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RESEARCH ARTICLES

Positive relationship between species richness and aboveground biomass in Kumaun Himalayan forest

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Abstract

Understory vegetation is an important part of forest ecosystem which affect the physical and chemical properties of soil, quality and quantity of forest litter and water storage capacity of litter soil layer. Thus, the influence of soil nutrients on the understory species composition of forest ecosystem cannot be ignored. The authors set 15 typical plots with area of 1 × 1 m in chir pine (*Pinus roxburghii* Sarg.), oak (*Quercus leucotrichophora* A. Camus)—chir pine mixed and oak–cypress (*Cupressus torulosa* D. Don) mixed forest. Chemical properties of the soil were analyzed at 0–10 cm, 10–20 cm and 20–30 cm in all the selected forest types. Phytosociological and diversity parameters were also calculated for each forest type. The present study reveals that carbon, nitrogen, pH and phosphorus are the most important environmental drivers which influence understory species composition. Plant species richness significantly correlated with species composition. To maintain the diversity and structure of ecosystems we should consider the co-evolution of both vegetation and soil. Further studies on climate and microorganism are needed to further explore the interactive relationships among vegetation and soil properties.

Keywords Soil fertility · *Pinus roxburghii* · *Quercus leucotrichophora* · *Cupressus torulosa* · Forest diversity

Introduction

The central Himalaya contains a range of vegetation types from tropical to subalpine forest, alpine scrub and alpine meadows (Singh and Singh 1992) which are severely threatened by human activities. Oak (*Quercus leucotrichophora* A. Camus) and chir pine (*Pinus roxburghii* Sarg.) are the most dominant forests types in the whole Uttarakhand (Ram et al. 2004). The growth and reproduction of a forest cannot be understood without the knowledge of soil properties. The chemical property of soil is greatly influenced by forest vegetation. Tree species absorb selective nutrients from soil and return them to soil which brings changes in soil property. Soil fertility gives useful information about nutrient cycling and biogeochemical cycle in the soil plant ecosystem. Forests have a greater influence on soil condition due to well develop "O" horizon, moderating temperature, and humidity at the soil surface input of litter with high lignin content, high total net primary production, and high nutrient demand (Binkley and Giardina 1998). The nature of soil is classified by the physical constitution like size and shape of soil particles (Jongmans et al. 2001). The physical properties increase the soil fertility and help to control erosion (Sharma and Bhatia 2003). The nutrient status of the soil is determined by their physico-chemical properties, which vary according to the climate, parent material, physiographic position and the vegetation (Behari et al. 2004). Estimation of biomass is essential for determining the status and flux of biological nutrients in ecosystems and for understanding ecosystem dynamics. For understanding future change of the climate system it is necessary to study the vegetation biomass. Depending on the quantity of biomass, vegetation cover can have a direct influence on local, regional and even global climate, particularly on air temperature and humidity (Bombelli et al. 2009). The knowledge of various forest soils and the complex relationship between plant richness and diversity is therefore necessary to study. The aim of this

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study was undertaken the nutrient dynamics in the soil and their effect on species composition and their productivity on chir pine, oak–chir pine, and oak–cypress (*Cupress torulosa* D. Don) mixed forest.

Methods

Study area

The study area is located between 29°20′ and 29°30′N latitude and 79°42′E longitude between 1300 and 2000 m a.s.l. in Uttarakhand, central Himalaya, India. Mean monthly maximum temperature ranged between 15 °C (January) to 27 °C (May) and mean minimum temperature ranged between 1 °C (January) to 16 °C (July). Mean annual rainfall was recorded as 91.75 mm. Meteorological data taken from ARIES, Nainital.

Sampling and data analysis

During the reconnaissance survey of the study area, three forest types according to altitude and species composition were selected for the study. Each forest type was named according to the composition of dominant tree species. The information about dominant tree species and associated shrub and herb species in different forest types is shown in Table 1. Fifteen quadrats of 1 × 1 m were established in each forest (total 45 quadrates) in June 2014, at the peak of biomass production for determination of species richness and other vegetation parameters. Two vegetation layers, i.e. shrubs and herbs, were analysed for species richness, density and diversity (Mishra 1968). Species richness (SR) was simply taken as a count of total number of species in that particular forest type. Shannon–Wiener diversity index was calculated as Shannon and Weaver (1963):

$$\overline{H} = -\sum_{i=1}^{R} pi \ln pi,$$

$pi = n_i/N$,
where, $\bar{H}$ is Shannon–Wiener diversity index, *Ni* is IVI of a species, *N* is total IVI of all species.

