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Altitudinal treeline dynamics of Himalayan pine in western Himalaya, India

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ABSTRACT

The instrumental weather records from the western Himalayan region for the past century show an increase in annual mean atmospheric temperature with winters warming at a faster rate. The vegetation of the upper ecotonal zones, already on the climatic threshold is sensitive to any such change in climate variable most limiting the growth. To investigate the impact of climate change on treeline dynamics of Himalayan pine (*Pinus wallichiana* A. B. Jackson), we investigated its recruitment pattern in 12 treeline sites of different ecological settings widely distributed in monsoon and monsoon-shadow zones in the western Himalaya, India. The study explicitly revealed that Himalayan pine treeline has shifted towards the upper elevation in the investigated sites, but with varying rate (11–54 m/10 yrs) largely due to site-specific microclimatic and biotic factors. Tree-ring-width chronologies of Himalayan pine prepared from two upper forest border sites, one each in monsoon and monsoon-shadow zone, respectively revealed that winter and early spring season mean temperature has direct relationship with the radial growth of trees. This indicates that the photosynthetic assimilates during winter and early spring seasons significantly influence the ensuing year's tree growth. The sensitivity of Himalayan pine to climate change revealed in this study indicates that the projected climate change under the background influence of greenhouse gases could have serious implications on biodiversity of upper elevations in the western Himalaya.

1. Introduction

The vegetation of the Earth system is in equilibrium with climate operating over specific sites in a long span of time. However, there is a growing concern in the scientific community to know how vegetation system might respond to global warming under the background influence of the increasing anthropogenic pressure. In view of this it is of great relevance to society to understand how global warming might affect the upper treeline dynamics as natural alpine treeline is largely controlled by inadequate air and soil temperature during the growing season (Körner, 2012; Paulsen and Körner, 2014). The empirical studies on treeline vegetation have revealed that the location of ecotones in high-altitude and latitude regions generally coincides with the 10 °C isotherm of air temperature of the warmest month (Grace et al., 2002; Holtmeier, 2009). Hence, any increase in warm season temperature above the threshold could be a major driver of treeline dynamics. The mountain regions, under dominant orographic forcing, have multitude of ecological niches in short distances and this makes them a natural laboratory to study the influence of climate change on shifting of plant species ranges (Smith et al., 2009).

The ground observations on colonization pattern of plant species over different geographic regions have demonstrated shifting of plant species to newer habitats, which were rather inhabitable

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before (Grabherr et al., 1994; Klasner and Fagre, 2002; Holtmeier and Broil, 2005, 2007; Hofgaard et al., 2009; Kullman, 2010; Liang et al., 2011; Kirdyanov et al., 2012; Shrestha et al., 2014). The ecotonal vegetation dynamics could be mediated through the increased regeneration/recruitment and/or higher growth of plants (Hofgaard et al., 2009; Woodall et al., 2009). It has been observed that the growing season temperature alone is not the sole driver of treeline dynamics at local to regional scales (Hofgaard et al., 2013) and there could be multitude of interacting factors playing dominant role (Malanson, 2001). Other than the growing season climate, tree recruitment and growth across the treeline ecotones also have been demonstrated to be controlled by non-growing season climate variables as well (Harsch and Bader, 2011; Mathisen and Hofgaard, 2011). The factors other than the climate variables such as biotic interactions (competition and herbivory) also greatly affect the treeline dynamics (Cairns and Moen, 2004; Bekker, 2005; Hofgaard et al., 2010; Elliott, 2011; Malanson et al., 2011). The rate of treeline dynamics is not found to be uniform across different ecological settings (Holtmeier and Broil, 2007; Harsch et al., 2009) and advancing, stationary and retreating treeline ecotones have been reported to occur concomitantly across different landscapes within the same region indicating that plant species response to climate change is not always simple (Schickhoff et al., 2015).

The vegetation over the lofty Himalayan mountain system lying in mid-latitude northern hemispheric region has shown altitudinal shifts in recent decades (Dubey et al., 2003; Schickhoff, 2005; Panigrahy et al., 2010; Negi, 2012; Rawat, 2012; Shrestha et al., 2012; Singh et al., 2012; Telwala et al., 2013; Aryal et al., 2014; Gaire et al., 2014; Schickhoff et al., 2015). However, response of high-altitude plant species in the Himalayan region to recent climate change has not been consistent across different ecological settings (Gaire et al., 2014; Schickhoff et al., 2015). Gaire et al. (2014) noted that *Abies spectabilis* has shifted to higher elevations in central Nepal with a rate of 2.61 m/year since 1850s, and the recruitment has been observed to be episodic with higher rate during 1950s and 1980s. However, the response of *Abies spectabilis* to recent climate change in Barun valley in eastern Nepal has been found to be negligible (Chhetri and Cairns, 2015). Similarly, the recruitment pattern of Himalayan birch (*Betula utilis*) also did not show any elevation change in central Nepal (Shrestha et al., 2007; Gaire et al., 2014) and the regeneration even has decreased in recent decades. The tree-ring studies have indicated that the growth of Himalayan birch in timberline zones in central Nepal are limited by inadequate moisture availability and decrease in pre-monsoon season precipitation in recent decades could be the possible reason for treeline lowering (Liang et al., 2014).

