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Stem radial growth in response to microclimate in an Asian tropical dry karst forest

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ABSTRACT

Relationships between environmental factors and stem radius variation at short temporal scales can provide useful information regarding the sensitivity of tree species' productivity to climate change. In this study, we used automatic point dendrometers to continuously record day-to-day stem radius variations of two evergreen (*Alphonsea monogyna* and *Celtis philippensis* Blanco) and two deciduous (*Lagerstroemia villosa*, *Garuga floribunda* var. *gamblei*) broadleaves species growing in a tropical karst forest in Xishuangbanna, Yunnan, southwest China. Daily stem radius increments were extracted from dendrometer traces, and were correlated with environmental variables recorded from nearby standard meteorological stations. The results indicated that stem radial growth of the four species initiated from late dry season (middle April), speeded in rainy season (July to August) and slowed down after October. Daily stem radius increments of the four species correlated positively with relative humidity (RH) and rainfall (Rain), while correlated negatively with daily maximum temperatures (T_{max}), vapor pressure deficit (VPD) and photosynthetic active radiation (PAR). Rainfall and moisture availability during early growth season (May–June) was important for stem radius growth of the four studied species. Stem radial growth rates of two deciduous species (*L. villosa*, *G. floribunda* var. *gamblei*) declined significantly during short-term drought events occurred during late April and late May to early June, then recovered quickly after one or more rainfall events, which indicated a more sensitive response to climatic factors as compared with evergreen species. These results provide evidences for studying and predicting tree growths and forest productivities in the tropical karst forests under future climate change.

1. Introduction

Dendroclimatological techniques are frequently applied to determine climate–growth relationships of trees in the high altitude or latitude regions where tree growth shows clearly visible annual growth boundaries due to the seasonal cambium activity [9,10,12]. Growth-limiting climatic factors are empirically determined by relating annual growth parameters (i.e. ring width, maximum latewood density) to monthly, seasonal and annual climate variables [16], which may only capture limited information on climatic forcing of tree growth, as comparable growth levels can be achieved through very different seasonal growth patterns [14,27]. Continuous monitoring of stem radial variation throughout the year is crucial for understanding the tree's reaction to short-term changes in environmental conditions, such as temperature, soil water content and rainfall [10]. High-resolution dendrometer measurements are useful in analyzing intra-annual growth and meteorological variables [13], especially in tropics where periodicity of tree-ring formation is often lacking [28].

To gain a better understanding of climate–growth relationships of trees at a higher temporal resolution, many studies have been undertaken to link stem radial variations with climate [3,9,11,22,24,36]. Dendrometer continuously monitor stem radius variations without invasive sampling of the cambium, and record a signal that is composed of irreversible tree growth as well as reversible rhythms of water storage depletion and replenishment [11,34,9,10,24–26]. High-resolution dendrometer are increasingly applied to investigate stem radius variations of trees [1,9,17,20].

Progresses have been achieved for monitoring tree growth in temperate and subtropical vegetation of China. Wang et al. [29] found that spring temperature is a critical factor determining the initiation of radial growth of Qilian juniper (*Sabina przewalskii* Kom.) in northwestern China. Jiang et al. [19] found daily stem radial growth of *Platycladus orientalis* is mainly limited by moisture availability in semi-arid areas of North China. Xiao et al. [32] showed that groundwater depth and the related soil moisture content are key factors potentially limiting the radial growth of *Populus euphratica* in arid regions of northwest China. However, studies on seasonal radial growth dynamics and related climatic forcing in Asian tropics have been scarce.

In Southeast Asia, limestone (karst) cover an area of around 400,000 km^2 (km^2). Karst habitats are characterized by complex terrains

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Table 1
Basic information about the sample trees.

Species	Life form	Tree no.	DBH (cm)	Height (m)
Alphonsea monogyna	Evergreen	Amo1	29.30	19.5
		Amo2	23.25	17.3
		Amo3	43.63	24.9
		Amo4	28.98	19.4
Celtis philippensis Blanco	Evergreen	Cph1	30.89	20.1
		Cph2	21.66	16.7
		Cph3	21.34	16.6
		Cph4	24.84	17.9
Lagerstroemia villosa	Deciduous	Lvi1	29.30	19.5
		Lvi2	30.57	20.0
		Lvi3	35.03	21.7
		Lvi4	22.61	17.1
Garuga floribunda var. *gamblei*	Deciduous	Gfl1	25.16	18.0
		Gfl2	42.68	24.5
		Gfl3	21.34	16.6

(e.g., fissured cliffs and extensive caves) and variable climatic conditions [8]. Because of the great diversity of edaphic conditions and topography, vegetation types on limestone karsts are extremely diverse and rich in endemic taxa in Xishuangbanna, Yunnan, southwest China [33]. In the karst habitat, the co-occurring evergreen species and deciduous species, which have different leaf phenology and eco-physiological traits, adopt drought tolerance and drought avoidance strategy to adapt to the seasonal drought climate, respectively [15].