Soil sampling and analysis

Composite soil samples were collected in triplicates from three different depths viz. (1) "upper" (0–10 cm) (2) "middle" (10–20 cm) and (3) "lower" (20–30 cm) for assessing the chemical property of the soil in all the selected forest types. The pH of soil was determined in 1:5 soil solution ratio using pH meter (pH scan-2 electrode). Walkley and Black's rapid titration method as modified by Walkley (1947) was adopted for organic carbon estimation. The factor 1.724 was used to convert the organic carbon (%) into soil organic matter (%). Total nitrogen estimation was done by the micro-Kjeldahl procedure (Mishra 1968). Total carbon was divided by total nitrogen (%) to get values of C:N ratio. Available phosphorus was measured by phosphomolybdic blue colorimetric method and available potassium by flame photometery (Jackson 1973).

Biomass

The belowground plant material was collected from each monolith (25 × 25 × 30 cm) from each harvested quadrat on sampling date after the aboveground components had been sampled. The monoliths were brought to the laboratory and washed with a fine jet of water using, successively, 2 mm and 0.5 mm mesh screens. The aboveground and belowground components were oven dried at 60 °C to constant weight and their dry weight was recorded. The mean values were multiplied by their density and summed to get the total stands net primary production.

Statistical analysis

To analyse the compositional differences among the plant communities of the three studied forest sites, redundancy analysis (RDA) ordination techniques were applied using the program PC-ORD (McCune and Mefford 1997). As a distance measure, the Bray–Curtis coefficients was used (also known as Sorensen or Czekanowski coefficient), which is one of the most robust measures for this purpose (Faith et al. 1987). RDA ordination was based on square-root-transformed cover data. We performed linear regressions of species diversity versus the scores of the RDA axes to analyze the effects of plant diversity (species richness, evenness) on productivity.

Results

Plant diversity and environmental parameters

Plant species richness in the 45 plots varied between two and eight species m^{-2}, effective diversity between 0.10 and 1.83, and Shannon evenness between 0.14 and 0.98. Mean aboveground plant biomass was 5.45 g m^{-2} (range 0.50–15.34 g m^{-2}). For range and descriptive statistics of plant and available soil nutrients see Table 2. The highest shrub density was recorded in oak–cypress (23.47 m^{-2}) followed by oak–chir pine (13.87 m^{-2}) and chir pine forest (10.40 m^{-2}). The highest herb density was recorded in oak–chir pine (111.20 m^{-2}) followed by chir pine forest

Table 1 Details of the forest types studied

Forest type (as per Osmaston 1927)	Altitude (m a.s.l.)	Tree species[a]	Shrub species[a]	Herb species[a]
Chir pine	1300–1700	***Pinus roxburghii*** Sarg.	***Berberis asiatica*** Roxb. ex D. Don, *Lantana camara* L., *Pyracantha crenulata* (D. Don) M. Roem., *Rubus ellipticus* Smith	*Arthraxon lancifolius* (Trin.) Hochst, *Artemisia nilagirica* (Cl.) Pamp., *Bidens pilosa* L., ***Cyperus rotundus*** L., *Dicliptera bupleuroides* Nee, *Erigeron karvinskianus* DC, *Eupatorium adenophorum* Spreng., *Geranium nepalense* Sweet., *Goldfussia dalhousiana* Nee, *Malaxis acuminata* D. Don
Oak–chir pine mixed	1300–1700	***Quescus leucotrichophora*** A. Camus, ***P. roxburghii***, *Cedrus deodara* (Roxb. ex D. Don) G. Don, *Cupressus torulosa* D. Don, *Rhododendron arboretum* Smith	***B asiatica***, *P. crenulata*, *R. ellipticus*	*Achyranthes bidentata* Blume., *Ainsliaea latifolia* (D. Don) Sch-Bip, *A. lancifolius*, *B. pilosa*, ***C. rotundus***, *E. karvinskianus*, *G. aparine*, *G. nepalense*, *Origanum vaulgare* L., *Oxalis corniculata* L., *Rubia cordifolia* L.
Oak–cypress mixed mixed	1600–2000	***Q. leucotrichophora***, ***C. torulosa***, *C. deodara*, *Myrica esculenta* Buch.-Ham ex D. Don	***Asparagas racemosus*** Will, *B. asiatica*, *Boenninghausenia albiflora* Reich. ex Meisn., *Indigofera heterantha* Wall. Ex Brandis, *Leptodermis lanceolata* Wall., *Myrsine africana* Linn., *P. crenulata*	***A. lancifolius***, *C. rotundus*, *D. heterocarpon*, *D. bupleuroides*, *E. karvinskianus*, *E. adenophorum* , *G. dalhousiana*, *O. vaulgare*, *R. indica*, *Stellaria media* (L.) Vill., *Tragopogon gracilis* D. Don

