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Altitude-dependent variation in biomass and wood production of subalpine *Abies spectabilis* forest in eastern Himalaya

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Abstract

Himalayan subalpine forests with a wide altitudinal range of distribution are ideal target for quantifying the change in biomass dynamics along altitude. We estimated aboveground biomass and coarse wood production rate of subalpine *Abies spectabilis* forest on a north-facing slope in Langtang National Park, Nepal, over the entire altitudinal range from 3170 to 3820 m a.s.l. We established 36 plots (3251 m^2 in total) for closed-canopy stands, and additional sapling plots in open-canopy sites (772 m^2) in October 2015. We recorded stem diameter at breast height D and top height H for all trees ($H \geq 2.0$ m) and saplings ($2.0 > H \geq 0.2$ m). We measured recent five-year radial growth in D for all canopy trees in the plots from stem-core samples and recorded recent three-year height growth of all saplings by annual bud scars on leader shoot. We quantified altitude-dependent change in D-H relationship, by extended allometric equation with asymptotic H. We estimated aboveground biomass (AGB) using an allometric equation between D^2H and aboveground tree biomass W. For canopy trees with past D estimates in 2010, we estimated past H from D-H allometry, and past W as well. Based on the change in W, we estimated aboveground coarse wood production rate (CWP) as the annualized increment of AGB for surviving trees. Tree height H of *Abies spectabilis* at any given D decreased with altitude. Relative growth rate (RGR) of W decreased with W and altitude. RGR of sapling height increased with altitude for taller saplings (> 0.5 m), whereas it decreased with altitude for shorter ones. AGB of *Abies* trees in 36 plots was 489 Mg ha^{-1} and CWP was 4.88 Mg ha^{-1} $year^{-1}$, indicating relatively slow biomass turnover rate by tree growth (CWP/AGB) at 1% per year. AGB and CWP decreased with altitude. CWP relative to AGB also decreased with altitude. Altitude-dependent decline in canopy height, AGB and CWP/AGB suggests adaptation to ambient conditions for the maintenance of forest structure.

Key words: allometry, coarse wood production, height, stem diameter.

Introduction

In subtropical mountains, intra-annual thermal variation is small compared to those in temperate regions (Ohsawa 1990, 1993; Cogbill and White 1991). Therefore, in Himalayas, there occurs no summer-green deciduous broadleaved forest, and evergreen broadleaved forests are replaced with altitude by evergreen coniferous forests. On moist north-facing slopes, *Abies spectabilis* forest is superseded by deciduous *Betula utilis* forest near the forest line. In contrast, on the southern slopes, subalpine zone is usually dominated by *Juniperus recurva*, suggesting that *Abies spectabilis* is less tolerant to drought than *Juniperus recurva*. Dwarf scrub of *Rhododendron* spp. are dominant in alpine zone (Stainton 1972).

Coniferous forests in the high elevation are strongly influenced by climatic conditions changing with altitude (Wang *et al.* 2006; Dang *et al.* 2007; Liang *et al.* 2010). The climatic conditions of Himalayan subalpine forests are harsh due to low temperature, cold wind and snow deposition. Ground surface of subalpine forests receive low light resource under dense canopy cover, whereas tree density and canopy closure tend to decrease with altitude (Liu 1997). Tree architecture and height distribution of saplings in Himalayan forests are variable and change with altitude. In mountains, tree shapes quantified by tree height and stem diameter vary with altitude (Aiba and Kitayama 1999; Wang *et al.* 2006; Miyajima and Takahashi 2007; Liang *et al.* 2010). Biomass increment rate is low in higher elevation due to cool conditions (Yoda 1968; Tadaki *et al.* 1970).

In this study, we examined the variation in aboveground biomass and coarse wood production rate along elevational gradient in *Abies spectabilis* forest in eastern Himalaya. Coarse wood production rate is defined to be annual biomass growth of survived trees and biomass gain by recruited trees, and it is the part of aboveground net primary production rate together with the production of high-turnover components of leaves, twigs and reproductive organs (Kira and Shidei 1967; Clark *et al.* 2001).

Yoda (1967, 1968) estimated biomass and net primary production rate along altitudinal gradient from tropical to subalpine forest zones in East Asian subtropical region including Nepal Himalaya and reported extremely high coverage in basal area and

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