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Influences of stand characteristics and environmental factors on forest biomass and root–shoot allocation in southwest China

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ABSTRACT

Tree biomass and it's allocation pattern may respond to the environmental conditions and are quite important for understanding the global carbon cycling, climate change, and forest management. However, how stand characteristics (e.g. tree age, density) and environmental factor (e.g. climate, site conditions, and soil chemistry) influence the biomass and biomass allocation in southwest of China has not been well investigated. We analyzed 318 field measurements of forest biomass in this region, which 62 sites were obtained from our field measurements and the others from the national forest inventory. The results showed that the average above-ground biomass (AGB) and below-ground biomass (BGB) were 134 Mg/ha and 28 Mg/ha, respectively. The root/shoot biomass ratio (R/S) ranged between 0.06 and 0.81, with an average of 0.22. Forest stand characteristics explained 43% and 21% of the variation in AGB and BGB, respectively, while climate only explained 2–4%, reflecting the strong effect of forest features on biomass. However, only 5% of the R/S ratio was explained by climate, soil chemistry, and stand characteristics, suggesting that these factors had no significant effect on biomass allocation. In addition, the scaling exponents between AGB and BGB did not differ significantly from 1, and did not vary with mean annual temperature, mean annual precipitation, longitude, latitude, altitude, soil pH, soil total nitrogen concentration, and stand age, but did vary with soil total phosphorus concentration, stand density, and forest type. Our findings suggest that stand characteristics have a marked impact on forest biomass, and root biomass scales isometrically with above-ground biomass in southwest China.

1. Introduction

Forests account for 30% of the land surface of the earth and contain 77% of the total carbon storage in global vegetation (Dixon et al., 1994; Luo et al., 2012, 2014). Previous studies have shown that about 638 Gt C is stored in forest ecosystems, with 283 Gt C in biomass alone (Keeling and Phillips, 2007). In China's forests, complicated stand conditions (e.g. age, density, soil nutrient, topography) and various climatic factors (e.g. temperature, precipitation) are believed to account for a large part of forest carbon stocks (Zhao and Zhou, 2006; Hui et al., 2012). Better understanding of their relative contributions is fundamentally important for making environmental policies and establishing ecosystem carbon management strategies for enhancing the forest carbon sink (Fang et al., 2001; Luo et al., 2012; Zhang et al., 2014).

Compared to above-ground biomass (AGB), below-ground biomass (BGB) is more challenging and costly to measure, and is a major source of uncertainties in large-scale biomass estimation and global carbon cycle prediction (Cairns et al., 1997; Mokany et al., 2006; Wang et al., 2014). The root-to-shoot ratio (R/S) is widely used for estimating BGB from AGB, and thus has been an important variable in forest ecosystem carbon models (Jackson et al., 1996; Cairns et al., 1997; Hui and Jackson, 2006; Mokany et al., 2005).

Whether the R/S varies with environmental factors has been debated in previous studies (Klepper, 1991; Cairns et al., 1997; Coomes and Grubb, 2000; Yang et al., 2009a,b; Hui et al., 2014; Zhang et al., 2015a). The isometric allocation hypothesis suggests that AGB scales one-to-one with respect to BGB, across a diverse

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range of plant species (Enquist and Niklas, 2002; Niklas, 2005, 2006) and community types (Cheng and Niklas, 2007). Recent studies have shown that BGB scales virtually isometrically with AGB, and that the scaling exponent does not vary with tree age, density, latitude, or longitude, but increases with tree size and elevation (Hui et al., 2014). In contrast, optimal partitioning theory (OPT) indicated that plants may allocate preferentially biomass to the organ that acquires the limiting resources (Bloom et al., 1985; Poorter and Nagel, 2000; Poorter et al., 2012). For example, many studies have demonstrated that various factors influence R/S, including stand development, species characteristics (e.g. life form and leaf trait) (Jackson et al., 1996; Zhang et al., 2010a,b), climate (Cairns et al., 1997; Mokany et al., 2006; Yang et al., 2009a; Zhang et al., 2010c), soil properties (Yang et al., 2009b; Lu et al., 2011), and topographical factors (Bruun et al., 2006). These debates suggest an urgent need for examining contributions of environmental variables and stand characteristics to the patterns of forest biomass allocation.

The southwest part of China (hereafter termed SW China), is the second most important forest region in China, accounting for ca. 23% of total country forest area and timber stocking, 25% of the national timber production (Li et al., 2008). In this region, spatial patterns of forest biomass were significantly related to topographic factors, soil nutrients, and habitat characteristics (Peng et al., 2008; Qi et al., 2013; Du et al., 2014). Specifically, the BGB of forest, varying with spatial heterogeneity, was more difficult and costly to obtain than the AGB (Zhang et al., 2013). The uncertainly about BGB estimation suggests an urgent need for examining the relationship between forest biomass allocation and environmental factors in SW China (Zhang et al., 2014).

