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ORIGINAL ARTICLE

# Low net primary productivity of dominant tree species in a karst forest, southwestern China: first evidences from tree ring width and girth increment

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**Abstract** Aboveground net primary productivity (ANPP) of two dominant species, one deciduous tree (*Platycarya strobilacea*) and one evergreen tree (*Machilus cavaleriei*), was estimated based on the tree-ring width and the girth increment as well as allometric functions in a karst evergreen and deciduous broadleaved mixed forest in central Guizhou Province, southwestern China. Results showed that the ANPP increased from 1961 to 2015, especially during the last 20–30 years, but with strong variations. The deciduous tree had higher ANPP than the evergreen tree according to two kinds of estimates by the tree ring and girth increment. The averaged ANPP for these two mature trees was 2.27 kg/individual/year, ca. 8 t/ha/year considering the normal stand density. Such karst forest productivity was lower than the natural subtropical forests in China and in the world.

**Keywords** Biomass increment · Tree ring · Girth measurement · Karst evergreen and deciduous broadleaved forest · Allometric functions

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## 1 Introduction

Karst terrain is widely and continuously distributed in southwestern subtropical and tropical China, with an area of ca. 0.51 million km$^2$ and accounting for 5.8% of the total land area in China. The dissoluble landforms naturally make the environment harsh, fragile, heterogenetic, and vulnerable to human disturbances. A type of land degradation called rocky desertification is thereby common in this region (Jiang et al. 2014). Therefore, vegetation living in such karst habitat has a low growth rate and low aboveground biomass (AGB) (Zhu et al. 1995a; Liu et al. 2009, 2013, 2016a), but with high belowground biomass (BGB) allocation (Ni et al. 2015).

Trees in karst evergreen and deciduous broadleaved mixed forests grow slowly based on the stem analysis (Zhu et al. 1995b), and forest net primary productivity (NPP) is therefore predicted to be lower than typical subtropical evergreen broadleaved forests. However there have been so far no field measurements to prove such hypothesis. In this study, we estimated aboveground NPP (ANPP) based on two variables, the tree-ring width (TRW) and the girth increment (GI) of two dominant tree species in an evergreen and deciduous broadleaved mixed forest in central Guizhou Province, southwestern China. We hypothesize, like the low AGB, that karst forests have low ANPP and even lower total NPP in southwestern China.

## 2 Methods

### 2.1 Study area

The field sampling and measurement were conducted in a permanent forest plot with an area of 2 ha located in the

Tianlongshan Mountain (26°14′40″–43″N, 105°45′42″–50″ E, 1402–1512 m), Puding County, central Guizhou Province. The sampling location is in the Houzhai River catchment with an area of 81 km$^2$, featured by the plateau-surface karst morphology. It lies in a middle subtropical region of China and is controlled by monsoon climates. The mean annual temperature during 1961–2013 is 15.2 °C, with mean temperatures of 5.2 and 23.0 °C in January and July, respectively. The average annual precipitation is 1341 mm. The area is cloudy all year with an annual average sunshine percentage of ca. 26%. This catchment is between 1100 and 1400 m above sea level, with a relative height of most hills at 100–200 m. Limestone and dolomite are distributed unevenly. In the plot, brown limestone soil is dominant with a shallow depth of 10–60 cm. The hill slope is very steep (30°–40°) and rock outcrops are distributed everywhere (30%–60% coverage). Secondary evergreen and deciduous broad-leaved mixed forest at the canopy layer of 6–10 m is distributed in hill tops with less human disturbances. Degraded shrub land and tussock are found at the middle and foot of hills. Canola-rice rotation is the key land use type in the drainage basin area.

The whole plot was surveyed in the summer 2012 and re-censused in the summer of 2015. All woody plants within the diameter at breast height (DBH) ≥1 cm were labeled, and species name, their relative positions, DBH, height (or length), and crown width were recorded (Liu et al. 2016a).

