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RESEARCH ARTICLE

Plant diversity patterns along environmental gradients in Nanda Devi Biosphere Reserve, West Himalaya

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Abstract
Mid to high-altitude vegetation in part of west Himalaya, India has been investigated and analyzed for assessing species distribution in relation to environmental variables. The buffer zone site of Nanda Devi Biosphere Reserve (NDBR) in Pindari–Sunderdhunga–Kafni (PSK) area (30 forest stands in 11 forest communities) of Kumaun and Lata–Tolma–Phagti (LTP) area (30 forest stands in 8 forest communities) of Garhwal region having 11 forest communities along different elevation gradients was identified for detailed surveys. Species composition showed a total of 451, distributed in NDBR along Pindari–Sunderdhunga–Kafni site and Lata–Tolma–Phagti transects. Among communities, *Quercus semecarpifolia* and Mixed *Abies pindrow-Quercus* spp. communities in Pindari–Sunderdhunga–Kafni site with 23 species each and *Pinus wallichian*a community in Lata–Tolma–Phagti site with 18 species showed highest species composition. The interrelationship between environmental variables and species distribution was analysed using Simple Linear Correlation analysis and Canonical Correspondence Analysis (CCA). Simple Linear Correlation and CCA indicated compositional differences in forest types that perhaps was caused by differences in species richness and forest composition. In both the sites, among all the environmental variables, elevation, slope and organic carbon were found to be the most controlling factor for species distribution. Different forest structural components like species richness, total basal area, canopy density was found to be varying greatly with environmental factors and human disturbance, however, more datasets of vegetation dynamics and responses are required to further strengthen this premise.

Keywords Canonical correspondence analysis · Environmental variables · Nanda Devi Biosphere Reserve · Species richness · Western Himalaya

Introduction

The Indian Himalayan Region (IHR), with a geographical coverage of over 5.37 lakh km^2, constitutes a significantly large portion of the Himalayan Biodiversity Hotspot. It covers 16.2% of total geographical area of the country. The temporal and spatial variations caused by diverse geological orogeny have resulted in marked differences in its climate and physiography, thus contributing greatly to the richness and representativeness of its biodiversity components at all levels (Anonymous 2009). These variations provide a suitable opportunity for studying species distribution patterns in relation to different environmental variables (Rawat 2014).

Field ecological investigations seem incomplete without understanding the patterns and processes of vegetation along environmental gradients. Vegetation heterogeneity and variation in species diversity across history, habitat, climate, productivity and biotic interactions have been well investigated along environmental gradients (Givinish 1999; Willig 2003; Currie and Francis 2004; Gonzalez-Espinosa 2004; Qian and Ricklefs 2004; Bhattarai and Vetaas 2006; Gairola et al. 2008; Acharya et al. 2011). Environmental features have been proven genuine towards underlining plant distribution and compositions (Keenan and Kimmins 1993). In the current global change context, prediction of species distribution and its assemblage with space and time across environmental gradients has been given the utmost importance to investigate the fate of biodiversity (Dubuis et al. 2011). Among other, influence of climate on the species distribution has been well observed using topographical aspects along with climatic parameters (Woodcock et al. 2002).

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Hence, the diversity in climate and topography is cause of distinct forest types. Spatiotemporal patterns act as function to which plant community of a region respond, however, environmental factors play a role in the formation of plant communities and their compositions (Kharkwal et al. 2005). These habitat factors not only influence the general vegetation composition but also play an important role in the distribution of native and alien flora (Arevalo et al. 2005; Khuroo et al. 2011). Distribution of distinct biological communities with high level of endemism in mountain ecosystems has been suggested through the study of topography and historical background of these ecosystems (Gentry 1993). Further, effect of slope on spatial heterogeneity and distribution of soil parameters has been investigated (Mohammad 2008). Apart from the influence of environmental factors on vegetation, human disturbance has been proven a major cause for disruptive changes in vegetation structure and its function (Naeem 2002). Effects of human disturbance on vegetation distribution, regeneration and functional diversity have been well documented (Biswas and Malik 2010; Fakhry et al. 2020).

Several ecological studies have been carried out on the high altitude of Indian western Himalaya including phytosociology, species composition, species distribution, climate change (Gairola et al. 2008; Rawal et al. 1991; Rawa and Pangtey 1994; Rawal and Dhar 1997; Joshi 2002; Rawat et al. 2015a, 2015b). However, studies explaining current vegetation distribution along environmental and other influential parameters human disturbance are meager (Gairola et al. 2008; Rawat 2014). As a result, there is limited information available about the distribution of vegetation and its underlying control in the Himalaya. Considering above, the present study is focused on the species diversity and distribution patterns of mid to high altitude vegetation in relation to different environmental parameters and human disturbance.

Methods

Study area and site selection

Nanda Devi Biosphere Reserve (NDBR) lies between 30°06′ and 31°04′ North latitude and 79°13′ and 80°17′ East longitudes (Fig. 1). Having an area of 6407.03 km^2, NDBR includes core zone with and area of 712.12 km^2 followed by buffer zone (5148.57 km^2) and transition zone (546.34 km^2). Two intensive study transects Pindari–Sunderdhunga–Kafni (PSK) in Kumaun and Lata–Tolma–Phagti (LTP) in Garhwal region was identified for the present study. Compositional patterns were recorded/observed across altitudinal range from 1800 m asl to 4000 m asl which covers temperate to sub-alpine forest communities in the region. 30 forest stands in each transects were investigated for the collection of data. Details of forest stands and site characteristics are presented for both sites in Tables 1 and 2. Extensive visits to these sites were made during 2012–2014. Thirty forest stands were further categorized into 11 forest communities in Pindari–Sunderdhunga–Kafni (PSK) and 8 in Kumaun and Lata–Tolma–Phagti (LTP). The detailed community characteristics along with soil properties are presented in Table 3.

Sampling and data collection

Stratified random sampling was adopted to investigate forest communities in study areas. To perform quadrat study, standard ecological methods were adopted (Misra 1968; Muller-Dombois and Ellenberg 1974; Dhar et al. 1997). Trees and saplings were investigated in ten (10 × 10 m) quadrats. Seedlings and shrubs were recorded in five (2 × 2 m) random sub quadrats within each 10 × 10 m quadrat. Herbs were enumerated in ten (1 × 1 m) quadrat within each 10 × 10 m quadrat. Based on the circumference at breast height (at 1.37 m from ground level) recorded for everyone, tree (> 31 cm CBH), sapling (11–30 cm CBH) and seedling (< 10 cm) were defined. Shrubs were considered as woody taxa based on branching from the base (Saxena and Singh 1982). A detailed sampling scheme has been presented in Fig. 2. The vegetation composition and species distribution parameters have already been attempted earlier (Rawat et al. 2015a), therefore, the highlights of compositional parameters in the result section are referred from Rawat et al. (2015a).

