



# Fine-scale distribution of treeline trees and the nurse plant facilitation on the eastern Tibetan Plateau



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## ARTICLE INFO

### Article history:

Received 28 July 2015

Received in revised form

17 December 2015

Accepted 22 January 2016

### Keywords:

Alpine treeline

Treeline dynamics

Tree rings

*Picea balfouriana*

Tree recruitment

Nursing effect

Safe sites

## ABSTRACT

Above-average climate warming occurred during the 20th century in high altitude regions, and alpine treelines are believed to be an early indicator to respond to these warming-related changes. However, empirical investigations on treeline dynamics showed diverse results. The main objectives of this study are: (1) to investigate if treeline position shifted and if tree recruitment changed along with climate warming, and (2) to test if adult trees have “nursing effect” on tree establishment at treelines. We investigated two Balfour spruce (*Picea balfouriana* Rehd. et Wils.) treelines in Chang Niang (CNT) and Dang Dui (DDT), Dingqing county, Changdu prefecture, eastern Tibet. At each treeline site, three replicate plots with a size 30 m × 50 m were established. The coordinates of each tree within the plots were recorded and the age of each tree was identified by dendrochronological method. The changes in treeline position and tree recruitment were examined from spatially fine-scale distribution of trees and their age structure. The spatial patterns of individual trees were analyzed to infer the neighborhood effects. Results indicate that plots CNT2, CNT3, DDT1 and DDT2 showed stable treeline position during the last century, whereas plots CNT1 and DDT3 showed treeline advancing movement. Tree recruitments in all the six plots were enhanced during the 20th century, with two peaks occurring in the 1890–1910s and the 1950–1990s. Seedlings and saplings showed a general clustered distribution in all the six plots. The diverse pattern of treeline movement and episodic regeneration suggest that the treeline activity is not merely a result of climate change. “Nursing effects” from adult trees may play an important role in shaping the treeline activities on the eastern Tibetan Plateau. Our findings reveal diverse patterns in treeline dynamics at a local scale and highlight the importance of incorporating biotic interactions into species distribution modeling approaches.

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## 1. Introduction

Global temperatures have increased during the last century (Houghton et al., 2001; IPCC, 2013; Rohde et al., 2013), especially in the Alpine areas (Diaz and Bradley, 1997; Liu et al., 2009). The global warming has caused changes in various aspects of mountain vegetation (Gottfried et al., 2012; Tingley and Beissinger, 2009; Wilson et al., 2005), including shifts in their range of distribution (Brusca et al., 2013; Grytnes et al., 2014; Hagedorn et al., 2014; Harsch et al., 2009; Kullman, 2002; Vitasse et al., 2012). The alpine treeline is one of the most striking natural boundaries,

generally believed to be influenced by the temperature during the growing season (Körner, 1998; Kullman, 2001; Panigrahy et al., 2010; Tranquillini, 1979), as well as length of the vegetation season (Li et al., 2008) and/or winter injury (Tranquillini, 1979). Many studies indicate that global warming has caused upslope shifting of the treeline through enhanced seed production, seedling emergence and survival (Danby and Hik, 2007; Harsch et al., 2009; Kullman, 2002; Kullman and Oberg, 2009; Singh et al., 2012). However, other studies have reported that treeline position has remained persistent regardless of the accelerated regional warming during the last century (Green, 2009; Harsch et al., 2012; Liang et al., 2011).

Variability in treeline response to climate warming is likely to result from multiple forcings and processes, including not only changing climatic conditions but also biological interactions (Holtmeier and Broll, 2007; Mamet and Kershaw, 2013; Weigl and Knowles, 2014). Interactions among plants play a role in regulating the regeneration and range expansion (Ettinger and

Abbreviations: CNT, Chang Niang Treeline; DDT, Dang Dui Treeline; SPPA, spatial point pattern analysis.

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<http://dx.doi.org/10.1016/j.ecolind.2016.01.041>

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HilleRisLambers, 2013; Zhang et al., 2015). “Nursing effect” hypothesis predicts that existing trees or shrubs can serve as shelter to protect new seedlings, and thus promote treeline advances (Batllori et al., 2009; Bekker, 2005). Establishment of new seedlings are related to their proximity to and abundance of parent trees (Batllori et al., 2009; Caspersen and Saprúnoff, 2005; Elliott, 2012; Kroiss and HilleRisLambers, 2014). Habitats sheltered by the adult trees may have higher soil moisture content or more stable temperature than open terrain (Körner, 2012). Converse to this hypothesis, competition among individual trees may be detrimental to new seedlings due to limited resources (Germino and Smith, 1999; Körner, 2012; Zhang et al., 2015). The biological interactions can confound the climatic effects and make predictions of treeline dynamics challenging (Holtmeier and Broll, 2007; Mamet and Kershaw, 2013; Wang et al., 2015).

Alpine treelines on the Tibetan Plateau are among the highest ones (c. 4500–4900 m a.s.l.) in the world (Miehe et al., 2007), yet only a few studies exist on the treeline dynamics in this region compared to those in Europe, North and South America. On the northeastern Tibetan Plateau, treelines formed by Qilian juniper (*Juniperus przewalskii* Kom.) has progressed upwards and the number of trees below the treeline has increased after the Little Ice Age, especially during the warm period of 1931–1970 CE (Fang et al., 2009; Gou et al., 2012). On the southeastern Tibetan plateau, the position of the treelines formed by Smith fir (*Abies georgei* var. *smithii* Viguié and Gaussen) has changed only little during the past 200 years but population density below the treeline has increased (Liang et al., 2011). In other parts of the Tibetan plateau, the history of treeline activity and the forcing mechanisms behind it remains largely unknown.