[a]Species in bold are dominant species

Table 2 Descriptive statistics [mean, SD, minimum (min) and maximum (max) values and coefficient of variation (CV)] of productivity, biodiversity parameters and soil variables of the three forest sites

	Mean	SD	Min	Max	CV (%)
Biomass (g_{dw} m^{-2})	5.45	3.90	0.50	15.34	135.10
Species richness	4.96	1.68	2	8	58.90
Effective diversity	1.24	0.45	0.10	1.83	63.40
Shannon evenness	0.79	0.17	0.14	0.98	54.60
Soil carbon (%)	0.65	0.17	0.40	0.99	80.50
Soil nitrogen (%)	0.22	0.07	0.10	0.30	73.10
C:N	3.29	1.21	2.00	7.00	113.00
K_{ava} (kg ha^{-1})	181.88	26.63	125.30	240.60	48.40
P_{ava} (kg ha^{-1})	19.30	6.41	9.60	36.20	96.70

dw dry weight, *ava* available

(92.53 m^{-2}) and oak–cypress (46.13 m^{-2}). The higher population density of shrub species in oak–cypress mixed forest and herb species in oak pine mixed forest site could be attributed to a number of interacting factors, lopping and felling of trees has created gaps in these forest stands, with enhance light intensity and soil temperature which favours herb and shrub density.

Relationship between soil properties and phytosociological parameters

Total organic carbon (0.65%) was highest mainly in oak–cypress mixed forest where species diversity was also highest. Higher concentration of total organic carbon in soil may facilitate higher productivity of shrubs in this forest. Nitrogen showed a positive relationship with $\bar{H}$ ($R^2=0.433$, $p<0.001$). K also showed a positive relationship with species richness ($R^2=0.362$, $p<0.05$).

Plant community composition

Plant species richness significantly correlated with species composition ($R^2=0.487$, $p<0.001$). RDA showed that two-dimensional solution was sufficient to achieve low stress values (the first axis/explains 59.92% and second axis/explains 21.49% of total variance) to explain plant composition (Fig. 1).

Environmental parameters and plant community

When tested in multiple linear regression models, 37.2% of the total variability in RDA2 was explained by soil variables i.e. C, N, K, P, pH and C/N ratio compared to RDA1 which explained only 27.2%. For productivity, 44.8% of variation was explained by effective diversity and evenness (Table 3).

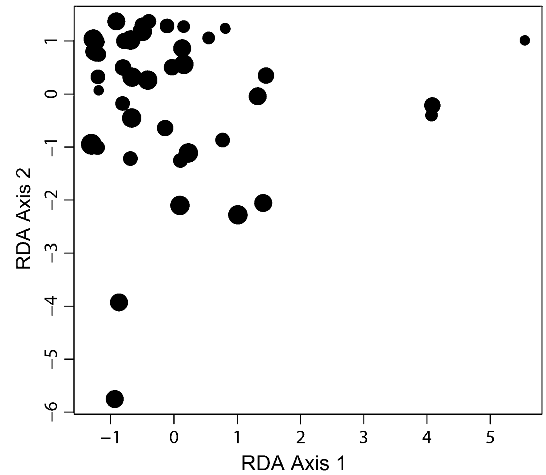

Fig. 1 Redundancy analysis (RDA) ordination of the 45 samples (the first axis/explains 59.92% and second axis/explains 21.49% of total variance, $R^2=0.617$). *Increasing symbol size* increasing plant species diversity