Taxonomic identification: natives and endemic species

The plant specimens collected during field investigations were preserved (Jain and Rao 1977) and identified with the help of regional and national flora (Hooker 1872–1897; Naithani 1984; Sharma and Balakrishnan 1993; Hajra and Balodi 1995; Kumar and Panigrahi 1995; Gaur 1999), monograph (Mukherjee and Constance 1993; Dikshit and Panigrahi 1998) and checklists (Uniyal et al. 2007).

The nativity of the species was assigned following Samant et al. (1998). Species originated from Himalaya and having distribution in neighboring countries/states were considered as natives. Endemism of the species was determined based on the extent of geographical distribution (Dhar and Samant 1993; Dhar et al. 1996; Dhar 2002).

Soil sampling and analysis

From each stand, five samples, preferably one from centre and four from corners were collected. Twenty-centimeter depth was used to core up soil and mixed to make a

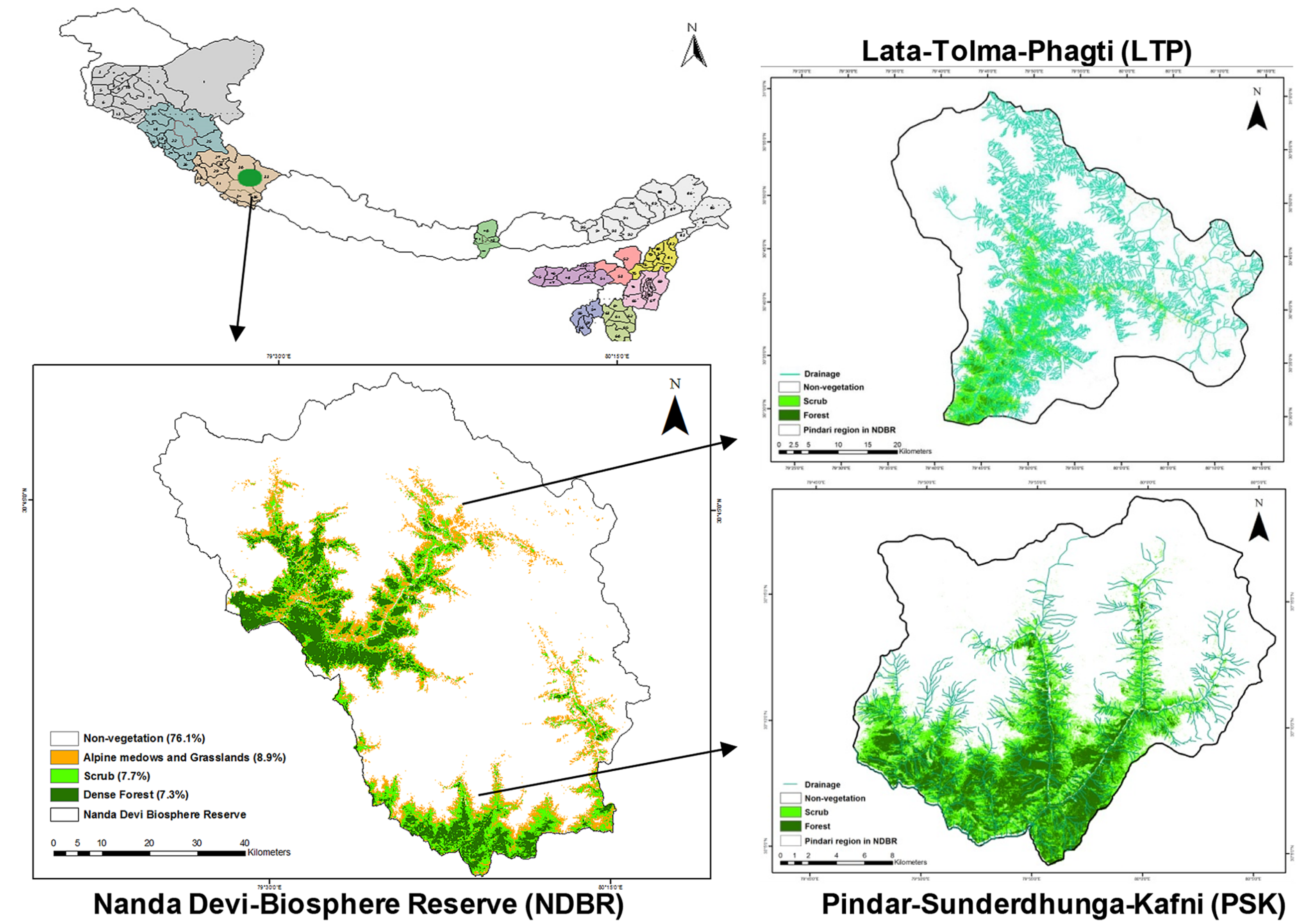

Fig. 1 Location map of study area–Nanda Devi Biosphere Reserve (NDBR) (bottom left) and target site Pindari–Sunderdhunga–Kafni (bottom right) and Lata–Tolma–Phagti (up right)

composite sample. The homogenized composite soil samples were brought to the laboratory in air-tight polythene bags. The fresh soil was used for pH measurement. Rest of samples were shade dried and passed through 2 mm sieve. Dried samples were analysed for organic carbon, organic matter, and total nitrogen.

Soil pH was determined by pH meter (LI-127, ELICO) and organic carbon and organic matter by rapid titration method (Walkley and Black 1934). Total nitrogen was calculated by sample digestion following Kjeldhal technique (Novosamsky et al. 1983) and distillation in Kjeltec unit (Teator, Kjeltec Auto 1030 analyser). Different soil parameters and their analysis are presented in Table 3.