In this study, we collected data of spatially fine-scale distribution of trees in two treeline sites in Dingqing county, Changdu prefecture in Tibet to investigate the history of treeline position and tree recruitment. The objectives of this study were (1) to investigate if treeline position and tree recruitment has changed along with climate warming during the last century, and (2) to test if adult trees offer a nursing effect to enhance the establishment of young trees at treelines.

## 2. Materials and methods

### 2.1. Study area

The two treeline sites under study are located in the upper reaches of the Nu Jiang, where deep gorges run northwest and southeast between towering ranges of mountains (Fig. 1). The region has a typical monsoon climate. According to the data (in period 1956–2010) at the nearest meteorological station in Dingqing (N31°25', E95°36', 3873 m a.s.l.), monthly mean temperatures ranged from  $-6.4^{\circ}\text{C}$  in January to  $12.3^{\circ}\text{C}$  in July, with a mean annual temperature of  $4.4^{\circ}\text{C}$  and a mean annual precipitation of 647 mm including 75% falling in the monsoon season (June–September).

The dominant tree species of the treeline forests is Balfour spruce (*Picea balfouriana* Rehd. et Wils.). Its pollination occurs between April and May and cones mature between September and October of the next year. Balfour spruce forms pure stands or is mixed with other conifers (e.g. *Sabina tibetica* Kom.) on the shady or semi-shady slopes where the substrate is mainly brown forest soil (Xu, 2001). The studied treeline sites were pure Balfour spruce stands and the shrub layer mainly included *Lonicera japonica* Suikazure, *Cotoneaster* spp, and *Ribes xizangense* L. T. Lu (Fig. 1). The treelines should be considered as climatic treeline, prejudged by a roughly equal elevation to treelines compared with counterparts at surrounding summits in this region ( $\sim 4300$ – $4500$  m).

### 2.2. Field survey and laboratory measurements

During the summer of 2010, we investigated two treeline sites. One is Chang Niang Treeline (CNT) and the other is Dang Dui Treeline (DDT), which is  $\sim 30$  km southeast of the CNT (Fig. 1). These sites are free from human activities. In each treeline site, we established three rectangular plots at least 40 m aside from each other along the horizontal direction (Table 1). These plots were 30 m wide (parallel to the slope contour) and reached 50 m down the slope. The upper border of each plot was positioned at the current treeline defined as the upper limit of continuous forest with a canopy coverage  $\geq 20\%$  and tree height  $\geq 2$  m (Kullman, 2001; Liang et al., 2011).

In each plot, the locations of living and dead trees were recorded and stem diameters at breast height (1.3 m) were measured. For each tree higher than 2 m, one core was extracted at breast height in a direction parallel to the slope contour using an increment borer (Table 1). For saplings ( $0.5 \text{ m} \leq \text{tree height} \leq 2 \text{ m}$ ) and seedlings (tree height  $< 0.5 \text{ m}$ ), the number of branch whorls was counted to estimate their age. To obtain accurate age of the saplings and seedlings, an average of 14 individuals (covering the heights of samplings and seedlings) per plot were felled to collect disk samples at ground level. In addition, a stem disk was taken at breast height from the felled saplings to calculate the years required to grow from ground level to breast height. In addition to the plots, we sampled all the isolated trees, as well as seedlings and saplings, above the treeline upper border until the uppermost individual tree (tree height  $> 2 \text{ m}$ ), i.e. up to the tree limit (ranges from 30 to 140 m in distance). The total number of adult trees within and above the plots was 101 at CNT, and 95 at DDT, respectively. The number of seedlings and saplings was 143 and 64 at CNT and DDT, respectively.

In the laboratory, the cores and disks were air-dried and surface-sanded. The ring-widths were then measured with a resolution of 0.001 mm using Lintab-5 tree-ring measurement equipment (Rinntech, Heidelberg, Germany). The ring-width measurements were crossdated by visual examination of the wood samples, graphical comparison of the ring-width measurements, and statistical checking of the ring-width series (Stokes and Smiley, 1968).

The age of adult trees (tree height  $> 2 \text{ m}$ ) was obtained by counting the number of rings in the crossdated samples. If the innermost ring of a core did not reach but was very close to the pith, the number of missed rings was added as judged by the curvature and widths of the innermost rings (Duncan, 1989). The true age of the tree was adjusted by adding the years needed to grow from the ground to the breast height. This adjusted age was obtained by calculating the number of rings in the discs taken at the ground level and at breast height. For the seedlings and saplings, tree ages were counted on the basis of branch whorls or directly from the number of rings in discs.

In each plot, we also collected topsoil samples (0–20 cm in depth) from randomly selected and relatively bare spots, including three samples within the plot and three samples above the plot (below the uppermost tree). The soil samples were air-dried indoors and then sieved by 0.16 mm resolution griddle to wipe off small rocks and plant roots. The total C and both instant (water soluble) and total N, P, and K were measured following the soil chemical analysis standard (Bao, 2005). The samples were used to evaluate if there were differences in soil nutrients in and above the treeline.

### 2.3. Spatiotemporal patterns in the distribution of individual trees

The fine-scale location and age of individual trees were used to identify the treeline position in the past. The number of trees established at each decade was counted to examine the temporal pattern of tree recruitment.

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