### 2.2 Tree-ring measurements

Two dominant tree species in the canopy layer, including one deciduous tree *Platycarya strobilacea* and one evergreen tree *Machilus cavaleriei*, were selected in the summer of 2014. We sampled two parallel cores in opposite positions at the breast height for 26 individual deciduous trees and 21 individual evergreen trees using the 5-mm diameter increment borer (Haglof, Sweden). In total, 47 increment cores of deciduous trees and 38 cores of evergreen trees were available. Increment cores were treated by the standard procedure (Cook and Kairiukstis 1990). Tree rings were visually cross-dated using skeleton plots. TRWs were measured to the nearest 0.01 mm with a LINTAB 5 Measurement System (Rinntech Inc., Germany). The cross-dated tree-ring sequences were quality checked by the

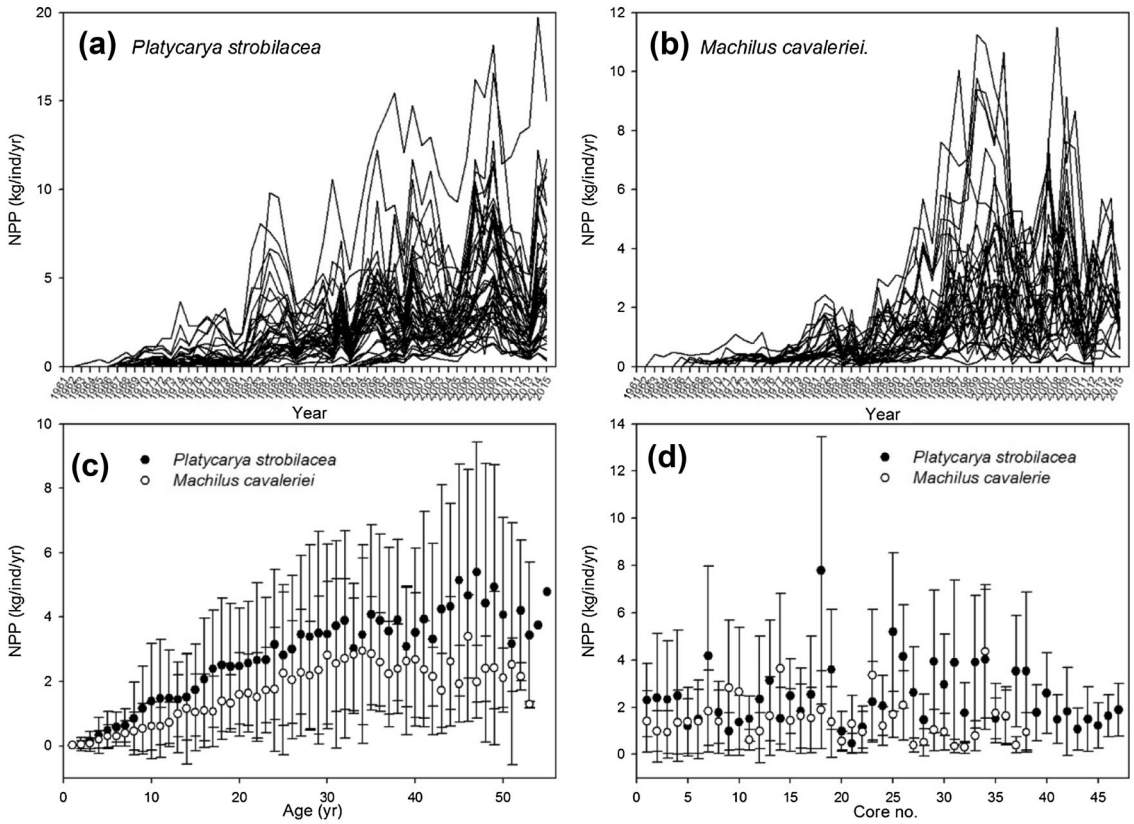


**Fig. 1** ANPP estimated based on TRW. **a**, **b** The real-time series ANPP estimates (i.e. each ANPP starts from the first year of tree-ring growth). **c** ANPP averaged based on ages regardless years (i.e. the first year of tree-ring growth is the age year one). **d** ANPP averaged based on individual cores through all-time series measurements