This study used electronic point dendrometers to monitor stem radius changes of four co-occurring evergreen (*Alphonsea monogyna* and *Celtis philippensis* Blanco) and deciduous (*Lagerstroemia villosa*, *Garuga floribunda* var. *gamblei*) tree species in an Asian tropical dry karst forest. Daily changes in stem radius were continuous monitoring throughout the year of 2014. Daily radial increments were extracted from dendrometer traces and theirs relations with environmental factors were determined. The aims of this study are (1) to determine seasonal radial growth dynamics of karst forest tree species and their response to meteorological variables; and (2) to compare mean radial growth and seasonal growth dynamics among the evergreen and deciduous tree species.

2. Materials and methods

2.1. Study site

The study was conducted in a tropical dry karst forest (21°54′N, 101°46′E, 680 m a.s.l.), which is a part of the Xishuangbanna National Nature Reserve located in Yunnan, southwest China. The forest is dominant by *Cleistanthus sumatranus*, *Lasiococca comberi* and *C. philippensis*. Some deciduous emergent trees, such as *L. villosa*, *G. floribunda* var. *gamblei*, *Chukrasia tabularis*, are sparsely dotted in the forest [33]. Xishuangbanna, which is located at the northern edge of the Asian tropics, has a strongly seasonal climate that is dominated by the South Asian monsoon. The annual mean temperature is 21.7 °C, with a maximum monthly temperature of 25.7 °C for the hottest month (June) and a monthly minimum of 15.9 °C for the coldest month (January). The mean annual precipitation is 1560 mm, of which approximately 87% occurs during May–October rainy season versus 13% in the pronounced 6-month dry season from November to next April. The dry season includes a foggy sub-season from November to February, and a hot sub-season from March to April.

2.2. Dendrometer measurements

Two evergreen tree species *C. philippensis* Blanco and *A. monogyna*, two deciduous tree species *L. villosa* and *G. floribunda* var. *gamblei*, were selected for this study. A total of 15 trees (3–4 per species) were selected for continuous growth observation for a whole vegetation period of 2014. The sampled trees ranged in diameter from 21.3 cm to 43.6 cm, and were healthy canopy adults without any sign of injury (Table 1).

Automatic high-resolution point dendrometers (type DR, Ecomatik, Germany) with a resolution of 2 μm were installed at a height of 1–1.3 m on the trunk and shielded from direct sunlight and physical damage by aluminium foils. The operating principle of the dendrometer is based on the use of a linearly variable differential transformer. Stem radius variations were automatically recorded at 10-min intervals and saved in data logger (DL15, Ecomatik, Germany). To reduce the influence of expansion and shrinkage processes of the bark, the outer barks were removed without wounding the cambial

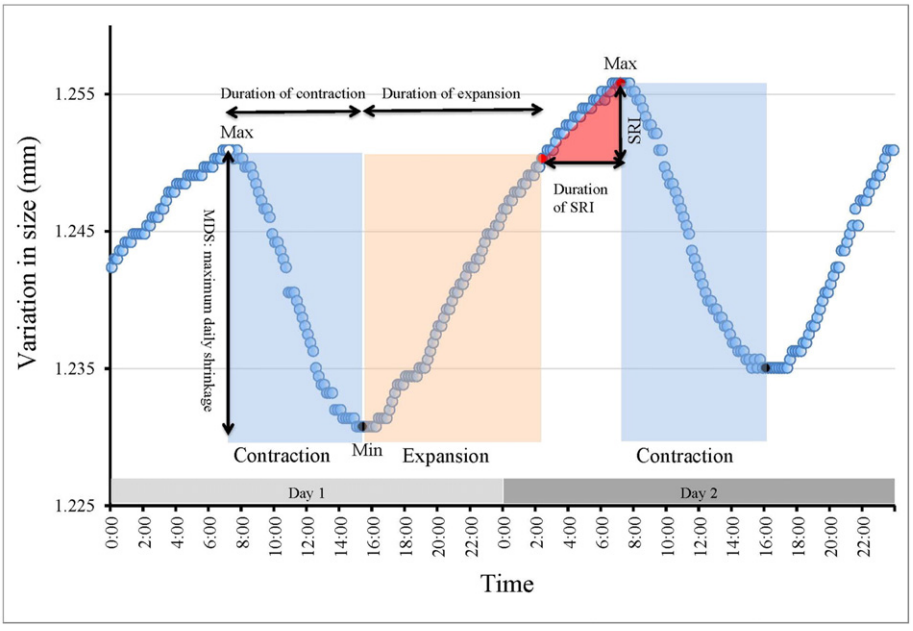

Fig. 1. Stem circadian cycle divided into three distinct phases: contraction, expansion and stem radial increment (SRI).