Statistical analysis

Simple Linear Correlation (SPSS statistics for windows version 17.0) was performed to evaluate changes to species richness across elevational and the environmental properties. Level of significance of data was checked at $P < 0.01$ and $P < 0.05$ level. The Correlation analysis data is finally combined, and species composition values are presented against environmental parameters (Table 4). Further, to interpret the combined effect environmental properties on species richness values and other compositional values, Canonical Correspondence Analysis (PC-ORD for windows version 4.2) was performed. For CCA, variables were considered strongly related to an axis when scores or factors loadings were greater than 0.5 for a given axis (Norusis 1994). Both the analyses were based on 5 environmental variables [i.e., altitude (ALT), soil pH, soil total organic carbon (OC), soil total nitrogen (N), slope of the stands (SLP)] and, human disturbance (disturbance in terms of grazing/lopping % (DST)) and their underlying control on different forest structural components [i.e., total canopy cover % (CNP), total basal area of each stand (TBA), species richness at tree (RT), herbs (HB), shrubs (SH), native species (NAT), non-native species (NN) and endemic species (E) level].

Table 1 Details of representative forest stands in Pindari–Sunderdhunga–Kafni (PSK) site

Forest communities	Altitude (m asl)	Slope (°)	Aspect	Latitude	Longitude
Alnus nepalensis	2050	40	NW	30°06′45″	79°55′49″
Alnus nepalensis	2075	40–45	SE	30°07′59″	79°55′23.5″
Mixed *Quercus-deciduous* spp.	2100	50–55	SE	30°06′55″	79°56′55.4″
Mixed *Quercus-deciduous* spp.	2300	40–45	SW	30°08′8.2″	79°57′44″
Mixed *Quercus-deciduous* spp.	2300	40–45	NE	30°08′15.7″	79°55′34.5″
Quercus floribunda	2300	45–50	NE	30°07′5.4″	79°56′60″
Quercus floribunda	2400	35–40	NE	30°8′22.3″	79°55′30.1″
Quercus floribunda	2400	40–45	SE	30°09′1.8″	79°58′15.2″
Quercus floribunda	2500	40–45	NE	30°09′50.1″	79°58′52.8″
Hippophae salicifolia	2300	5–10	NW	30°08′16.5″	79°57′56″
Hippophae salicifolia	2500	10–15	SE	30°10′37.4″	79°59′37.3″
Hippophae salicifolia	2650	10–15	NE	30°11′13″	79°55′33″
Quercus semecarpifolia	2500	45	SE	30°08′57″	79°55′25″
Quercus semecarpifolia	2500	40–45	NE	30°10′12.1″	79°59′12.7″
Quercus semecarpifolia	2600	45–50	NW	30°8′55″	79°55′25″
Quercus semecarpifolia	2900	45–50	SW	30°04′21″	79°55′18″
Mixed deciduous	2600	30	SE	30°10′29.7″	79°59′21″
Mixed deciduous	2650	50–55	NW	30°10′38.1″	79°59′46″
Mixed deciduous	2850	50–55	SW	30°11′19.5″	79°59′49″
Mixed *Abies pindrow–Quercus* spp.	2600	40–45	SE	30°04′56″	79°55′10″
Mixed *Abies pindrow–Quercus* spp.	3000	30–35	NW	30°04′01″	79°54′27.4″
Mixed *Abies pindrow-Rhododendron-Acer* spp.	2650	40	SW	30°12′32″	79°55′28″
Mixed *Abies pindrow-Rhododendron-Acer* spp.	2700	50	SE	30°10′51.8″	79°59′44″
Mixed *Abies pindrow-Rhododendron-Acer* spp.	2900	40–45	SE	30°10′31.3″	80°0′14.8″
Abies pindrow	2700	60	SE	30°10′34.3″	79°59′56″
Abies pindrow	3200	60–65	SW	30°10′53″	80°01′24.9″
Mixed *Betula utilis-Abies pindrow*	3200	60	NW	30°11′27.4″	79°59′43.5″
Mixed *Betula utilis-Abies pindrow*	3200	50–60	NE	30°12′54″	79°55′5″
Betula utilis	3300	60–65	SW	30°12′54.6″	80°00′16″
Betula utilis	3300	50–60	NE	30°12′58″	79°55′1″

Results

Compositional pattern

The study transects in NDBR comprised of a total 451 plant species belonging to 94 families. Among all, herb with 318 species showed the maximum contribution (70.51%) followed by shrubs with 80 and trees with 53 species. Pindari–Sunderdhunga–Kafni site shares 73.6% and Lata–Tolma–Phagti site 54.9% of total species (Rawat et al. 2015). Maximum number of tree species (23 spp.) was recorded in Mixed *Abies pindrow-Quercus spp*. and *Quercus semecarpifolia* communities. In sapling and seedling layer, *Q. floribunda* showed highest contribution with 18 species of sapling and 19 species of seeding. In all cases, minimum species richness was observed in *Hippophae salicifolia* community. Maximum shrub and herb species were recorded in *Q. semecarpifolia* (23 spp.) and Mixed *Quercus-deciduous* spp. (96 spp.) communities, respectively. In Lata–Tolma–Phagti site, species richness varies greatly from 4 to 18 species in tree, 10–29 species in shrubs and 18–107 species in herbs. Highest tree species was recorded from *P. wallichiana* community with 18 species and lowest was recorded from Mixed *Taxus wallichiana-Abies pindrow* with 4 species. Maximum shrub (29 spp.) and herb (107 spp.) were recorded from *P. wallichiana* community (Rawat et al. 2015a).

Species diversity along environmental gradients

Simple Linear Correlation explains interrelationship between species richness parameters and environmental parameters in both the study sites (Table 4). In Pindari–Sunderdhunga–Kafni site species richness of tree,