In the present study, to examine factors affecting large-scale biomass patterns and root–shoot biomass allocation, we used 318 field biomass measurements from seven forest types across the study area in SW China. We used statistical approaches to evaluate (1) how forest biomass and R/S vary across SW China, (2) how forest biomass and R/S respond to stand characteristics and environmental variables, and (3) test the isometric theory at the community level.

2. Materials and methods

2.1. Study sites

The southwest part of China is defined here as including Yunnan, Guizhou, and Guangxi provinces, covering an area of ca. 790,000 km^2. Geographically, this region is mainly located on the Yungui plateau, which is characterized by complex topography. SW China has a subtropical monsoon climate, which is mainly controlled by the southeast and southwest wind. Mean precipitation ranges from 1,000 to 1,300 mm/year and the average annual temperature ranges from 16.8 to 18.1 °C (Wang, 2002). The soil includes red soil, yellow soil, and limestone soil, which belong to HaplicAcrisol, HaplicAcrisol, and EurticVertisol respectively, according to international soil taxonomy (Yuan, 2003). The study area possesses all the major forest types in a subtropical and a tropical region; these include the seven forest types: boreal/alpine *Picea–Abies* forest (BAPF), subtropical montane *Pinus yunnanensis* and *Pinus khasya* forest (SPPF), subtropical *Pinus massoniana* forest (SPMF), Subtropical montane *Pinus armandii*, *Pinus taiwanensis*, and *Pinus densada* forest (SPPPF), subtropical *Cunninghamia lanceolata* forest (SCLF), subtropical evergreen broadleaved forest (SEBF), and tropical rainforest and monsoon forest (TRMF). For just about 4% of all forest area and only three field plots available, the subtropical broadleaved deciduous forests was not included in this study. The more details for seven forest types are provided in the Appendix Dataset.

2.2. Large-scale forest biomass data

We collected tree biomass measurements for 318 field sites across SW China (Fig. 1), including shoot (stem, branch, and leaf) and root biomass. Here, we sampled 62 sites of the major forest types in Guangxi Province. Another 256 sites were obtained from national forest inventory (2004–2008). All sites were selected by the integrated consideration with climate, soil, and forest characteristics. In detail, these sites showed a sound spatial distribution of climate gradients across SW China, ranging from 3.3 to 24.1 °C in

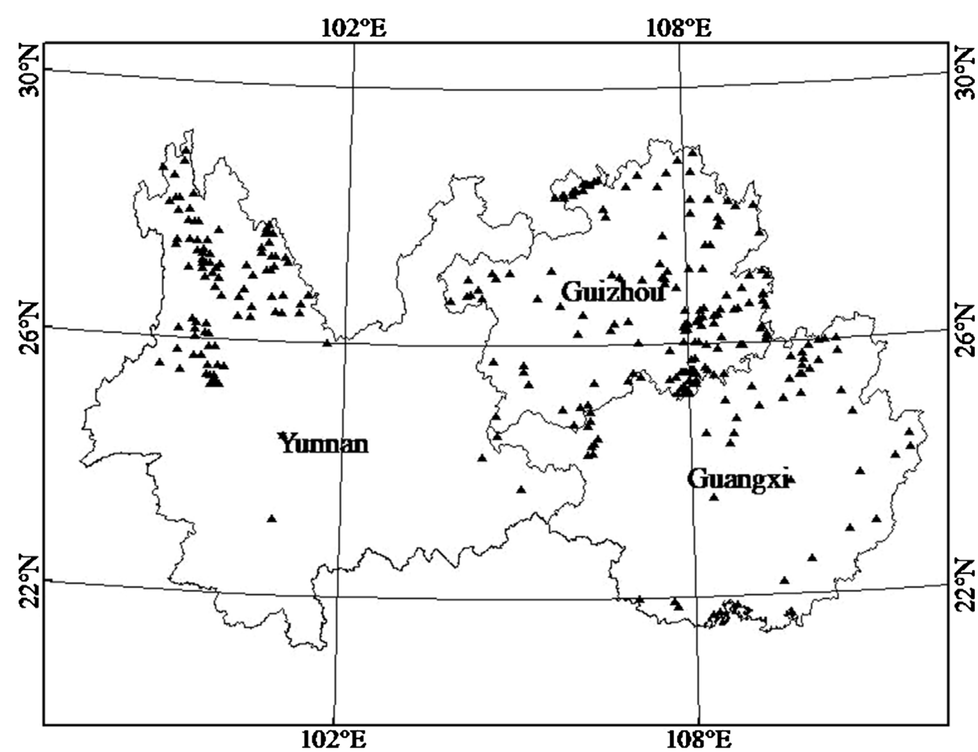

Fig. 1. Locations of the 318 sampling sites across the forests of southwest China.