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Original article

Tree growth and climate sensitivity in open and closed forests of the southeastern Tibetan Plateau

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ABSTRACT

The creation of forest openings is a frequently observed phenomenon in many types of forests. On the southeastern Tibetan Plateau, where the average elevation is greater than 4000 m above sea level, differences in tree growth between forest stands with openings and completely closed stands are poorly characterized. Here, we presented a dendrochronological study of Tibetan juniper (*Juniperus tibetica* Kom.) and Sikkim spruce (*Picea spinulosa* (Griff.) Beissn.) in an open and a closed stand, near Qamdo of eastern Tibet. We found that the growth of juniper responded to climate in a similar way in the open and closed stands, and was positively correlated with temperature from October to January and with the Palmer Drought Severity Index (PDSI) from September to June. In contrast, the growth of spruce responded to climate differently in the open and closed stands: growth was positively correlated with the PDSI from September to May in the open stand, whereas it was positively correlated to November and December temperatures (of the prior year) and current June temperature in the closed stand. Interannual variation in, and standard deviations among, juniper tree ring widths were similar in both stands for the past four centuries, whereas they differed in spruce over the past two centuries, particularly in the 1900s. These results suggest that juniper tree ring growth is less sensitive to stand structure than that of spruce, thus providing more reliable climate signals. The data obtained from our study will help forest managers understand the ecology of juniper and spruce in open and closed stands and are therefore useful for management planning.

Introduction

Forest openings play an important role in shaping the structure of landscapes and also in promoting species coexistence (Zhang and Oliver, 2006; Schliemann and Bockheim, 2011). The function of forest clearings may vary from one opening to another, depending on their size, shape, history, surrounding forest type and tree species (Canham, 1988; Bräker and Baumann, 2006; Perez-de-Lis et al., 2011; Vepakomma et al., 2011; Ge et al., 2013).

In general, forest openings are known to promote tree growth as a result of increased space and access to resources (Bräker and Baumann, 2006; Corcuera et al., 2006; Zhang and Oliver, 2006). However, decreased tree growth was observed in northern Finland, following the creation of openings of various sizes (Ge et al., 2013). As such, growth differences seen in trees in open stands versus closed stands may vary with respect to tree species and local conditions. Regarding growth–climate relationships, the sensitivity of forest trees to climatic factors has generally been found to be stronger in low density versus high density stands (Gea-Izquierdo et al., 2009; Perez-de-Lis et al., 2011). However, tree growth can sometimes be more tolerant of climatic extremes in open stands than in closed stands (McDowell et al., 2006; Martin-Benito et al., 2010; Magruder et al., 2013). In other cases, tree density has had no distinct influence on climatic sensitivity (Kerhoulas and Kane, 2012). Although studies of forest openings have been numerous, spanning many forest types and different landscapes (Brokaw, 1982; Denslow et al., 1998; Zhang and Oliver, 2006), such studies are rare on the Tibetan Plateau.

Spruce and juniper forests cover a vast area on the southeastern Tibetan Plateau, where the average elevation is greater than 4000 m above sea level (Xu, 1981). Forest openings, or clearings, are a frequently observed phenomenon in forests of this region (Ren and Luo, 2013). Maintaining a sustainable forestry industry in the context of future climate change dictates an urgent need to address

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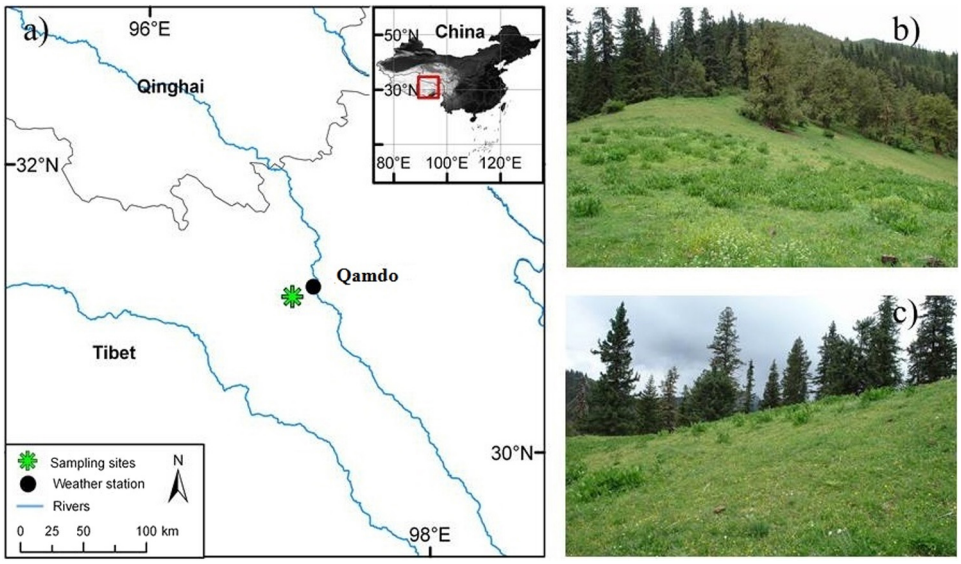

