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Current and potential carbon stocks in Moso bamboo forests in China

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ABSTRACT

Bamboo forests provide important ecosystem services and play an important role in terrestrial carbon cycling. Of the approximately 500 bamboo species in China, Moso bamboo (*Phyllostachys pubescens*) is the most important one in terms of distribution, timber value, and other economic values. In this study, we estimated current and potential carbon stocks in China's Moso bamboo forests and in their products. The results showed that Moso bamboo forests in China stored about 611.15 ± 142.31 Tg C, 75% of which was in the top 60 cm soil, 22% in the biomass of Moso bamboos, and 3% in the ground layer (i.e., bamboo litter, shrub, and herb layers). Moso bamboo products store 10.19 ± 2.54 Tg C per year. The potential carbon stocks reach 1331.4 ± 325.1 Tg C, while the potential C stored in products is 29.22 ± 7.31 Tg C a^{-1}. Our results indicate that Moso bamboo forests and products play a critical role in C sequestration. The information gained in this study will facilitate policy decisions concerning carbon sequestration and management of Moso bamboo forests in China.

1. Introduction

Combustion of fossil fuel and changes in land use and land cover, such as those resulting from deforestation, are considered as the primary causes for the increasing concentration of atmospheric CO_2 (IPCC, 2007). Current strategies to combat climate change have shifted from focusing only on reducing CO_2 emission to an integrated approach of reducing anthropogenic CO_2 emission and conserving natural ecosystems with high carbon (C) sequestration rates (Canadell and Raupach, 2008). For example, the United Nations Collaborative Programme REDD (Reduced Emissions from Deforestation and Forest Degradation in Developing Countries) proposed financial incentives for forest management that controls C emission (Miles and Kapos, 2008). Our ability to adequately prioritize conservation and restoration efforts relies on accurate estimates of the C stock and C retention potential of various ecosystems (Keith et al., 2009). C dynamics in terrestrial forests have received substantial attention from ecologists (IPCC, 1999; Sabine et al., 2004), and recent research has underscored the important and disproportionate contribution of bamboo forests to C cycling (Chen et al., 2009; Isagi et al., 1997; Wang and Wang, 2003; Yen and Lee, 2011; Zhou et al., 2011).

Bamboos are a group of plants that belong to the subfamily *Bambusoideae* in the family *Gramineae*. There are approximately 1500 species of bamboo in 87 genera worldwide (Li and Kobayashi, 2004). Bamboo is an important forest type in tropical and subtropical areas (Song et al., 2011), with a total area of 31.5 million ha globally, accounting for about 0.8% of the world's total forest area in 2010 (FAO, 2010). Although the total forest area in many countries has drastically decreased, bamboo forest area has progressively increased (Guo et al., 2005).

China has the richest bamboo resources in the world in terms of number of species (>500 species in 39 genera) and area, and has long been known as the "Kingdom of Bamboo". In past 30 years since China's economic reforms, the bamboo industry in China has been rapidly developed. The area of bamboo forests has steadily increased and is currently at about 6.72 million hm^2 (data from the Seventh National Forest Resource Inventory Report); 63% of which is occupied by Moso bamboo (*Phyllostachys pubescens*) forests.

Moso bamboo is economically important because it can be used in many ways. The edible shoot is a popular delicacy, and the timber of Moso bamboo has been widely used for flooring, furniture, and

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the making of charcoal (Liu et al., 2011; Song et al., 2011). Because of Moso bamboo's high economic return, its cultivation has dramatically increased in recent decades. The increased cultivation compensates for the increasing rate of tropical deforestation. In addition to providing economic benefits, Moso bamboo can help reduce soil erosion (Austin et al., 1970) and increase C sequestration (Zhou et al., 2011).

Moso bamboo is one of the fastest-growing plants in the world, and grows to its full height in 2–3 months (Fu, 2001). It grows so rapidly in part because the developed rhizome system that connects culms in the soil enables the transport of nutrients and carbonates from mature to young culms (Komatsu et al., 2012; Li et al., 1998). According to previous research, 1/4 of the biomass in tropical regions and 1/5 in subtropical regions is represented by bamboo (Anonymous, 1997). Given that most Moso bamboo can grow within the broad band circumscribed by the Tropics of Cancer and Capricorn, its contribution to global C sequestration could be substantial.

