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Aboveground carbon stock, allocation and sequestration potential during vegetation recovery in the karst region of southwestern China: A case study at a watershed scale

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ABSTRACT

Karst landscape in southwestern China is one of the most typical landscapes developed on carbonate bedrock and has the largest area in the world. Carbon sequestration potentials during secondary karst vegetation recovery remain uncertain. Based on the vegetation map and 87 sampling plots at five stages of natural vegetation succession, this study estimated aboveground (AG) vegetation carbon stocks and dynamics at a watershed scale. AG carbon density of grasslands, shrublands, shrub forests, secondary forests and primary forests was 1.70, 4.15, 22.3, 70.3, 142.2 Mg ha^{-1}, respectively. The ten most important species stored 71.6–96.1% of total AG carbon stock, indicating that carbon pool in karst vegetation was determined by a few dominant species. Main contributors to AG carbon stock shifted from individuals in small diameter classes in shrublands to individuals in large diameter classes in primary forests, indicating that carbon increases in the early vegetation succession resulted from high recruitment of woody plants, while carbon accumulations in the later forests were mainly due to tree growth. The long time required for secondary forests to recover carbon density to the level of primary forests could be explained by the slow speed of large evergreen trees reaching a high level of dominance during secondary succession on the harsh habitats. The total AG carbon stock of the studied watershed (7.50×10^3 ha) was 85.9×10^3 Mg, of which paddy fields, dry lands, grasslands, shrublands, shrub forests and secondary forests accounted for 22.6%, 3.49%, 0.34%, 5.97%, 12.3% and 55.3%, respectively. The AG carbon stock in this watershed would increase by 92.5% in 50–100 years and by 4.40 times in 140–200 years if the degraded vegetation types could continue to develop into mature forests. Although carbon density of karst forests was significantly lower than that of the forests on non-karst habitats in the same latitudinal zone, the degraded karst vegetation showed a great carbon sequestration potential due to the large distribution area in southwestern China.

1. Introduction

The dynamic of carbon storages in terrestrial ecosystems plays an important role in regulating the global carbon cycle and atmospheric CO_2 concentration (Dixon et al., 1994; Houghton et al., 2000). Quantifying carbon stocks and assessing carbon sequestration potentials of different ecosystem types is one of the key issues of global carbon cycle study (Houghton et al., 2000; Fang et al., 2007; Yu et al., 2010a). Many forestry-developed countries or continents, such as America (Pacala et al., 2001), Brazil (Houghton et al., 2000) and Europe (Janssens et al., 2003; Nabuurs et al., 2003), have comprehensively assessed their national vegetation carbon stocks, especially carbon stocks in forests. In China, previous studies have assessed the carbon stocks in grasslands

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(Ni, 2002; Piao et al., 2007; Fan et al., 2008), shrublands (Hu et al., 2006; Yu et al., 2010a), forests (Zhou et al., 2000; Fang et al., 2001; Wang et al., 2001; Zhao and Zhou, 2006) and terrestrial ecosystems (Fang et al., 2007; Piao et al., 2009; Yu et al., 2010a).

Both biotic and abiotic factors, such as climate, site condition, species composition, community structure and human disturbance, largely influence vegetation carbon stocks. The different understanding of how these factors affect carbon cycle process, different estimating methods, and the spatial and temporal variability and complexity of ecosystem carbon stocks result in large uncertainties in estimating Chinese vegetation carbon stocks (Zhou et al., 2000; Wang et al., 2001; Zhao and Zhou, 2006). For example, the estimates of carbon storage in Chinese grasslands ranged between 1.05 Pg C (Piao et al., 2007) and 3.32 Pg C (Fan et al., 2008), while the estimates for Chinese forest carbon stock varied from 3.26 Pg C (Wang et al., 2001) to 7.47 Pg C (Yu et al., 2010a). China, with a vast territory, has a variety of climates, topographies and ecosystem types. Therefore, based on the local ecological and environmental conditions, the detailed study on carbon stocks and cycles at small regional and/or ecosystem scales is urgently needed for explaining and assessing these uncertainties and improving the accuracy of estimating carbon storages in Chinese terrestrial ecosystems (Yu et al., 2010a).