Relationship between diversity and standing crop biomass

The plant species richness had no significant effect, while Shannon evenness showed a negatively high significant effect on productivity (above ground standing biomass) when tested in linear regression (Fig. 2a, b). However, species composition represented as RDA1 and RDA2 was highly significantly related to productivity. RDA1 showed a positive significant effect on productivity ($R^2=0.509$, $p<0.001$) while RDA2 was negatively related to productivity ($R^2=0.368$, $p<0.001$) (Fig. 2c, d).

Discussion

Carbon (C), nitrogen (N), pH, phosphorus (P) and potassium (K) were important soil factor in this study. Majority of plant species showed a significant positive correlation along with the concentration of these elements (Fig. 3). Concentration and availability of N and P determine soil fertility and site productivity as these minerals are required in large amounts by plants.

A correlation between P and distribution of plant species was observed by Biggelow and Canham (2002). Phosphorus was positively correlated with organic C (0.630, $p<0.01$) and available K (0.513, $p<0.01$). Gupta and Sharma (2008) also observe same positive correlation between available P and organic C.

Nitrogen is a main factor in plant growth and a key nutrient in many biological processes. In well drained soil it is subject to leaching. The role of nutrient elements in the distribution and constancy of plant is studied and established by

Table 3 Multiple linear regression models for RDA1 and RAD2. Separate models were calculated for the parameter group soil and species composition

Dependent variable	Independent parameter group	Details of multiple regression model				Model summary	
		Variable	b	t	*p*	R^2	*p*
RDA1	Soil	Carbon	−1.021	−.331	0.742	0.272	**0.049**
		Nitrogen	−13.592	−1.105	0.276		
		Potassium	0.712	1.925	0.062		
		Phosphorus	−3.187	−0.805	0.426		
		pH	−0.033	−0.068	0.946		
		C:N ratio	−0.318	−0.500	0.620		
RDA2	Soil	Carbon	4.796	1.674	0.102	0.372	**0.005**
		Nitrogen	−0.800	−0.070	0.945		
		Potassium	−0.246	−0.716	0.478		
		Phosphorus	−13.617	−3.705	**0.001**		
		pH	1.229	2.746	0.009		
		C:N ratio	0.037	0.063	0.950		
Productivity	Species composition	Effective diversity	5.621	3.562	**<0.001**	0.448	**<0.001**
		Shannon Evenness	−23.077	−5.684	**<0.001**		