Several researchers have explored C cycling in bamboo and Moso bamboo forests and have synthesized information concerning primary production, biomass, litter production, C emission, and other variables (Yen and Lee, 2011; Zhou et al., 2011). These reports have confirmed that Moso bamboo forests are important C sinks and have a high C sequestration potential. These reports, however, have mostly focused on the quantities of C stored in each part of the Moso bamboo ecosystem (vegetation, soil, and litter) and have largely ignored the quantity of Moso bamboo C that is moved out of the forest and used to make products. The quantity of C stored in bamboo products is important because C is generally separated from soil and may degrade very slowly. Several studies have attempted to quantify the C in specific bamboo stands (Du et al., 2010; Xu et al., 2013; Yen and Lee, 2011), but no study has considered C stocks of Moso bamboo forests, the C transfer in the Moso bamboo products, and the potential for C storage in Moso bamboo forests at the national level. Such information is needed for developing policy for the management of Moso bamboo forests in China. Therefore, the objectives of this study are to quantify the current C stocks in Moso bamboo forests and in its products in China, and the potential for C storage in such forests and products.

2. Material and methods

2.1. Data sources

Four datasets: the 7th National Forest Resource Inventory Report (NFRIR) in 2010 (Ministry of Forestry (2010)), statistical yearbooks of each province, biomass and soil C data in published research articles, and land use and land cover data from Land Cover Products of China are used in this research (see Table 1). The 7th NFRIR was the most comprehensive inventory available for China and provided Moso bamboo area, distribution, and culms quantity. The statistical yearbooks of each province provided the quantity of Moso bamboo products. The published literature provided ecosystem C storage, including vegetation C (i.e., aboveground and belowground C in the Moso bamboo), ground layer C (i.e., C in shrubs, herbs, and litter), and soil organic C (SOC). We searched for data concerning Moso bamboo forests in China in “China Knowledge Resource Integrated Database” and “Google Scholar Database” until the end of 2013. Land Cover Products of China was downloaded from the Cold and Arid Regions Science Data Center.

2.2. Estimation of C storage in Moso bamboo ecosystem and its products

(1) Ecosystem C storage

The ecosystem C storage is estimated as:

$$C_{ECO} = C_{VEG} + C_{GL} + C_{SOIL} \quad (1)$$

where C_{ECO} is C storage in the Moso bamboo ecosystem, and C_{VEG}, C_{GL}, and C_{SOIL} are C stored in vegetation, the ground layer, and soil, respectively.

The total C stock of Moso bamboo forests in China is the sum of C_{ECO} in each province.

(2) Vegetation C storage

Moso bamboo is one of the fastest growing plants and can rapidly recover from removal of biomass (Zhou et al., 2005). When a Moso bamboo stand becomes mature, its living biomass tends to be at the maximum and remains in a dynamic balance (Shang, 2002). A loss of biomass due to harvesting can be rapidly compensated for by subsequent regrowth. Therefore, the biomass of mature Moso bamboo stands can be assumed to be steady-state.

Vegetation C is calculated by multiplying the average biomass (including both aboveground and belowground biomass) and the C:biomass ratio. The biomass per ha of a Moso bamboo stand varies with geographical location, stand density, site conditions and management practices. Studies on Moso bamboo biomass in each province have been reviewed, and the biomass data have been collated (Chen et al., 2009; Fei et al., 2011; Guo et al., 2013). The national forestry inventory provides the area of Moso bamboo stands in each province. The C stocks in living biomasses of Moso bamboo forests are calculated as:

$$B_i = Ba_i \times A_i \times 10^{-6} \quad (2)$$

where B_i is the total biomass (Tg dm), Ba_i is the average biomass per ha (Mg dm hm^{-2}), A_i is the area (hm^2 dm) of Moso bamboo forests, and i represents the province number.

3) Ground layer and soil C storage

C_{GL} is estimated by multiplying the dry mass of the ground layer

Table 1
Description of the four datasets used in this study.

	Datasets	Data contents	Data sources
I	7th NFRIR	Moso bamboo area, distribution, culm quantity of each province; Major plantation forests types, area, timber volume	Data from Ministry of Forestry, China
II	Statistical yearbooks	Moso bamboo products quantity of each province	Data from each province statistical bureau
III	Literature data	Moso bamboo biomass, carbon density, culm density, SOC, ground layer biomass	Data mostly from Chen et al., 2009; Fei et al., 2011; Guo et al., 2013
IV	Land cover products	Land cover types, elevation, climate	Data from Cold and Arid Regions Science Data Center