Karst topography is widespread throughout the world and covers about 12% of the world's land area (Liu, 2009). China has approximately 3.44 million km^2 of karst areas (buried, covered, and exposed carbonate rock areas), about 36% of its total land and 15.6% of all karst areas in the world (Jiang et al., 2014). The karst landscape of southwestern China is one of the most typical landscapes developed on carbonate bedrock in the world and is characterized by extremely slow soil formation from the underlying limestone and very shallow and patchy soil with a low water retention capacity (Zhu, 1997; Liu, 2009). The dominant vegetation in the subtropical karst region is a mixed evergreen and deciduous broad-leaved forest, which is remarkably different from the typical vegetation types in non-karst regions of China (i.e., evergreen broad-leaved forest) and in other regions of the world (e.g., deserts in Northern Africa and Central Asia) at the same latitudinal zone (Guo et al., 2011). Quantifying vegetation carbon storages in this unique region is very important for improving the accuracy of estimating Chinese vegetation carbon storages and evaluating the role of Chinese terrestrial ecosystems in global carbon cycle. However, due to the high habitat heterogeneity, high vegetation fragmentation, and complex and irregular plant growth forms, biomass and carbon stocks of different vegetation types in the region are difficult to be measured and have seldom been studied (Liu et al., 2009; Tan et al., 2014). Only a few studies have reported the biomass of karst forests (Yang and Cheng, 1991; Zhu et al., 1995; Liu et al., 2009; Yu et al., 2010b) and shrublands (Tu and Yang, 1995).

Land-use and land-cover change plays an important role in CO_2 exchange between terrestrial biosphere and atmosphere (IPCC, 2001). Secondary forests have the potential to capture large amounts of C released during vegetation degradation and can play an important role in sequestering atmospheric CO_2 and regulating regional carbon cycle (Orihuela-Belmonte et al., 2013). In the past decades, many karst forests have experienced varying degrees of degradation due to human disturbances, such as deforestation, agricultural expansion, livestock overgrazing and fire (Liu, 2009). Rocky desertification is the most serious ecological and environmental problem in this region. The desertification area is about 12 million ha, which is up to 26.5% of the whole karst area of southwestern China (The State Forestry Administration of China, 2012). Many protection measures and re-vegetation programs have been carried out to counteract this trend, leading to widespread secondary vegetation succession in this region. Dramatic changes in species composition and vegetation structure occur during the process of secondary succession (Liu et al., 2011b), which largely influence carbon stocks and dynamics (Culmsee et al., 2010; Mascaro et al., 2012; Orihuela-Belmonte et al., 2013). However, carbon dynamics during secondary karst vegetation recovery have seldom been addressed. Only a few studies reported significant carbon accumulations during natural karst vegetation recovery (Liu et al., 2013; Tan et al., 2014) and in an age-sequence of *Zanthoxylum bungeanum* plantations (Cheng et al., 2015). Moreover, regional carbon sequestration potential during vegetation recovery in this area is still unclear, which is important for assessing its contribution to global carbon cycle and providing new insights into reforestation programs and carbon sink managements in this region (Cheng et al., 2015).

In this paper, based on the vegetation map and data collected from 87 plots at different stages of karst vegetation succession, we

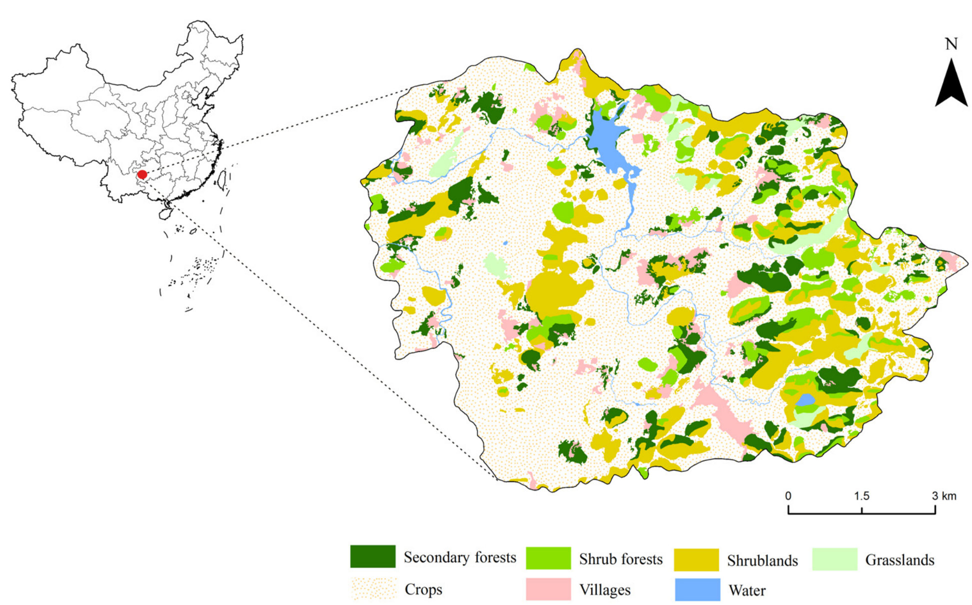

Fig. 1. Vegetation map of the Houzhai watershed, SW China.