Studies thus far conducted on recruitment pattern of Himalayan pine in upper ecotonal zones of the Himalayan region have shown conflicting results (Dubey et al., 2003; Shrestha et al., 2014). In view of this we performed a detailed study on recruitment pattern of Himalayan pine over several sites distributed in monsoon and monsoon-shadow zones of the western Himalaya. Dendrochronological analyses were also performed to identify the climatic variables associated with the radial growth of trees in high elevation forest borders in the western Himalaya. The findings of this study should provide valuable insight into identifying the climate change sensitivity of Himalayan pine, a dominant constituent of upper temperate forests in the western Himalaya.

2. Data and methods

2.1. Study sites and materials

Himalayan pine, an important constituent of upper treeline in the western Himalaya, is a primary colonizer on dry, sandy soils and avoids very wet and badly drained grounds (Troup, 1921; Raizada and Sahni, 1960). It occurs gregariously all along the Himalaya in temperate zone between 1800 and 3000 m asl extending up to Bhutan in the east, though absent from Sikkim (Raizada and Sahni, 1960). Himalayan pine occasionally extends up to 3900 m asl and above in the western Himalaya mixing with *Betula utilis* and *Juniperus* (Troup, 1921) at higher elevations. In view of its high elevation ecological preferences Himalayan pine could be taken as one of the important target species to understand climate change impact on treeline dynamics. In our present study we selected 12 high elevation sites in the western Himalayan region of Uttarakhand and Himachal Pradesh where Himalayan pine was found growing naturally along the altitudinal gradients. Of these selected sites 8 are located in the area under the influence of southwest summer monsoon in Uttarakhand and Himachal Pradesh and 4 in monsoon-shadow zone in Lahaul and Spiti region, Himachal Pradesh (Fig. 1, Table 1). The Pir Panjal ranges act as the orographic barrier for the southwest summer monsoon currents north of the Rohtang making Lahaul and Spiti region cold arid. The sites in monsoon zone are relatively mesic as compared to the sites in monsoon-shadow zone of the western Himalaya. We took utmost care in selection of undisturbed sites for our study; however, it could not be avoided in some cases due to prevalent grazing pressure. In our study young Himalayan pines above 2 m height were categorized as trees. The trees of sufficient thickness (girth >8 mm) were sampled using increment corer of 4 mm diameter. The increment cores were taken at the root collar zone so as to retrieve the recruitment year of the tree. However, when coring at root collar zone was not possible due to unavoidable obstacles, the samples were taken from suitable heights and details recorded. Old trees of Himalayan pine growing in upper forest borders were sampled using increment corer to prepare ring-width chronologies to understand tree-growth/climate relationship. For this one Himalayan pine stand in the upper forest border located under the influence of southwest summer monsoon (Saram, Himachal Pradesh; 32°01′N–77°27′E; 2464 m asl) and the other in monsoon-shadow zone north of the Pir Panjal range (Madgram, Himachal Pradesh; 32°45′N–76°37′E; 2710 m asl) were selected. The increment core samples from old trees were collected from Saram, Himachal Pradesh in October, 2002 and Madgram near Udaipur, Lahaul and Spiti, Himachal Pradesh in June, 2004 by authors BD, JS and RRY (Fig. 1). For sampling, attempts were made to collect usually two core samples from opposite sides of the stem of healthy undisturbed trees at breast height (~1.4 m). The increment cores were mounted on wooden frames using glue and their cross-sectional surface polished using abrasives of 200 and 400 grit until the cellular details became clear under the stereozoom binocular microscope. The growth ring sequences in such samples were cross-dated by skeleton plot method (Stokes and Smiley, 1968) and ring widths measured using linear encoder (LINTAB) coupled with personal computer (Rinn, 2003). The ring-width measurements were again used in crosschecking the dating quality using software COFECHA (Holmes, 1983) that uses cross-correlation of individual measurement series with mean series created from all the series used in the analysis. The ring-width measurements of segments in series showing weak correlation with the master series were rechecked and possible errors, if any, corrected. Very good coherence in ring-width pattern of trees as revealed by high mean correlation among series in COFECHA analyses (Holmes, 1983) (mean correlation from 0.53 to 0.64) and year-to-year similarity in ring-width plots underpinned common climate forcing driving growth dynamics of trees in the respective two sampling sites.