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Growth response of *Sabina tibetica* to climate factors along an elevation gradient in south Tibet

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ABSTRACT

We examine the climate significance in tree-ring chronologies retrieved from *Sabina tibetica* Kom. (Tibetan juniper) at two sites ranging in elevation from 4124 to 4693 m above sea level (a.s.l.) in the Namling region, south Tibet. The study region is under the control of semi-arid plateau temperate climate. The samples were grouped into high- and low-elevation classes and standard ring-width chronologies for both classes were developed. Statistical analysis revealed a decreasing growth rate yet increasing chronology reliability with increasing elevation. Overall, correlation analyses showed that radial growth in *S. tibetica* at the study sites was controlled by similar climatic factors, regardless of elevation; these factors comprised early winter (November) and early summer (May–June) temperatures as well as annual precipitation (July–June). Slight differences in the correlation between tree growth along the elevation gradient and climate variables were examined. The correlations with early winter temperature varied from significantly positive at the low-elevation site to weakly positive at the high-elevation site, whereas the correlations between radial growth and early summer temperature increased from weakly negative at the low-elevation sites to strongly negative at the high-elevation sites. The abundant precipitation through the year may have masked variations in tree growth on different elevation aspects. Our results will aid future dendroclimatological studies of Namling tree rings in south Tibet and demonstrate the potential of *S. tibetica* Kom. for improving our understanding of environmental impacts on tree growth.

Introduction

High-elevation mountain environments, comprising glaciers, snow, permafrost, etc., are not only the uppermost distribution zone of many vegetation species and other life forms, but are also the most sensitive and fragile environments to global climatic change (Stone, 1992; Kullman, 1993; Shugart, 1998; Thompson, 2000; Diaz et al., 2003). In mountainous areas, the radial growth of trees may be subject to environmental gradients (e.g. in air temperature and soil moisture) associated with elevation (LaMarche, 1974; Hughes and Funkhouser, 2003; Tardif et al., 2003). Climate change affects the distribution and growth dynamics of tree species at high elevations (Payette and Filion, 1985; Kullman, 2002; Camarero and Gutierrez, 2004; Devi et al., 2008). An understanding of tree growth over elevation gradients may be used to evaluate and predict variations in the response of forests to future climate change. A growing number of studies have demonstrated that tree growth can vary with elevation, providing insights into the variability of the growth response under a range of climatic conditions (Fritts et al., 1965; LaMarche, 1974; Hughes and Funkhouser, 2003; Zhang and Hebda, 2004; Gou et al., 2005; Massaccesi et al., 2008).

Standing on the south-facing slope and occupying open forest ranging vertically from 2800 to 4500 m a.s.l., *Sabina tibetica* (Tibetan juniper), one of the most important tree species in western China, is distributed widely in south and east Tibet. This dominant tree species not only provides local residents with lumber but also acts as a major agent for soil and water resource conservation in mountainous areas.

Despite the long history of dendrochronology, studies on the radial growth of *Sabina* species were first reported in the late 1980s (Wu et al., 1988, 1989, 1990; Wu, 1990). Recently, numerous studies of *S. tibetica* have been carried out to reconstruct climate change (Bräuning, 1994, 2001; Wang et al., 2008; Liu et al., 2010, 2011; Yang et al., 2010; Zhu et al., 2011).

High-elevation forests on the Tibetan Plateau (TP) are potentially sensitive to climate change. South Tibet is characterized by semi-arid climates, allowing the distribution belt of junipers to take

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Table 1
Information of sampling sites and the instrumental data.

Sampling/instrumental data sites	Latitude (°N)	Longitude (°E)	Elevation (m a.s.l.)	C/T No.	Length (year)	Time span
NMJW	30.08	89.11	4507–4693	77/37	636	1375–2010
NMNM	29.52	89.59	4124–4210	62/32	417	1594–2010
RKZ	29.15	88.53	3836		55	1956–2010
NAM	29.41	89.06	4000		20	1991–2010
NIM	29.26	90.10	3809.4		37	1974–2010
PDSI	31.25	88.75	–		50	1956–2005
CRU	29.25–30.25	88.75–89.75	4272–5215		47	1956–2002

NMJW and NMNM are two tree-ring sampling sites at the Namling region; RKZ, NAM, and NIM indicate Rikaze, Namling, and Nimu meteorological stations; PDSI is the closest extracted Palmer drought severity index grid from Dai et al. (2004); CRU represents extracted gridded monthly precipitation data of CRUts2.1 from Mitchell and Jones (0.5° × 0.5°, 2005; the original data can be downloaded from http://www.cru.uea.ac.uk/cru/data/hrg/); C/T No. is core/tree number.

up a wide elevation range. Historical climate (expressed as annual temperatures) has been reconstructed using tree-ring widths from the highest Tibetan junipers located in southwest Tibet (Yang et al., 2010). However, little is known about how the radial growth of these trees may vary with elevation.