Table 2 Details of representative forest stands in Lata–Tolma–Phagti (LTP) site

Forest Communities	Altitude (m asl)	Slope (°)	Aspect	Latitude	Longitude
Cedrus deodara	2300	38	N	30°29′53″	79°43′19.2″
Cedrus deodara	2540	47	N	30°31′34.7″	79°44′54.5″
Cedrus deodara	2490	55	N	30°31′35.16″	79°44′52.99″
Juglasn regia-Prunus cornata mixed	2530	48	NW	30°29′43.1″	79°43′30.7″
Acer caesium-Prunus cornata mixed	2650	45	NW	30°29′35.4″	79°43′34.1″
Pinus Wallichiana	2500	30	N	30°29′27.5″	79°42′25.5″
Pinus Wallichiana	2600	40	N	30°29′50.36″	79°43′41.60″
Pinus Wallichiana	2600	40	N	30°29′53.74″	79°43′45.78″
Pinus Wallichiana	2880	48	NW	30°29′48″	79°44′11″
Pinus Wallichiana	2840	10	N	30°31′10.66″	79°45′28.60″
Pinus Wallichiana	2930	15	N	30°31′6.25″	79°45′21.20″
Pinus Wallichiana	2980	40	N	30°31′3.36″	79°45′24.18″
Pinus Wallichiana	3000	40	N	30°33′07.02″	79°46′18.97″
Pinus Wallichiana	3200	37	N	30°32′58.56″	79°46′3.40″
Abies spectabilis	3460	50	SW	30°30′32.88″	79°45′18.60″
Abies spectabilis	2690	45	N	30°33′27.7″	79°46′25.6″
Taxus wallichiana-Abies pindrow mixed	3096	25	N	30°30′52.3″	79°45′32.9″
Abies pindrow	3400	45	N	30°30′33.5″	79°45′39.1″
Abies pindrow	3000	40	N	30°31′0.95″	79°45′28.36″
Abies pindrow	3050	30	N	30°30′57.63″	79°45′25.26″
Abies pindrow	3040	25	N	30°30′58.15″	79°45′12.74″
Abies pindrow	3150	55	N	30°30′50.02″	79°45′16.00″
Abies pindrow	3230	40	W	30°29′49.08″	79°44′28.62″
Abies pindrow	3350	55	W	30°29′53.58″	79°44′34.12″
Abies pindrow	3425	45	NW	30°30′03.34″	79°44′36.86″
Betula utilis	3800	40	N	30°32′40.8″	79°46′9.5″
Betula utilis	3590	50	NW	30°29′56.8″	79°44′49.8″
Betula Utilis	3800	55	N	30°29′49.0″	79°45′0.5″
Betula Utilis	3800	52	NW	30°30′14.2″	79°45′48.6″
Betula Utilis	3000	45	W	30°29′37.43″	79°44′14.61″

shrub, native and endemic species richness are significantly correlated variedly with one or another environmental parameter. Total species richness, species richness of herbs and canopy cover remains unaffected from influence of environmental parameters. Species richness of non-native species, disturbance and TBA are showed correlation with elevation. A significant decrease in disturbance ($P < 0.01$), TBA ($P < 0.05$), non-native species richness ($P < 0.05$) and increase in endemic species richness ($P < 0.01$) has been observed across elevation. Species richness of tree ($P < 0.01$), native ($P < 0.01$) shrubs ($P < 0.05$) and TBA ($P < 0.05$) show significant positive correlation with pH. Native ($P < 0.01$) and endemic ($P < 0.05$) species richness has positive correlation with organic carbon. Nitrogen has significant relationship with shrub ($P < 0.05$), native ($P < 0.05$) and endemic ($P < 0.05$) species richness. Slope has good positive relationship with tree ($P < 0.05$), shrub ($P < 0.01$), native ($P < 0.05$) and endemic ($P < 0.05$) species richness. While in Lata–Tolma–Phagti site, canopy and TBA did not show significant correlation with any environmental parameters. However, all species richness parameters (total- $P < 0.01$; tree- $P < 0.01$; herb- $P < 0.01$; shrub-$P < 0.01$; native- $P < 0.01$; non-native- $P < 0.01$; endemic- $P < 0.01$) showed significant correlation with organic carbon. Disturbance showed good negative ($P < 0.01$) and species richness of endemic showed positive correlation ($P < 0.05$) with elevation. pH shows significant increase with increasing disturbance ($P < 0.05$). Slope shows good impact on species richness of herb ($P < 0.05$), native ($P < 0.01$), non-native ($P < 0.05$) and endemic ($P < 0.01$). Level of disturbance ($P < 0.01$) is less prominent in higher slopes (Table 4).

Further, the datasets obtained from Simple Linear Correlation analysis has supported ordination analysis to establish combines effects of each environmental parameter on species richness and other compositional values. In the CCA of environmental data with species richness, most variances

Table 3 Details of representative forest communities Pindari–Sunderdhunga–Kafni (PSK) and Lata–Tolma–Phagti (LTP) sites in Nanda Devi Biosphere Reserve (NDBR)

Communities	No. of Stands	Altitude (m)	Soil Parameters (Avg)		
PSK site			pH	Organic carbon (%)	Total nitrogen (%)
Betula utilis	02	3150–3350	6.75 ± 0.01	4.69 ± 0.09	0.91 ± 0.06
Mixed *Betula utilis-Abies pindrow*	02	3100–3200	6.81 ± 0.02	4.63 ± 0.02	0.86 ± 0.06
Abies pindrow	02	2750–3150	6.77 ± 0.08	4.50 ± 0.74	0.84 ± 0.20
Mixed *Abies pindrow–Quercus spp*	02	2700–2900	6.84 ± 0.06	4.67 ± 0.12	0.86 ± 0.01
Mixed *Abies pindrow-Rhododendron-Acer* spp.	03	2650–3175	7.04 ± 0.04	4.23 ± 0.02	0.76 ± 0.03
Mixed deciduous	03	2600–2800	6.86 ± 0.17	4.22 ± 0.07	0.74 ± 0.07
Quercus semecarpifolia	04	2500–2900	6.86 ± 0.09	3.90 ± 0.15	0.72 ± 0.07
Hippophae salicifolia	03	2300–2550	6.57 ± 0.05	3.47 ± 0.19	0.40 ± 0.13
Quercus floribunda	04	2400–2500	6.91 ± 0.21	4.06 ± 0.86	0.62 ± 0.18
Mixed *Quercus-deciduous* spp.	03	2100–2350	6.93 ± 0.02	4.14 ± 0.31	0.68 ± 0.13
Alnus nepalensis	02	1850–2038	6.78 ± 0.01	3.38 ± 0.64	0.63 ± 0.30
LTP site					
Betula utilis	5	3385–3890	5.34 ± 0.44	6.90 ± 0.14	1.10 ± 0.04
Abies pindrow	8	2700–3500	5.31 ± 0.16	5.49 ± 0.07	0.79 ± 0.17
Mixed *Taxus wallichiana-Abies pindrow*	1	3150	5.12 ± 0.00	5.49 ± 0.00	0.85 ± 0.00
Abies spectabilis	2	3050–3100	4.79 ± 0.10	3.32 ± 0.01	0.34 ± 0.09
Pinus wallichiana	9	2435–3010	6.06 ± 0.58	3.37 ± 0.20	0.36 ± 0.07
Mixed *Acer caesium-Prunus cornuta*	1	2650	6.27 ± 0.00	1.21 ± 0.00	0.22 ± 0.00
Mixed *Juglans regia-Prunus cornuta*	1	2450	6.11 ± 0.00	4.06 ± 0.00	0.5 ± 0.00
Cedrus deodara	3	2350–2550	6.32 ± 0.03	4.03 ± 0.11	0.39 ± 0.05

