Global and Planetary Change 132 (2015) 54–63

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Influence of non-climatic factors on the relationships between tree growth and climate over the Chinese Loess Plateau

Keyan Fang [a,b,*], Dan Chen [a], Xiaohua Gou [c], Rosanne D'Arrigo [d], Nicole Davi [d,e]

[a] Key Laboratory of Humid Subtropical Eco-geographical Process (Ministry of Education), College of Geographical Sciences, Fujian Normal University, Fuzhou 350007, China
[b] Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[c] Key Laboratory of Western China's Environmental Systems (Ministry of Education), Research School of Arid Environment and Climate Change, Lanzhou University, Lanzhou 730000, China
[d] Tree-Ring Lab, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA
[e] Department of Environmental Science, William Paterson University, Wayne, NJ 07470, USA

ARTICLE INFO

Article history:
Received 12 August 2014
Received in revised form 17 June 2015
Accepted 19 June 2015
Available online 24 June 2015

Keywords:
Dendroclimatology
Climate–growth relationship
Boosted Regression Tree (BRT)
Tree age
Drought

ABSTRACT

Modulations of non-climatic factors on climate–growth relationships can confound the interpretation of dendroclimatic reconstructions. Accordingly, we evaluated the influences of core direction, tree age, tree size, growth rate and species on the climate–growth relationships of 210 tree-ring cores from Kongtong Mountain and Xiaolong Mountain on the semi-arid Chinese Loess Plateau. We employed both the linear methods of correlation and response function analyses, and the nonlinear method of the Boosted Regression Trees (BRT). Most trees are sensitive to the moisture availability. Old trees are more sensitive to drought than young trees, which may be related to the intensified hydraulic resistances and reduced photosynthesis in response to drought. Tree cores taken from the southern direction are often more sensitive to drought than cores taken from other directions. The enhanced drought sensitivity for the southern cores may be possibly related to more branches and leaves for photosynthesis. Slow-growing trees show higher correlations with precipitation of the September prior to growth. This indicates that the extremely stressed, slow-growing trees tend to rely largely on nutrients produced prior to the growing season. For the reconstructions of annual drought in this region, we suggest collecting tree cores from the southern side of old trees growing at stressed sites.

1. Introduction

Non-climatic factors, including the biological and microsite factors, can modulate the climate–growth relationships, challenging the task to extract climate signal from tree rings (Cook and Kairiukstis, 1990; Fang et al., 2014b; Fritts, 1976; Pederson et al., 2013; Wilmking et al., 2005). These factors could lead to systematic biases in tree-ring based reconstructions (Nehrbass-Ahles et al., 2014). Investigations on the influences of non-climatic factors can aid interpretation of dendroclimatic reconstructions (Fang et al., 2014b; Nehrbass-Ahles et al., 2014; Tardif et al., 2003). Different species may respond to different climate variables in a region (Pederson et al., 2013), suggesting the influences of species-related genetic controls on the climate–growth relationships. In addition, special attention was needed to consider the effects of tree age, because it can complicate the stability of the reconstruction through time (Briffa and Melvin, 2009; Carrer and Urbinati, 2004; Li et al., 2012; Szeicz and MacDonald, 1994; Yu et al., 2008). Old trees, for example, can be more sensitive to climate (Carrer and Urbinati, 2004), while other studies found that the young trees are comparably sensitive to climate (Li et al., 2012; Szeicz and MacDonald, 1994).

Microsite factors can modulate the input of external climate conditions that influence tree growth. In dendroclimatology, tree-ring samples are often collected from forest ecotonal boundaries such as the treeline locations. For the warm and humid sites, it is preferable to select sites with stressful microenvironments with, for example, very shallow soil (Fang et al., 2012a). Since trees experiencing different microsite conditions may respond differently to climate, one must carefully evaluate the microsite conditions for the growth of individual trees before averaging them together to reconstruct climate (Fang et al., 2014b). For example, trees growing at shaded locations may be less sensitive to drought in arid regions. In addition, different microsite conditions can lead to different growth rates, which can also lead to systematic biases in the dendroclimatic reconstructions (Briffa and Melvin, 2009).

Both biological and microsite conditions were significant factors impacting tree growth in Europe and America as investigated by previous studies (Nehrbass-Ahles et al., 2014; Pederson et al., 2013; Tardif et al., 2003). However, the influences of biological and microsite factors on climate–growth relationships in arid Asia and their implications for dendroclimatic reconstructions remain poorly understood. In addition, there are still some non-climatic factors that are not fully addressed previously. For example, although previous studies have considered the

* Corresponding author at: Key Laboratory of Humid Subtropical Eco-geographical Process (Ministry of Education), College of Geographical Sciences, Fujian Normal University, Fuzhou 350007, China.
E-mail address: kfang@fjnu.edu.cn (K. Fang).

http://dx.doi.org/10.1016/j.gloplacha.2015.06.008
0921-8181/

directions of cores for dendrochronological studies to avoid reaction wood (Speer, 2010) and for the reconstruction of net primary productivity (Babst et al., 2014), limited studies have concerned the directions of cores on the climate–growth relationships. Moreover, this study investigated both the linear relationships using the correlations and response functions and nonlinear relationships using the Boosted Regression Tree (BRT) method. Accordingly, we studied the impacts of nine biological and microsite factors on the climate–growth relationships and their implications for dendroclimatic reconstructions at two locations, Xiaolong Mountain and the Kongtong Mountain, in the Chinese Loess Plateau, where a number of tree-ring based reconstructions have been conducted (Li et al., 2007; Liang et al., 2006; Shao and Wu, 1994; Yang et al., 2010). This study hypothesized that climate–growth relationships for individual tree-ring series can be different due to the changes of the non-climatic factors from tree to tree. We thus first grouped the climate–growth relationships for individual tree-ring series and then detect the relationships between these groupings and the non-climatic factors.