Fig. 1. Location of the sampling site in Qamdo of eastern Tibet (a) and pictures of part of the open stand (b and c).

two questions. First, is there any difference in the growth–climate relationship for trees in open versus closed stands? And second, does the comparison of historical tree ring patterns in open and closed stands provide any clues for identifying the origins of forest openings?

In this study, we attempt to answer the above two questions using a case study on the southeastern Tibetan Plateau. To do so, we examine tree-ring characteristics of Tibetan juniper (*Juniperus tibetica* Kom.) and Sikkim spruce (*Picea spinulosa* (Griff.) Beissn.) growing in either an open stand or a closed stand, and compare the growth–climate response and historical growth patterns in the two stands.

Materials and methods

Study site

This study was located in Qamdo, China on the southeastern Tibetan Plateau (Fig. 1). Data collected at the Qamdo meteorological station (31°09′N, 97°10′E, 3306 m.a.s.l.) reveal that mean monthly air temperature ranges from −2.1 °C in January to 16.2 °C in July for the study area. Mean annual total precipitation is 480 mm, with the bulk of the precipitation occurring from June to September (Fig. 2). Forest coverage in this region is 34.2%. The dominant forest species are Tibetan juniper and Sikkim spruce, which both grow at elevations of up to 4500 m above sea level.

We chose two sites for tree-ring sample collection in this study. The first was a forest stand including a forest opening located at 31°5′N, 97°1′E and at an elevation of 4100 m, and the second, selected for comparison purposes, was a nearby closed forest stand (CS). In the open stand (OS), the opening was 77 m in length and 59 m in width, with mature Tibetan juniper and Sikkim spruce surrounding the opening. Soils were similar in the open and closed stands, and forest floors contained various species of shrubs and herbs (Fig. 1b and c). Inside the forest opening, there were no dead trees or young trees, but there was a single living, older juniper (with a hollow stem). The tree species composition was the same in the open and closed stands, and both stands experienced the same climatic conditions.

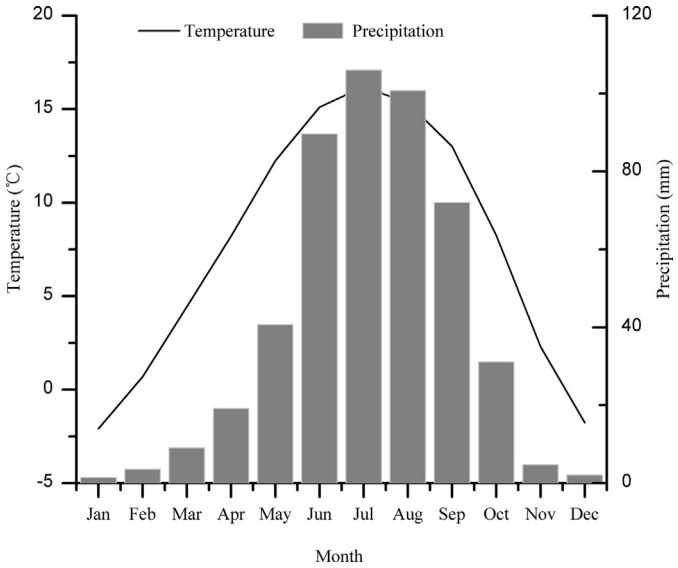

Fig. 2. Climate regime from Qamdo meteorological station for the period 1954–2009.

Tree-ring data

Increment cores (one core per tree) were collected at breast height from juniper and spruce trees in both forest stands. In the OS, tree-ring samples were collected from all the trees at the edge of the opening and also from trees within five meters of the edge, to increase the number of samples. A total of 40 cores from juniper and 16 cores from spruce were collected. In the CS, older (i.e. larger) trees were selected for sampling. A total of 32 cores from juniper and 30 cores from spruce were collected.

In the laboratory, the core samples were mounted and polished to make the ring boundaries clearly visible. Ring widths were measured to a precision of 0.001 mm using a Lintab tree-ring measurement system. The samples were crossdated for each species at each site (Fritts, 1976). The quality of crossdating was checked using the COFECHA program (Holmes, 1983). A tree-ring width residual chronology for each species at each site was obtained using the program ARSTAN, where a 128-year spline with a 50%