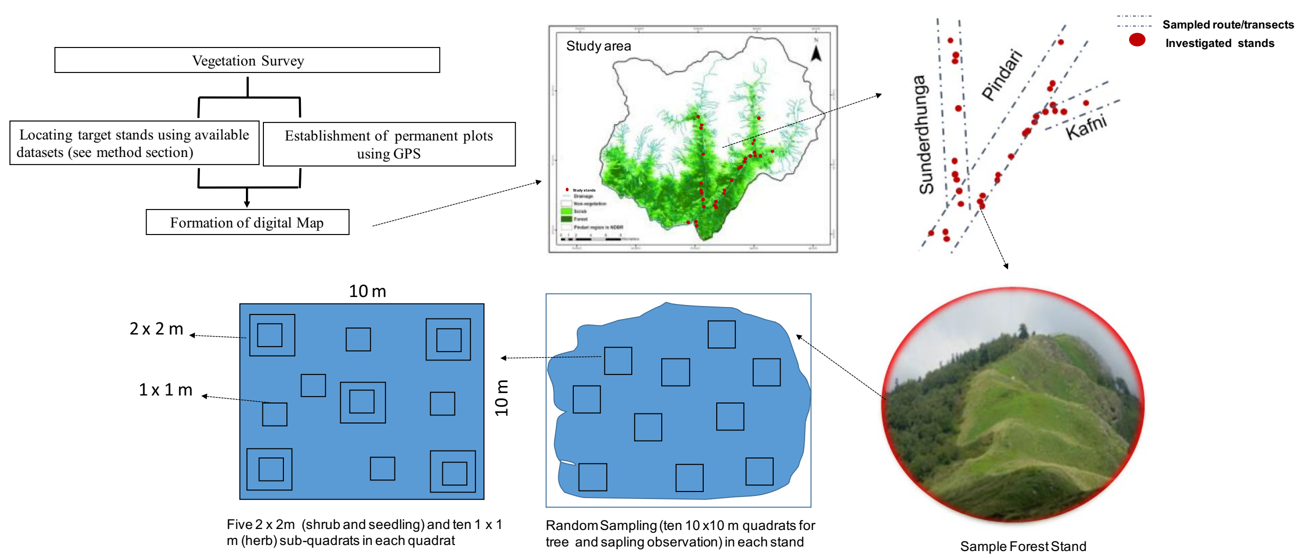

Fig. 2 Sampling scheme adopted for survey and vegetation analysis in Nanda Devi Biosphere Reserve (NDBR)

for species richness (43%—Pindari–Sunderdhunga–Kafni site; 55.6%—Lata–Tolma–Phagti site) were explained by the first three axes, which all had eigenvalues > 0.5 (Table 5); only the first two axes are plotted (Fig. 3). Most factors were strongly related to axis 1 and 2 having factor loadings greater than 0.5 in both the sites.

As depicted in Fig. 3a, in Pindari–Sunderdhunga–Kafni site, low elevational areas are highly disturbed supporting high total basal area and species richness particularly of non-native species. These areas are represented by moderate slopes. While, in higher elevations, good canopy cover in steep slopes supports good numbers of native, herbs

Table 4 Effect of environmental variables on different vegetation parameters in Pindari–Sunderdhunga–Kafni (PSK) and Lata–Tolma–Phagti (LTP) sites

Pindari–Sunderdhunga–Kafni (PSK) site	Species richness							Other attributes		
	Total	Tree	Herb	Shrub	Native	Non-native	Endemic	Canopy cover	Disturbance	TBA
Elevation	– 0.011	– 0.143	– 0.016	0.293	0.295	– 0.364*	0.520**	– 0.041	– 0.557**	– 0.394*
pH	0.260	0.714**	0.096	0.366*	0.482**	0.045	0.337	0.245	0.085	0.391*
Organic carbon	0.163	0.153	0.115	0.252	0.470**	– 0.086	0.425*	0.01	– 0.263	– 0.112
Nitrogen	0.253	0.231	0.175	0.437*	0.375*	0.011	0.463*	0.298	– 0.331	– 0.036
Slope	0.110	0.370*	– 0.017	0.547**	0.370*	– 0.244	0.381*	0.193	– 0.276	0.021
Lata–Tolma–Phagti (LTP) site										
Elevation	0.119	– 0.201	0.161	0.216	0.167	0.267	0.401*	0.150	– 0.633**	0.093
pH	0.166	0.222	0.145	0.113	0.133	0.229	0.026	0.217	0.462*	0.057
Organic carbon	0.735**	0.493**	0.691**	0.795**	0.684**	0.595**	0.730**	0.231	0.030	– 0.207
Nitrogen	– 0.085	– 0.246	– 0.080	0.101	– 0.131	0.031	0.164	0.230	– 0.272	0.290
Slope	0.326	– 0.019	0.381*	0.289	0.487**	0.387*	0.551**	0.148	– 0.664**	– 0.130

*Values are significant $P<0.05$

**Values are significant at $P<0.01$

and considerable numbers of endemic species. Native and endemic species are abundant in nutrient rich soil with higher amount of organic carbon, nitrogen, and pH (Fig. 3a). Low elevational areas in Lata–Tolma–Phagti site under high influence of disturbance but this has no impact on species richness variables except tree species richness. Good numbers of non-native species in moderate slopes are characteristics of these areas. High elevational zones are not influenced by disturbances, thus support highly nutrient rich soil and species richness of endemic and native species (Fig. 3b).

Discussion

Compositional pattern

Among total species richness, maximum was recorded from herb layer (70.51%). Herb layer contributes remarkable to overall plant species richness in any plant community and thus holds control over tree species regeneration thorough competitive and facilitative interactions (Gilliam 2007). In addition, overall forest productivity is depending on the herb layer contribution (Mölder et al. 2008). Among sites, maximum species richness contribution comes from Pindari–Sunderdhunga–Kafni site (73.6%) in Nanda Devi Biosphere Reserve. More diverse forest communities in Pindari–Sunderdhunga–Kafni site contribute maximum species richness (Rawat et al. 2015a). Changes in climatic and environmental parameters are more pronounced in diverse types of forest and these forests having a direct bearing on the habitat types and species diversity (Singh et al. 1996; Muller 1982). Therefore, more climatic fluctuations and more mesic (moist) conditions in Pindari–Sunderdhunga–Kafni site than Lata–Tolma–Phagti site are possible reason of greater variations in community types and species richness in Pindari–Sunderdhunga–Kafni site. Lata–Tolma–Phagti site, having comparatively more dry conditions than Pindari–Sunderdhunga–Kafni site, is more suitable for growth of coniferous forests (Joshi 2002).

