2. Field sampling

A total of three 135 m long transects was established parallel in fringe forest (near the river bank), through to transitional forest, and to interior forest during December 2012, with each transect having three 7 m radius circular plots spaced 45 m from their respective center, and the distance between transects was approximately 70 m. The fringe forest was dominated primarily by the *A. alba*, *A. officinalis*, and *S. caseolaris* (Fig. 1). The transitional and interior forests had a high density of *R. apiculata*, *A. alba*, *A. officinalis*, and *B. parviflora* (Fig. 1).

Within each sampling plot, the above-ground C stock was obtained by measuring the biomass of living and standing dead trees, and downed woody debris. The below-ground C stock was obtained by measuring mangrove roots and sedimentary organic C (Donato et al., 2011; Kauffman et al., 2011). For tree biomass measurement, all trees rooted within the circular plot with a stem diameter >5 cm or a tree height >1.3 m were measured for the stem diameter at breast height (DBH) at 1.3 m or above the highest prop root of *R. apiculata*. In all sampling

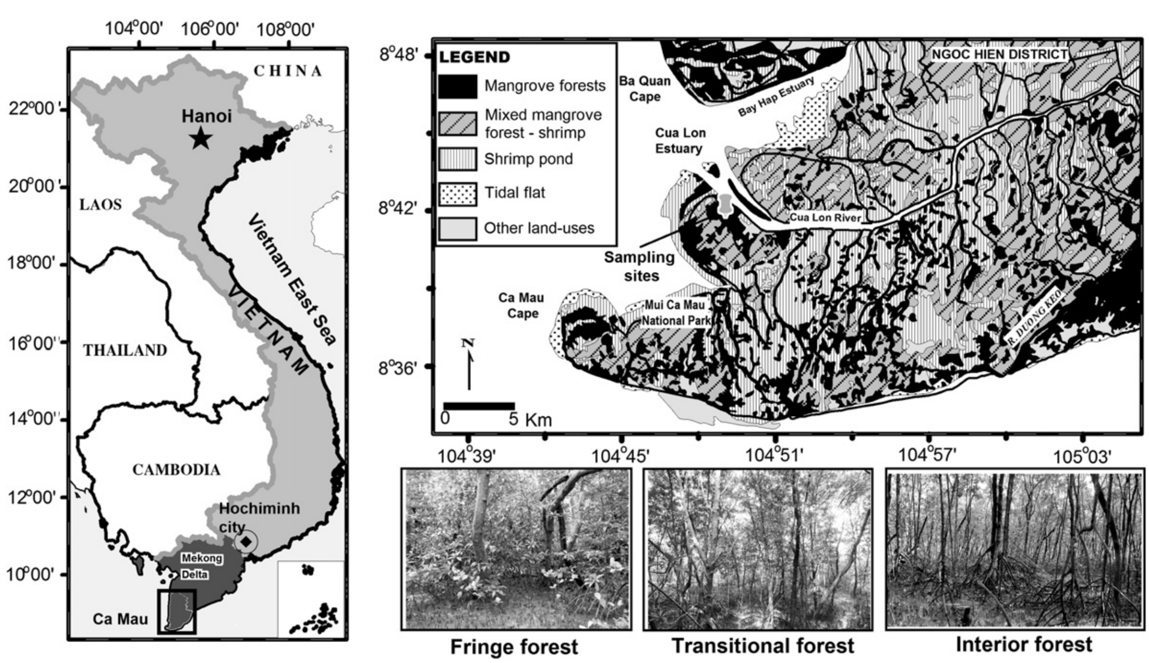

Fig. 1. Sampling locations in mangrove forest of Mui Ca Mau National Park, Vietnam. Mangrove photos show an example of the typical floristic composition in the fringe forest (dominated by *A. alba*, *A. officinalis* and *S. caseolaris*), transitional forest (dominated by *R. apiculata*, and *A. alba*), and interior forest (dominated by *R. apiculata*).