From a traditional perspective, tree growth at high-elevation timberline is associated with air temperature, while a positive correlation with precipitation predominates at low elevations (Fritts et al., 1965; LaMarche, 1974). In contrast to this generalized idea, several studies have observed similar growth variation patterns along the elevation ranges, and some common limiting climatic factors might synchronize tree growth at different elevations. For example, in western North America, the growth of bristlecone pine in a limited elevational band (elevation range within 150 m) of upper treeline was strongly regulated by temperature regardless of elevation (Salzer et al., 2009). Liang et al. (2010) demonstrated that the initiation of tree-ring growth in Smith firs (*Abies georgei var. smithii*) is controlled by common climatic signals such as July minimum temperature across a broad elevational range (elevation difference is ~800 m) in the Sygera Mountains of the southeastern TP. Li et al. (2012) reported a high degree of similarity in faxon fir growth variation among the elevation gradients (elevation difference is ~400 m) in western Sichuan.

The main aim of this study was to represent two tree-ring width chronologies retrieved from Tibetan junipers along an elevation gradient in south Tibet and to examine the characteristics of the differences in tree growth/climate relationships.

Materials and methods

Study area

Lying on the northern bank of the middle-upper reaches of the Yarlung Tsangpo River Valley, our study region (Fig. 1) (30.08–29.52° N, 89.11–89.59° E; 4124–4693 m a.s.l.) is located in the Namling region, south Tibet, which is between the eastern Gangdese and the Nyainqentanglha Mountains (Mts.). The terrain ascends from southwest to northeast with a typical elevation of 3790–4901 m. The Niangrequ, Tubujiapuqu and Xiangqu Rivers, and their various tributaries, flow through the mountains in this region. The highest point of the study area is the northeastern-oriented Kangzhongma Summit (6043 m a.s.l.) whilst the lowest point is the confluence of the Xiangqu and Yarlung Tsangpo Rivers (3704 m a.s.l.), yielding a relative height difference of 2339 m. Exposed bedrock, loose surfaces and serious gully erosion constitute the main landscape features in the southern parts, while deep valleys and numerous of glacial lakes are found in the northern mountainous areas.

The region is characterized by a semi-arid plateau temperate climate. Annual average temperature is 5.9 °C and the extreme minimum/maximum temperatures are −17.7/26.5 °C, respectively; the annual sunshine is 2917 h and the coldest/hottest month is January/August. Annual average precipitation is 413 mm and the average annual evaporation is 2298 mm, with the majority of the rainfall falling from June to September. *S. tibetica* constitutes the main forestry in the region, and the alpine shrubby steppe soil supports flourishing grass and bush stands.

Tree-ring sampling and chronology development

S. tibetica is a non-shade-tolerant species standing on the south-facing slopes between 4100 and 4600 m a.s.l. in the mountainous area of the Namling region. Field work was conducted in the autumn of 2008 and the spring of 2011. Two study sites were selected at different elevations. The NMNM site (29.52° N, 89.59° E, 4124–4210 m a.s.l.) was chosen at the lower boundary of the juniper forest, and the NMJW site (30.08 °N, 89.11 °E, 4507–4693 m a.s.l.) was located in forest stands at the upper elevation limits of *S. tibetica* in the study area (Fig. 1 and Table 1). Both the high- and low-elevation sites are subject to similar weather patterns. All trees were growing in relatively sparse or isolated conditions with infertile shallow soil, which represent the optimal conditions for the purpose of maximizing climate signals contained in the growth rings.

We collected 77 cores from 37 trees at the high-elevation site (NMJW) and 62 cores from 32 trees at the low-elevation site (NMNM). Two increment cores were collected from each tree using an increment borer at breast height. All of the cores were extracted in this manner to obtain an orthogonal representation of tree growth and to reduce variation in the growth signals caused by variable micro-habitat conditions. In total, 139 increment cores were collected from 69 healthy trees (Table 1).

All the cores were air-dried and mounted on grooved sticks with the transverse surfaces facing upward (Phipps, 1985). Cores were prepared with razor blades to expose ring details to the cellular level (Stokes and Smiley, 1968). Ring widths were registered with a LINTAB 6 measuring system at a resolution of 0.01 mm, and all series were cross-dated by visual inspection (Stokes and Smiley, 1968) and by statistical tests (sign-test and *t*-test) using the software package TSAP-Win (Rinn, 2003). For quality control, we discarded cores which were not good enough for cross-dating (Table 2) and the COFECHA (Holmes, 1983) program was further applied to statistically check the cross-dating results of the samples.

Table 2
Statistical characteristics of STD chronologies for high- and low-elevation sites.

Site	AVE	MS	AC	Core/tree	MSL	Period
High elev.	0.954	0.203	0.37	77/34	636	1375–2010
Low elev.	0.974	0.289	0.44	39/24	417	1594–2010