Species diversity along environmental gradients

Simple Linear Correlation and CCA based analysis showed that higher elevations (cool temperate to sub-alpine) in both the sites are associated with higher slopes, high organic carbon, and nitrogen. Plant distribution and composition is well known to be determined by local environmental features (Keenan and Kimmins 1993). Among others, soil characteristics such as organic carbon, nitrogen and pH have been reported to strongly correlate with vegetation (Wales 1967; Pregitzer and Barnes 1982; Pregitzer et al. 1983). Increase in soil organic carbon, organic matter and nitrogen with increase in elevation has already been predicted (Sims and Nielsen 1986; Garten et al. 1999; Xu et al. 2010; Dai and Huang 2006; Proll et al. 2011). Besides, high altitude communities (sub-alpine) also support moderate canopy cover, richness of native, endemic and shrub species. Distribution of native species along altitude has also been demonstrated (Khuroo et al. 2011). Low-mid altitudinal zones (cool temperate) support high richness of tree and seedlings and high TBA in moderately disturbed areas with open canopy. The open canopy sites supported good density of recruitment and shrub species (Mishra et al. 2003; Mishra et al. 2004). Further, species and community responses to the climatic

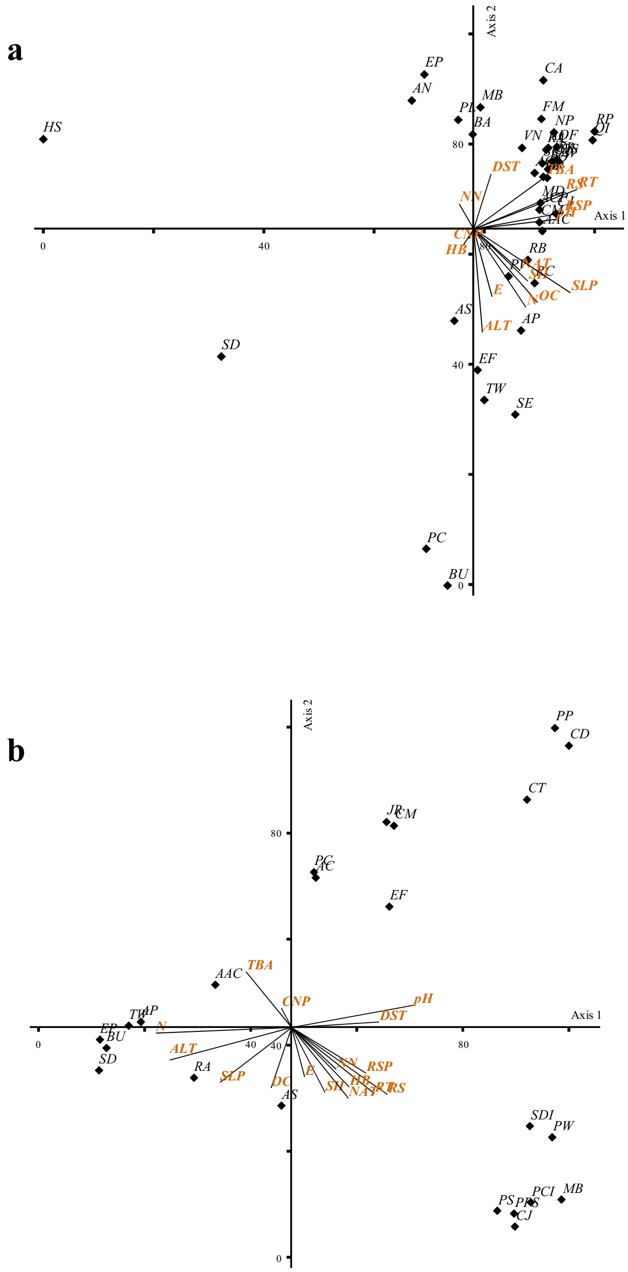

Fig. 3 CCA plots of factor loadings along the first two axes for the subsets of vegetation units and environmental variables in NDBR; (**a**) Pindari–Sunderdhunga–Kafni site; (**b**) Lata–Tolma–Phagti site

gradients and atmospheric gases are well established (Aguado-Santacruz and Garcia-Moya 1998; Vasseur and Potvin 1998).

In general, both the study sites showed good species richness in mid elevational zones where levels of disturbance and steepness of slopes are moderate. The open canopy in Lata–Tolma–Phagti site and closed canopy in Pindari–Sunderdhunga–Kafni site in mid elevational zones supporting high species richness may be attributed to the physiognomic types in the regions (> 60% broadleaf forest in Pindari–Sunderdhunga–Kafni site; >60% coniferous forest in Lata–Tolma–Phagti site).

Conclusions

Present study highlights the forest species distribution in relation to different associated factors influencing the growth and establishment of species/communities in the west Himalayan region. Of five environmental variables that were measured, elevation, slope and organic carbon were found to be the most influencing variable. However, nitrogen and pH showed their impact on certain compositional parameters. In the western Himalayan forest, some site variable like soil components and non-native proliferation may act as a baseline data of past disturbance regime and can be utilized for assessing the recovery and regenerative potential of disturbed sites. Changes in land use and habitat alterations because of human pressure are very intense in Himalayan regions, needs initiatives towards mitigating effects of non-native invasive species. As a result of such land use changes, habitat alterations and approach to new sites due to dispersal, non-native species in lower elevations can be enriched in range towards higher elevations in the future that needs an immediate attention in the reserve. This is amongst the few studies depicting the distribution pattern of forest species as well as communities in relation to different associated factors responsible for the growth and establishment of species/communities in NDBR, west Himalaya. This scenario, therefore, calls for similar studies on various attributes highlighted in present study in other Himalayan biosphere reserves (HBRs).