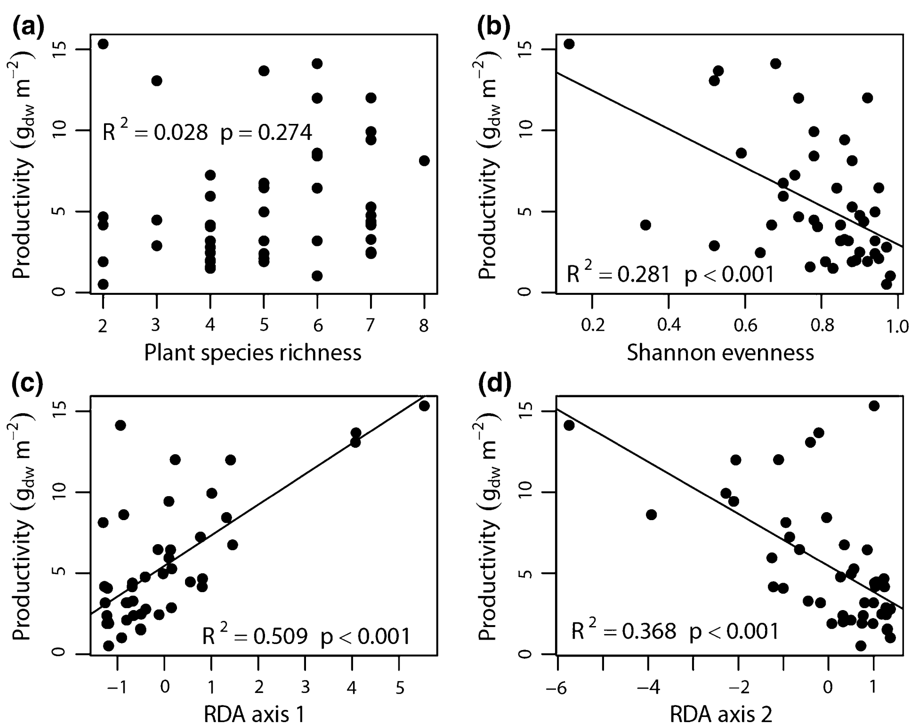

Fig. 2 Relationship between different plant diversity measures and community composition to above ground productivity

Abella and Covington (2006). Nitrogen and P are important nutrients in plant metabolic processes: N is an important component of protein; P is a key element in cellular energy transfer and a structural element in nucleic acids. N and P are also the primary nutrients that restrict plant growth in many natural environments (Jiang et al. 2012). The values of total nitrogen were higher in upper layers compared to lower layers. High amount of organic matter in the upper layers may also be the reason for richness of N in upper layers. The availability of N depends to a large extent on the amount properties of organic matter (de Haan 1977). Total N showed a significant positive relationship with organic C (0.444, $p<0.05$).

Organic materials, rich in nitrogen, have high absorption capability, increases the soils fertility levels (Zhenghu et al. 2004). The organic C content decreased with the depth of

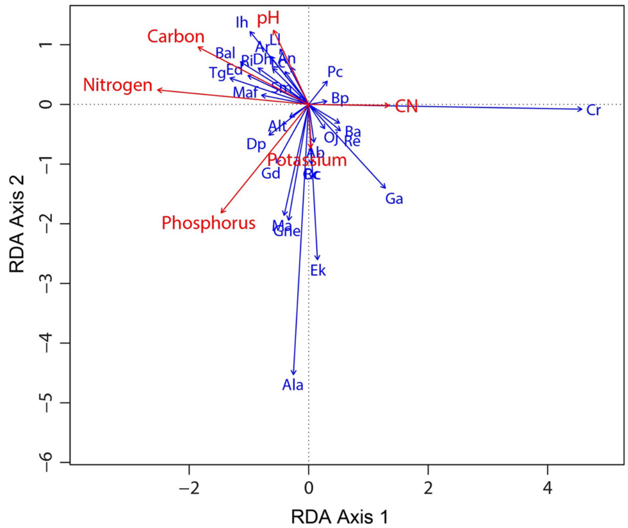

Fig. 3 A biplot showing the relationship between the plant communities and soil gradients. The length and position of the arrows indicate the strength of the relationship and direction of change. Ab *A. bidentata*, Al *A. latifolia*, Ala *A. lancifolius*, An *A. nilagirica*, Ar *A. racemosus*, Ba *B. asiatica*, Bp *B. pilosa*, Bal *B. albiflora*, Cr *C. rotundus*, Dh *D. heterocarpon*, Db *D.bupleuroides*, Ek *E. karvinskianus*, Ea *E. adenophorum*, Ga *G. aparina*, Gn *G. nepalense*, Gb *G. dalhousiana*, Ih *I. heterantha*, Lc *L. camara*, Ll *L.* lanceolata, Ma M. acuminata, Maf *M. africana*, Oj *O. javanica*, Oc *O. corniculata*, Pc *P. crenulata*, Ri *R. indica*, Rc *R. cordifolia*, Re *R. ellipticus*, Sm *S. media*, Tg *T. gracilis*

the soil in all forest types, which due to the humus formation and decomposition of organic matter takes place in the upper layers. A positive correlation of organic matter with available P (0.627, $p<0.01$), available K (0.431, $p<0.05$), total N (0.445, $p<0.05$), and C:N ratio (0.560, $p<0.01$) is observed which supported the findings of Gupta and Sharma (2008) and Gairola et al. (2012).