COFECHA program (Holmes 1983). The ARSTAN program was used to de-trend the TRW sequences using a negative exponential curve or a straight line with negative slope (a horizontal line) and to average the standardized ring-width sequences into a master chronology (Cook 1985; Cook and Kairiukstis 1990). The DBH of each tree individual in each year can be calculated according to the increment of TRW.

### 2.3 Tree girth monitoring

In May 2014, ten major tree species and in total 192 individuals with different DBH classes were selected to set up the permanent tree girth band D1 at 0.01π resolution (UMS AG, Munich, Germany). This includes 24 individuals of *Platycarya strobilacea* and 19 individuals of *Machilus cavaleriei*. The GI was measured every two months (the DBH can be directly read from the girth band), and so far, until January 2017 there have been 16 DBH measurements available. The increment of DBH from the first vegetation survey measurement in July 2012 to the first girth measurement in May 2014 was divided by 11 times to obtain the GI of May 2014.

### 2.4 Biomass and NPP estimates

Based on the current relationships of tree height and DBH, the past tree height can be converted for trees of measured tree-ring and girth. Then using allometric functions: ABG (kg) = $1.9611(D^2H)^{0.8921}$ for *Platycarya strobilacea* and ABG (kg) = $2.6211(D^2H)^{0.8565}$ for *Machilus cavaleriei* (Liu et al. 2009, 2016a), where D (cm) is the tree DBH and H (m) is the tree height, we estimated the annual AGB for trees with tree-ring measurements and the AGB of every two months for trees with girth measurements. All ANPP of both measurements were then calculated according to AGB increments.

## 3 Results and discussion

### 3.1 ANPP based on TRW

ANPP is usually lower during the first 10–20 years and higher during the next 20–30 years (Fig. 1a, b), but has strong variation among different years (Fig. 1c) and among individual trees (Fig. 1d) with strong or weak trends of increase or decrease. Such large variation between years may be partly related to the competition in the forest ecosystem. The individual (ind) deciduous tree (2.41 ± 1.33 kg/ind/year in average) had higher ANPP (Fig. 1) than the individual evergreen tree (1.46 ± 0.91 kg/ind/year).