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Table 5 Eigenvalues, cumulative % variance, and factor loadings for environmental and ecological variables along axes using CCA in Nanda Devi Biosphere Reserve, India

	PSK site			*LTP site*		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Eigenvalue	0.838	0.713	0.384	0.748	0.732	0.613
Cumulative % variance	18.6	34.5	43.0	19.9	39.3	55.6
ALT (altitude)	0.062	**− 0.882**	− 0.339	**− 0.698**	− 0.333	0.110
SLP (slope)	**0.728**	**− 0.541**	0.114	− 0.410	**− 0.566**	0.160
pH (soil pH)	**0.622**	0.088	− 0.108	**0.694**	0.235	− 0.065
OC (organic carbon)	0.478	**− 0.624**	− 0.064	− 0.118	**− 0.620**	0.411
N (nitrogen)	0.395	**− 0.670**	− 0.155	**− 0.778**	− 0.061	0.225
RS (richness of seedling)	**0.687**	0.326	0.015	**0.546**	**− 0.689**	− 0.134
RSP (richness of sapling)	**0.678**	0.138	− 0.024	0.425	− 0.468	0.118
RT (richness of tree)	**0.775**	0.336	− 0.113	0.470	**− 0.684**	− 0.037
HB (richness of herbs)	− 0.077	− 0.137	0.391	0.330	**− 0.616**	0.369
SH (richness of shrubs)	0.408	− 0.441	0.103	0.192	**− 0.674**	0.168
NAT (richness of natives)	0.346	− 0.355	0.167	0.325	**− 0.728**	0.230
NN (richness of non-natives)	− 0.106	0.217	0.381	0.254	− 0.435	0.355
E (richness of endemics)	0.135	**− 0.579**	0.217	0.073	**− 0.506**	0.283
CNP (canopy)	− 0.036	− 0.077	0.163	− 0.059	0.202	− 0.06
DST (disturbance)	0.131	0.471	0.133	0.498	0.057	0.037
TBA (total basal area)	**0.541**	0.446	− 0.190	− 0.264	**0.578**	0.416

Numbers in bold denote variables having strong scores (> 0.50) with a given axis

References

Acharya BK, Chettri B, Vijayan L (2011) Distribution pattern of trees along an elevation gradient of Eastern Himalaya, India. Acta Oecol 37:329–336

Aguado-Santacruz GA, Garcia-Moya E (1998) Environmental factors and community dynamics at the southernmost part of the North American Graminetum. Plant Ecol 135:13–29

Anonymous (2009) Governance for Sustaining Himalayan Ecosystem (G-SHE)-Guidelines & best practices. MoEF & GBPIHED, pp. 1–51

Arevalo JR, Delgado JD, Otto R, Naranjo A, Salas M, Fernandez-Palacios JM (2005) Distribution of alien vs native plant species in roadside communities along an altitudinal gradient in Tenerife and Gran Canaria (Canary Islands). Perspect Plant Ecol Evol Syst 7:185–202

Bhattarai KR, Vetaas OR (2006) Can Rapoport's rule explain tree species richness along the Himalayan elevation gradient Nepal? . Divers Distrib 12(4):372–378

Biswas SR, Mallik AU (2010) Disturbance effects on species diversity and functional diversity in riparian and upland plant communities. Ecology 91(1):28–35. doi:https://doi.org/10.1890/08-0887.1

Currie DJ, Francis AP (2004) Regional versus climate effect on taxon richness in angiosperms: reply to Qian and Ricklefs. Am Nat 163:780–785

Dai W, Huang Y (2006) Relationship of soil organic matter concentration to climate and altitude in zonal soils of China. Catena 65:87–94

Dhar U (2002) Conservation implication of plant endemism in high-altitude Himalaya. Curr Sci 82(2):141–148

Dhar U, Samant SS (1993) Endemic diversity of Indian Himalaya I: Rannunculaceae and II: Paeoniaceae. J Biogeogr 20:659–668

Dhar U, Rawal RS, Samant SS (1996) Endemic plant diversity in Indian Himalaya III: Brassicaceae. Biogeographica 72(1):19–32

Dhar U, Rawal RS, Samant SS (1997) Structural diversity and representativeness of forest vegetation in a protected area of Kumaun Himalaya, India: implications for conservation. Biodivers Conserv 6:1045–1062

Dikshit BK, Panigrahi G (1998) The Family Rosaceae in India—Revisionary studies on Potentilla L. Dehradun, p 348

Dubuis A, Pottier J, Rion V, Pellissier L, Theurillat JP, Guisan A (2011) Predicting spatial patterns of plant species richness: a comparison of direct macroecological and species stacking approaches. Divers Distrib 17:1122–1131

Fakhry AM, Khazzan MM, Aljedaani GS (2020) Impact of disturbance on species diversity and composition of *Cyperus conglomeratus* plant community in southern Jeddah, Saudi Arabia. J King Saud Univ Sci 32(1):600–605

Gairola S, Rawal RS, Todaria NP (2008) Forest vegetation patterns along an altitudinal gradient in sub-alpine zone of west Himalaya, India. Afr J Plant Sci 2(6):42–48

Garten CT, Post WM, Hanson PJ, Cooper LW (1999) Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains. Biogeochemistry 45:115–145

Gaur RD (1999) Flora of District Garhwal, North West Himalaya with ethnobotanical notes. Transmedia Publication, Srinagar

Gentry AH (1993) Pattern and floristic composition in neotropical montane forests. Proceedings of neotropical montane ecosystem symposium, New York

Gilliam FS (2007) The ecological significance of the herbaceous layer in temperate forest ecosystems. Bioscience 57:845

Givnish TJ (1999) On the causes of gradients in tropical tree diversity. J Ecol 87:193–210

Gonzalez-Espinosa M, Rey-Benayas JM, Ramirez-Marcial N, Huston MA, Golicher D (2004) Tree diversity in the northern Neotropics: regional patterns in high diverse Chiapas. Mexico Ecography 27:741–756

Hajra PK, Balodi B (1995) Plant wealth of Nanda Devi Biosphere Reserve. Botanical Survey of India, Culcutta

Hooker JD (1872–1897) Flora of British India (Vol. 1–7). Reeve & Co., London

Jain SK, Rao RR (1977) A handbook of field and herbarium methods. Today and tomorrow's Printers and Publishers, New Delhi

Joshi HC (2002) Assessment of habitat diversity, forest vegetation and human dependence in the buffer zone of Nanda Devi Biosphere Reserve of west Himalaya. Ph.D. theis (Botany). Kumaun University, Nainital

Keenan RJ, Kimmins JP (1993) The ecological effect of clear cutting. Environ Rev 1:121–144