2. Data and methods

2.1. Tree rings and climate

The mean temperature of our study region in the Chinese Loess Plateau (Fig. 1) is ~9 °C and the annual total precipitation is ~500 mm. Summer precipitation comprises over two thirds of the annual total precipitation with its peak in July, when the Asian summer monsoon front reaches this region (Fang et al., 2012a,b). Xiaolong Mountain in the south is warmer and wetter than Kongtong Mountain, as the Asian summer monsoon propagates from south to north. Winter conditions are influenced by the winter monsoon, which extends over a long and cold season. Located at the southern boundary of the Chinese Loess Plateau, Xiaolong Mountain is a transitional region between boreal and subtropical forests, and is dominated by both green and evergreen broadleaf species. The *Pinus tabulaeformis* samples were collected from 3 sampling plots at mountain peaks and cliff areas of Xiaolong Mountain (Table S1). Located in the interior region of the Chinese Loess Plateau, Kongtong Mountain is surrounded by grasslands and croplands. The porous loess cannot well retain the precipitation and the thus forests are mainly found over the "rocky island" with rocky substrates to retain moisture on Chinese Loess Plateau. Kongtong Mountain is dominated by summer green broadleaf and the coniferous forests of *Pinus purpurea* and *P. tabulaeformis* are found for some locations. We collected tree-ring samples from both coniferous species from 14 sampling plots (Table S1).

We collected 224 tree-ring cores from 100 trees at Xiaolong Mountain and Kongtong Mountain (Fig. 1 and Table S1). Of these, 122 of the older tree-ring series were used for generating climatic reconstructions (Fang et al., 2012a,b). The additional 104 tree-ring series were mostly taken from young *P. purpurea* trees at Kongtong Mountain. In addition, we considered the information of the species, tree age, basal perimeter, perimeter at breast height, tree height, growth rate, direction of cores, distribution of branches and correspondence between directions of the branches and the cores for individual tree-ring cores. In the field we usually took four cores and tried to reach the pith of each tree. Tree age was then determined by the number of crossdated tree rings of the longest core of a tree. Basal perimeter and perimeter at breast height were both measured in the field. Tree height was estimated by measuring degree of elevation and distance from the tree. Tree height was less accurately measured at numbers in a 5 m interval, such as 5 m, 10 m and 15 m. The average growth rate was calculated as the ratio between perimeter at breast height and tree age. Tree cores were taken from all four sides (i.e. south, north, east and west) when possible (many coniferous trees grow near cliffs with only one or two sides can be sampled). Uneven distribution of branches was observed, particularly for cliff trees, which may influence the growth rate of tree cores in different directions. We thus also recorded whether the tree core direction coincided with directions with most of the branches. It should be noted that some non-climatic factors are not considered in this study, such as the slopes and the canopy density, because most of the sampled coniferous woods are located on mountain peaks or cliff areas (Fig. S1), where it is impractical to measure their slopes and canopy density. We used climate data from the nearest meteorological stations: from Pingliang for Kongtong Mountain and Tianshui for Xiaolong Mountain (Fig. 1).

Following standard dendrochronological methods (Cook and Kairiukstis, 1990), cores were mounted, air dried, and polished for crossdating and measurements of ring width. The crossdating procedure assigns calendar years to individual rings by first visually checking matching of the extremely narrow and wide ring sequences. Measurements were then tested using the program COFECHA for quality control

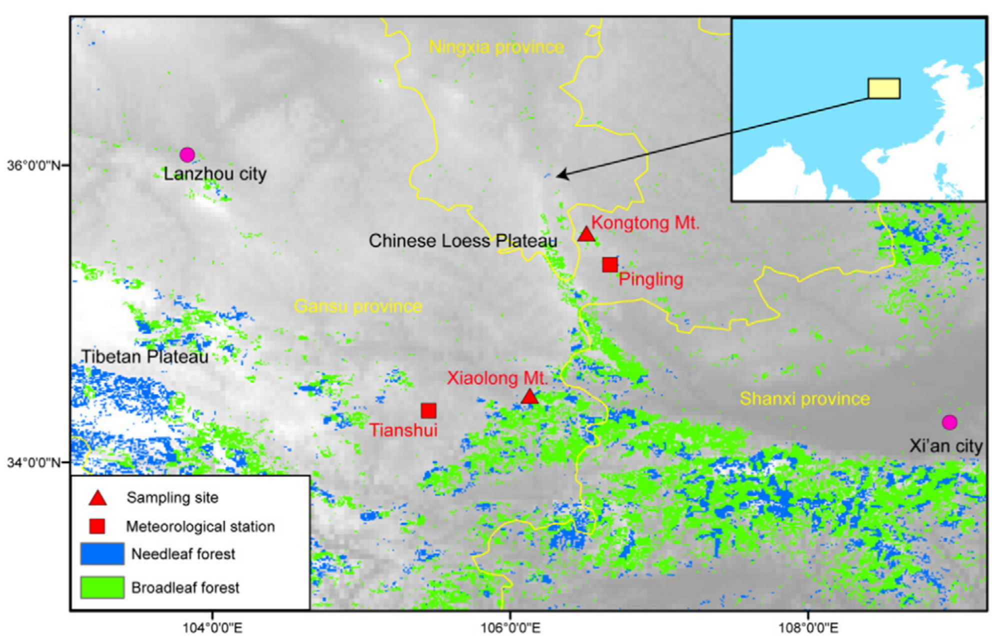

Fig. 1. Locations of the sampling sites, meteorological stations and the topography and distribution of the needleleaf and broadleaf forests over the Chinese Loess Plateau study region. The location of the study region in eastern Asia is also shown.