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Elevational behaviour on dominance–diversity, regeneration, biomass and carbon storage in ridge forests of Garhwal Himalaya, India

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ABSTRACT

The present study was conducted along the elevational gradient in ridge forests of Bhagirathi catchment area of Garhwal Himalaya. The purpose of the study was to understand the growth behaviour of tree species at different altitudes in terms of dominance–diversity, regeneration dynamics, biomass and carbon storage in forests of Bhagirathi catchment area. Plot design, with main plot size of 0.1 ha, was used to analyse quantitatively and qualitatively the tree, sapling and seedling vegetation. The maximum mean tree density (708 ± 153 trees ha^{-1}) was recorded in *Abies spectabilis–Quercus semecarpifolia* forest association (between 2800 and 3100 m asl), while minimum (425 ± 32 trees ha^{-1}) in *Q. semecarpifolia–Cedrus deodara* forest association (between 3100 and 3400 m asl). The total basal cover values ranged between 28.80 ± 5.27 m^2 ha^{-1} (below 700 m asl) to 99.69 ± 29.64 m^2 ha^{-1} (above 3400 m asl). The highest Shannon index value (0.83 ± 0.14) was observed in *Anogeissus latifolia–Mallotus philippensis* forest association whereas, lowest (0.26 ± 0.09) in *Q. semecarpifolia–C. deodara* forest association. The maximum similarity (85.23 ± 5.04%) was noticed in *Quercus floribunda–Rhododendron arboreum* forest association while, minimum (59.32 ± 5.18%) in *A. latifolia–M. philippensis* association. Similarly the species richness, Simpson index, Shannon index, seedling density, total basal cover and above ground biomass density showed positive–significant elevation–wise variation in various growth phases (i.e., tree, sapling and seedling). The total biomass density values oscillated from 189.38 ± 14.35 Mg ha^{-1} (between 1600 and 1900 m asl) to 520.72 ± 114.57 Mg ha^{-1} (between 3100 and 3400 m asl). Consequently, the total carbon density at various elevational ranges varied from 85.22 ± 6.46 Mg C ha^{-1} to 234.32 ± 51.56 Mg C ha^{-1} for the corresponding elevations. The Detrended Correspondence Analysis (DCA) clearly indicated the prevalence of distinct habitats and resultant associations of tree species in various ridge forests whereas, on the other hand the Canonical Correspondence Analysis (CCA) has shown a complex interrelationship amongst species clustering, mountain ranges and climatic/environmental variables. The study revealed that the *Pinus roxburghii* was invariably affecting the habitats of mixed broad–leaved forests at lower altitudes, whereas *Cedrus deodara* was noticed to encroach continuously the higher elevational habitats. The study has also indicated that the old growth coniferous and broad leaved forests of higher altitudes of Garhwal Himalaya (like *A. pindrow*, *A. spectabilis*, *A. acuminatum*, *B. utilis*, *C. deodara*, *Q. semecarpifolia* and *R. arboreum*) have more carbon storage potential and hence recommended for carbon management through afforestation at higher altitudes of Himalaya.

1. Introduction

Elevational gradient is well known as a decisive factor for shaping the spatial patterns of species diversity as it is directly correlated with various environmental variables and provide more specific ecological conditions (Brown, 2001; Lomolino, 2001). Generally plants can grow and survive in a particular range of environmental condition (Block and Treter, 2001), however small variation in these conditions such as temperature, light intensity/availability and precipitation equally play a crucial role in shaping up the forest regeneration pattern along different altitudes (Duan et al., 2009).

The variation in species diversity can be linked to several ecological gradients (Palmer, 1992; Huston and DeAngelis, 1994; Chawla et al., 2008). It is well known that various environmental factors, such as

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temperature, precipitation, atmospheric pressure, solar and UV–B radiation and wind velocity, change systematically with elevations. Therefore, elevational gradients could become the most powerful "natural triggers" for monitoring ecological and evolutionary responses of biota to environmental changes (Fang et al., 2004; Cui et al., 2005; Korner, 2007). Although changes in species composition, biodiversity, community structure and distribution along altitudinal gradients have been well documented (Vetaas and Gerytnes, 2002; Kharkwal et al., 2005; Sharma et al., 2010; Gairola et al., 2012; Sharma et al., 2014), altitudinal patterns of dominance–diversity, regeneration dynamics, biomass and carbon storage in Himalayan ridge forest ecosystems remained unexplored so far.

Regeneration is a key process for the existence of species in a community under the prevalent environmental conditions. The potential regenerative status of tree species is critical in a forest which often depicts the future composition of forests within a stand in space and time (Henle et al., 2004). Regeneration of any species is confined to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographical distribution (Grubb, 1977). Successful regeneration often ensures the long-term sustainability of the forests (Malik et al., 2014). Therefore an understanding of the processes that affect regeneration of forest species is of crucial importance to both ecologists and forest managers (Slik et al., 2003).

In mountain areas, maximum number of endemic species are expected to occur at high elevations due to isolation mechanism, that promotes speciation and mainly governed by terrain characteristics (Shrestha and Joshi, 1996), which cause species range limitation and decreased anthropogenic impacts, which could leave the system highly vulnerable to climate change (Zomer et al., 2014). Himalayan ridge top vegetation is considered to be more responsive to global warming than the vegetation growing on valley slopes and aspect, as they are characterized by uniform sunlight exposure (Sharma et al., 2016a). Hence, they serve as ideal places for monitoring and comparing the effects of climate change and for predicting the future changes in species composition. Furthermore, it is supposed that in the event of a rise in temperature at lower elevations, the movement/migration of vegetation would be towards upper elevational ridge tops (Padma, 2014, Sharma et al., 2016b). It is understandable, because the recent global warming has resulted in disturbances of ecological relationships, alteration in plant life history and general upward shift in the species distributional ranges (McKone et al., 1998; Klanderud, 2005; Jurasinski and Kreyling, 2007; Pauli et al., 2012).