Kharkwal G, Mehrotra P, Rawat YS, Pangtey YPS (2005) Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. Curr Sci 89(5):873–878

Khuroo AA, Weber E, Malik AH, Reshi ZA, Dar GH (2011) Altitudinal distribution pattern of the native and alien woody flora in Kashmir Himalaya, India. Environ Res 111:967–977

Kumar A, Panigrahi G (1995) The family Rosaceae in India - Revisionary studies on Cotoneatster Medik, vol 3. Bishen Singh Mahendra Pal Singh, Dehradun, p 292

Mishra BP, Tripathi RS, Tripathi OP, Pandey HN (2003) Effect of disturbance on the regeneration of four dominant and economically important woody species in a broadleaved subtropical humid forest of Meghalaya, northeast India. Curr Sci 84:1449–1453

Mishra BP, Tripathi OP, Tripathi RS, Pandey HN (2004) Effect of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. Biodivers Conserv 13:421–436

Misra R (1968) Ecological work book. Oxford & IBH Publishing Company, Calcutta

Mohammad A (2008) The Effect of Slope Aspect on Soil and Vegetation Characteristics in Southern West Bank. Bethlehem Univ J 27:9–25

Mölder A, Bernhardt-Römermann M, Schmidt W (2008) Herb-layer diversity in deciduous forests: raised by tree richness or beaten by beech? For Ecol Manag 256:272–281

Mukherjee PK, Constance L (1993) Umbelliferae (Apiaceae) of India. Oxford & IBH, Calcutta

Muller-Dombois D, Ellenberg H (1974) Aims and methods of vegetation ecology. John Wiley and Sons, New York

Naithani BD (1984) Flora of Chamoli district. (Vol. I & II). Botanical Survey of India, Howrah, Culcutta

Naeem S (2002) Ecosystem consequences of biodiversity loss: the evolution of a paradigm. Ecology 83(6):1537–1552

Norusis MJ (1994) SPSS: SPSS Advanced Statistics 6.1. SPSS Inc., Chicago, Illinois, USA

Novosamsky I, Houba VJG, Eck Van R, Vark Van W (1983) A novel digestion technique for multi element plant analysis. Soil Sci Plant Anal 14:239–249

Pregitzer KS, Barnes BV (1982) The use of ground flora to indicate edaphic factors in upland ecosystems of the McCormik experimental forest, upper Michigan. Can J For Res 12:661–672

Pregitzer KS, Barnes BV, Lemme GD (1983) Relationship of topography to soils and vegetation in an upper Michigan ecosystem. Soil Sci Soc Am J 47:117–123

Proll G, Dullinger S, Dirnbock T, Kaiser C, Richter A (2011) Effect of nitrogen on tree recruitment in a temperate montane forest as analysed by measured variables and Ellenberg indicator values. Preslia 83:111–127

Qian H, Ricklefs RE (2004) Taxon richness and climate in angiosperms: is there a globally consistent relationship that precludes region effect? Am Nat 163:773–779

Rawal RS, Dhar U (1997) Sensitivity of timberline flora in Kumaun Himalaya, India: Conservation implications. Arct Alp Res 29:112–121

Rawal RS, Pangtey YPS (1994) Distribution and structural-functional attributes of trees in the high altitude zone of central Himalaya, India. Vegetatio 112:29–34

Rawal RS, Bankoti NS, Samant SS, Pangtey YPS (1991) Phenology of tree layer species from the timberline around Kumaun in central Himalaya, India. Vegetatio 93:109–118

Rawat B (2014) Changes in vegetation diversity and plant responses in Nanda Devi Biosphere Reserve over the last two decades. PhD thesis. Submitted to Kumaun University Nainital, Uttarakhand, India, 182 pp

Rawat B, Gairola S, Rawal RS (2015) Assessing Conservation values of forest communities in Nanda Devi biosphere reserve: plant diversity, species distribution and endemicity. J Mt Sci 12(4):878–899

Rawat B, Gairola S, Sekar KC, Rawal RS (2015) The present status and future prospects of forest vegetation in part of Nanda Devi Biosphere Reserve (a World Heritage Site), India. J For Res 26(4):897–904. https://doi.org/10.1007/s11676-015-0109-x

Samant SS, Dhar U, Palni LMS (1998) Medicinal plants of indian himalaya: diversity distribution potential values. Gyanodaya Prakashan, Nainital

Saxena AK, Singh JS (1982) A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. Vegetatio 50:3–22

Sharma BD, Balakrishnan NP (1993) Flora of India, vol 2. Papaveracea-Caryophyllaceae. BSI, Calcutta

Sims ZR, Nielsen GA (1986) Organic carbon in Montana soils as related to clay content and climate. Soil Sci Soc Am J 50:1269–1271

Singh SP, Adhikari BS, Garkoti SC, Rawat YS (1996) Structural and functional characteristics of the forest ecosystems around Nanda Devi Biosphere Reserve. In: Ramakrishnan PS, Purohit AN, Saxena KG et al (eds) Conservation and management of biological resources in Himalaya, New Delhi. Oxford & IBH Publishing Co. Limited, New Delhi, pp 413–432

Uniyal BP, Sharma JR, Chowdhery U, Singh DK (2007) Flowering plants of Uttarakhand (A checklist). Bishen Singh Mahendra Pal Singh, Dehradun

Vasseur L, Potvin C (1998) Natural pasture community response to enriched carbon dioxide atmosphere. Plant Ecol 135:31–41

Wales BA (1967) Climate, microclimate and vegetation relationships on north and south forest boundaries in New Jersey. William L. Hutcheson Memorial Forest Bull 2:1–67

Walkley A, Black IA (1934) An examination of Degtjiareff method for determining soil organic matter and a proposed modification of chromic acid titration method. Soil Sci 37:29–38

Willig MR, Kaufman DM, Stevens RD (2003) Latitudinal gradients of biodiversity: pattern process, scale and synthesis. Ann Rev Ecol Evol Syst 34:273–309

Woodcock EC, Macomber AS, Kumar L (2002) Vegetation cover mapping and monitoring. In: Skidmore A (ed) Environmental modeling with GIS and remote sensing. Taylor and Francis, New York, New York

Xu X, Zhou Y, Ruan H, Luo Y, Wang J (2010) Temperature sensitivity increased with soil organic carbon recalcitrance along an elevational gradient in the Wuyi Mountains, China. Soil Biol Biochem 42:1811–1815