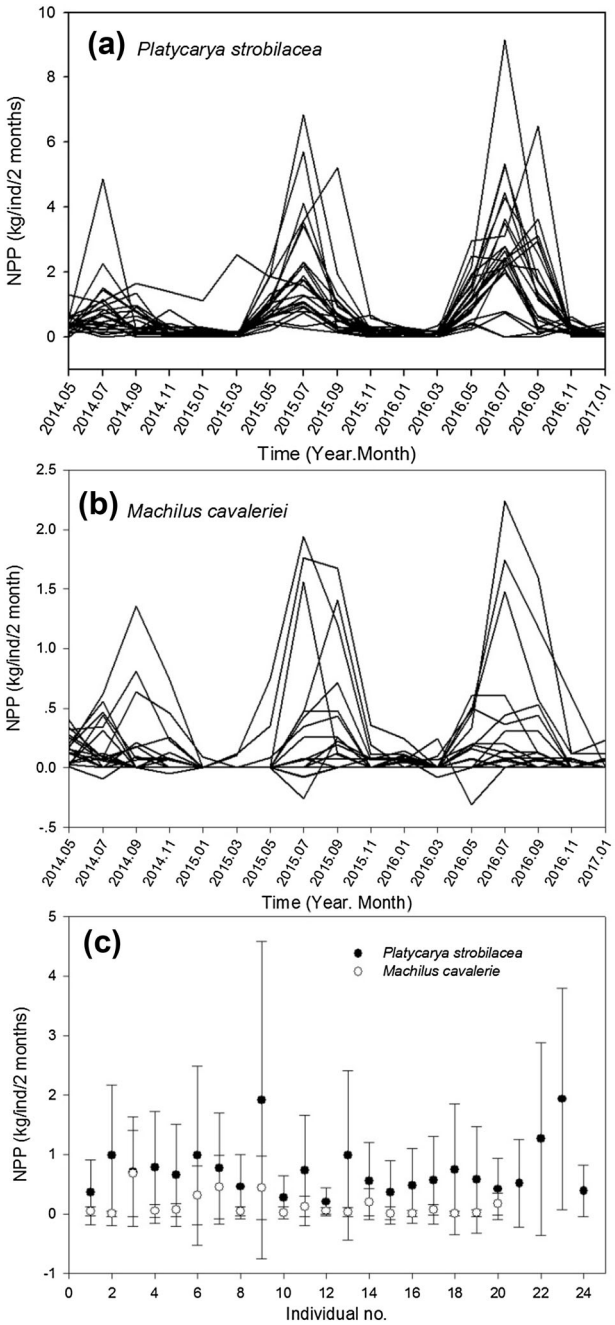


**Fig. 2** NPP estimated based on GI. **a**, **b** The time series NPP estimates. **c** NPP averaged based on individual trees through all-time series measurements

### 3.2 ANPP based GI

Increasing trends of ANPP were observed for most tree individuals during most time intervals, but decreasing trends can also be found for few individuals and periods (Fig. 2a, b). Errors in measuring girth might have happened. The deciduous tree (Fig. 2c) has higher growth rate (0.73 ± 0.44 kg/ind/2 months in average, equals to

4.38 kg/ind/year) than the evergreen tree (0.14 ± 0.19 kg/ind/2 months = 0.84 kg/ind/year).

ANPP of the deciduous tree estimated from GI are about 1.8-fold than NPP based on TRW, but that of the evergreen tree ca. 50% lower (Figs. 1, 2), likely because the former was calculated through all growing years including young, middle-aged and mature trees, and the latter through recent 4.5 years including mature trees only. Bigger deciduous trees have higher NPP than younger ones, and verse versa for evergreen trees.

The stand density of individuals within DBH ≥ 1 cm is 7422 stems/ha in the plot. Five tree species including two trees studied in this paper occupy 92.4% of AGB of this karst evergreen and deciduous broadleaved forest (Liu et al. 2016a). The averaged ANPP for these two mature trees based on both the tree ring and girth measurements is 2.27 kg/ind/year. According to these numbers we could simply estimate the whole forest stand ANPP. If the stand is full of these two trees, ANPP of this stand would be 16.87 t/ha/year. If there is only half the number of such trees, ANPP of this stand would be 8.43 t/ha/year. Such estimated forest ANPP in central plateau-surface karst terrain is therefore in the lower range of natural forest ANPP of subtropical southwestern China, which is from 1.4 to 29.6 t/ha/year with a mean value of 13.6 t/ha/year (Liu et al. 2016b). The dissoluble physical environments of karst terrain, harsh and heterogenetic habitats contribute significantly to this low forest ANPP, the same reason as found in low forest biomasses of this region (Liu et al. 2009, 2016a, b).

Although the belowground NPP (BNPP) is missing in this study, we imagine that the karst forest total NPP could be also lower than the averages of both Chinese (Ni et al. 2001) and global (Luyssaert et al. 2007) subtropical and tropical forest NPP. However, more studies are envisaged in the near future to explore more longer term research of tree-ring and girth measurements, and to investigate the BNPP, of karst forests in different areas of southwestern China. Eddy covariance technique and remote sensing method should be used as supplements of site-based field observation to estimate regional NPP.

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