Potassium (K) regulates photosynthesis, carbohydrate transport, protein synthesis and other important physiological process (Hasanuzzaman et al. 2018). Fu et al. (2004) pointed out that the distribution of plants is determined by organic matter and nitrogen content. Spencera et al. (2004) also emphasized the role of organic compounds in plant growth. The K is not much influenced by soil organic matter because it is not supplier of K (Gupta and Sharma 2008). In present study, available K showed a significant positive relationship with organic carbon (0.434, $p<0.05$) and pH (0.537, $p<0.05$). This was supported by the finding of Basumatary and Bordoloi (1992), Boruah and Nath (1992) and Gairola et al. (2012), who reasoned that a layer of organic matter significantly improves the retention of K in the soils. The oak individuals are related with higher K release (Tomlinson and Tomlinson 1990) which is the main reason for the higher content of K in the soils of oak–chir pine and oak–cypress mixed forest.

The productivity capability of a site is strongly determined by its pH (Jobbagy and Jackson 2003). Its acidity has a strong influence on nutrient availability (Farley and Kelly 2004). Kashina et al. (2003), and Brofske et al. (2001) have shown the important role of pH in the separation of plant groups. The high pH may be due to disturbed nature of soil in the study area. Robertson and Vitousek (1981) and Adams and Sidle (1987) have also recorded low pH in undisturbed natural forest as compared to disturbed ecosystem.

The studies investigating the effects of biodiversity on ecosystem functions have been highly debated in the literature because of experimental design, data interpretation and potentially confounding 'hidden treatments' (Schmid and Pfisterer 2003). To account for such hidden treatment we incorporated soil variables and community composition into our data (Table 3). Our study is consistent with previous studies that have determined the importance of species composition for the stability of ecosystem functions (Grime et al. 2000; Wardle et al. 2000). Species composition is significant in the model for above ground productivity (Table 3).

The C:N ratio was found to be significantly and negatively correlated with total N (−0.477, $p<0.05$) and positively correlated with organic carbon (0.561, $p<0.01$) and available P (0.438, $p<0.05$), which is obvious as increasing N content will automatically decrease C:N ratio. The C:N ratio reflects the release of N in the soil through organic matter decomposition and therefore indicates the degree of decomposition of organic matter in the forest soils (Ulrich, 1971).

The relationship between productivity and plant species richness has been described to peak at intermediate levels of productivity in numerous ecosystems (Kahmen et al. 2005). We tested if diversity had an effect on productivity and found that simple diversity measures such as species richness showed no significant relation with productivity (Fig. 2a). However, species evenness showed a strong and negative relationship with productivity. Some experimental studies showed an asymptotic increase in biomass with increasing plant diversity or evenness (Loreau et al. 2002; Polley et al. 2003; Symstad et al. 2003). Our results are in line with these observations (Table 3, Fig. 2b). For these experimental studies, it was argued that the observed positive effects on biodiversity on productivity in experimental studies are largely due to niche complementary (Tilman et al. 2002; Loreau and Hector 2001). The niche complementary effect suggests that an increasing number of species results in a more efficient exploitation and thus enhanced ecosystem functioning.

In contrast to plant diversity, community composition (RDA1 and RDA2) had a significant effect on the productivity of the studied forest. Community composition is correlated with several highly productive plant species, suggesting that species with specific traits such as high nutrient use efficiency may be the important drivers in the relationship of community composition and productivity (Fig. 2c, d). This would be analogous to results found in several experimental biodiversity studies where species were a better predictor for ecosystem functioning than species richness (Petchey et al. 2004). The role of biodiversity in the creation, maintenance and functioning of ecosystem has, however, only recently been addressed (Naeem 2002) and much of the recent debate about biodiversity and ecosystem functioning has focused on the relative contribution of any of these factors to the observed ecosystem processes.

Conclusion

The present study gives relevant information about some important environmental factors which affect distribution patterns of vegetation in Kumaun Himalaya. According to results, understory composition and assemblage are strongly influenced by soil nitrogen, carbon and phosphorus. However, the studied site is heavily affected by anthropogenic activities like collection of fodder and fuel by local peoples. For making better land policies it is necessary to understand the relationships between environmental variables and vegetation. To maintain the diversity and structure of ecosystems we should consider the co-evolution of both vegetation and soil. Further studies on the properties of other factors, such as climate and microorganism, are needed to further explore the interactive relationships among vegetation and soil properties.

Compliance with ethical standards

Conflict of interest The author(s) declare that they have no conflict of interests.

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