Climate change can modify tree species composition and migration patterns (Bu et al., 2008), which can further alter the forest composition and affect the rate of carbon sequestration (Bunker et al., 2005). The global studies based on forest biomass and soil survey have revealed broad geographical patterns of forest biomass and soil organic carbon stocks and suggested the role of climate and vegetation types in shaping these spatial patterns (Piao et al., 2005; Yang et al., 2007). Variation among forest carbon stocks also depends on geographic location, plant species composition, stand age and management practices (Shrestha and Singh, 2008; Chaturvedi et al., 2011; Chaturvedi and Raghubanshi, 2015; Sharma et al., 2016c). Forest ecosystems fix more carbon and possess more carbon density than croplands or grasslands (Zhou et al., 2011). Temperate forests are supposed to play a significant role in the global carbon cycle as they store 650 Pg of C in plant biomass and 2300 Pg C in the soil (Field et al., 2004). Approximately 80% of the aboveground carbon is found in the form of standing timber, branches and foliage and 40% of the world's belowground carbon stock is sustained in the roots in forest ecosystem (Dixon et al., 1994; IPCC, 2001). The total carbon pool in forest ecosystems was estimated to be about 1150 Gt, of which 49% is in the boreal forests, 14% in temperate forests and 37% in tropical forests (Dixon et al., 1994). However, Pan et al. (2011) have indicated that 471 T 93 Pg C (55%) is stored in tropical forests, 272 T 23 Pg C (32%) in boreal forests and 119 T 6 Pg C (14%) in temperate forests. According to Donato et al. (2011), carbon is mostly stored as aerial vegetal and below ground biomass in descending order. Below ground biomass rooting structure is crucial in order to understand numerous interactions which stabilize soil by increasing shear strength and reduce its erosion (Frei, 2009). Therefore, a substantial interest has been sparked by the need of accurate estimate of carbon stored in root system (Brunner and Godbold, 2007).

An assessment of forest composition on ridge tops will be crucial in order to assess future species coexistence and species shift in Himalayan range. Composition of vegetation and its analysis on ridge tops can effectively predict the influence of climate change on migration of woody species. Through this work we have tried to answer the following questions: (i) How do the forest structure, composition, diversity and regeneration of species change on the ridge tops along altitudes in Bhagirathi catchment area of Garhwal Himalaya? and (ii) What is the biomass and carbon storage potential of ridge forests at various altitudes ?

2. Material and methods

2.1. Study area

The state of Uttarakhand is situated in the northern part of India and shares an international boundary with China in the north and Nepal in the east. It has an area of 53,483 km^2 and lies between latitudes 28°43′ and 31°28′N and longitudes 77°34′ and 81°03′E. The state has a temperate climate except in the plain areas, where the climate is tropical. Of the total geographical area of the state, about 19% is under permanent snow cover having glaciers and steep slopes, where tree growth is not possible due to climatic and physical limitations (FSI, 2009). The recorded forest cover of the state is 24240 km^2, which constitutes 45.32% of its geographical area (FSI, 2015). This study was conducted in Bhagirathi catchment area which represents tropical to subalpine forests in Garhwal Himalaya. The study area is located between the latitudes 30°04′25.4″–30°49′56.2″N and longitudes 078°37′35.9″–078°47′35.00″E, comprised of two districts (Uttarkashi and Tehri) of Uttarakhand state. A reconnaissance survey of the study area was done from June to February in the years 2014 and 2015. We selected 55 ridge top forests at every three hundred meters altitudinal gap along 11 different elevational ranges that were situated from less than 700 m asl (tropical zone) to above 3400 m asl (subalpine/timberline ecotone). The details of the study area and forest types are given in Fig. 1 and Table 1 respectively. The meteorological data of year 2013–2014 for all the four different mountain ranges were taken from the accuweather (Website:www.accuweather.com and en.climate/data/org). Monthly values of climate data were used for calculation of average annual data, which were interpreted to assess climatic impact on forest vegetation. The climatic variation across different mountain ranges of Bhagirathi catchment area has been presented in Fig. 2.

2.2. Vegetation sampling and data analysis

The vegetation was sampled at three different growth levels namely adult/tree [≥30 cm circumference at breast height (CBH)], sapling (≥10 cm to ≤30 cm CBH) and seedlings (≤30 cm height, but < 10 cm CBH) following Saxena et al. (1984). Further, five sample plots of 0.1 ha (31.62 m × 31.62 m), each were randomly laid out on surveyed ridge tops within each altitudinal range to analyse the tree composition (11 elevational stands × 5 sample plots each = 55 sample plots). Within each 0.1 ha plot, 5 m × 5 m sized quadrats (11 elevational stands × 5 sample plots each × 8 quadrats each = 440 quadrats) were laid out randomly to analyse the tree saplings (as per Majila and Kala, 2010) and 1 m × 1 m sized quadrats (11 elevational stands × 5 sample plots each × 16 quadrats each = 880 quadrats) for tree seedlings (Curtis and McIntosh, 1950; Phillips, 1959). Circumference at breast height (cbh at 1.37 m from the ground) was taken and converted to diameter for the determination of basal cover for both trees and saplings. The