Effects of the environment on species richness and composition of vascular plants in Manaslu Conservation Area and Sagarmatha region of Nepalese Himalaya

S. K. Rai[1,2,3], S. Sharma[2], K. K. Shrestha[2], J. P. Gajurel[2,3], S. Devkota[3],
M. P. Nobis[3] and C. Scheidegger[3]

This study analyzed how the environmental conditions constrained the species richness and composition in the four river valleys of Central Nepal i.e. two from Manaslu Conservation Area (MCA) and two from Sagarmatha region. Topographical, bioclimatic and measured variables were used to analyze their effects on the vascular plant diversity along elevation and land use gradients. Altogether, 148 plots were established at five elevation levels between 2,200 m and 3,800 m above the mean sea level. Four land use types namely crop field, meadow, exploited forest and natural forest were sampled at each elevation level. Altogether, 790 species of vascular plants belonging to 114 families were recorded; Asteraceae had the highest number of species (84) followed by Rosaceae (52) and Poaceae (50). Explorative data analysis of species composition by canonical correspondence analysis (CCA) showed that the topographical variables explained the composition better than both the bioclimatic set of variables and the logger data. However, all groups of variables revealed significant effects on species composition. Generalized Linear Model (GLM) also revealed significant effects of elevation, land-use types, slope angle, aspect, temperature and precipitation on species richness.

Key words: Canonical correspondence analysis, elevation, generalized linear model, land use types, multivariate analysis, species richness

Species diversity patterns are governed by a varied set of biotic and abiotic factors. Keeping biotic interactions at one end, the abiotic environmental drivers of species distribution has gained much attention in recent studies (Guisan and Zimmermann, 2000). There are several environmental relationships that can be used to describe patterns of species distributions as well as species richness. Changes of species distributions along the latitudinal and elevation gradients are well known since the advent of modern biogeography (Lomolino, 2001; Colwell *et al.*, 2004). The effect of latitude on species richness has been known for a long time (Pianka, 1966; Stevens, 1989). Stevens (1989) has compiled the published literatures showing the effect of latitudinal gradients in the species richness at regional as well as local scales. Species richness and their distribution are also affected by the elevation gradients (Stevens, 1992; McCain and Grytnes, 2010), for example, in mammals (McCain, 2007), birds (Island, 2012) and vascular plants (Trigas *et al.*, 2013). However, both latitude and elevation alone cannot elucidate all the causal biological factors, instead they are proxy for numerous variables such as temperature, moisture energy and so on that change along the elevation (Körner, 2007), topography (Hofer *et al.*, 2008) and latitude (Carpenter, 2005). Land use and geographic factors such as aspect and slope also play important roles in distribution of species in any area (Sanders and Rahbek, 2012).

In the Himalaya of Nepal and adjoining countries, the species richness along the elevation gradients have shown the mid-elevation peaks for vascular plant species (Vetaas and Grytnes, 2002; Bhattarai and Vetaas, 2003), ferns (Bhattarai *et al.*, 2004), bryophytes (Grau *et al.*, 2007), lichens (Baniya *et al.*, 2010) and reptiles (Chettri *et al.*, 2010). Those studies have often focused on elevation

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[1] Department of Plant Resources, Kathmandu, Nepal. E-mail: sanjeevkrai4@gmail.com
[2] Central Department of Botany, Tribhuvan University, Kathmandu, Nepal
[3] Swiss Federal Institute for Forest, Snow and Landscape Research, Switzerland

pattern in the species richness taken as proxies of changes in temperature, energy and water availability (Bhattarai *et al.*, 2004). In contrast, the topographical variables such as slope angle, aspect or regional differences were rarely analyzed in the Himalayan region (Paudel and Vetaas, 2014).The same hold for microclimates such as point temperature and water availability which might affect upon the species distribution (Geiger *et al.*,1995). In addition, different land use types also indicate different species communities with varying species richness and pattern. The settlements in the mountains of the Himalaya chiefly rely on agro-pastoral system. The shifting and open grazing system is practiced in the mountain areas. Besides crop farming, the mountain people keep herds of cattle for the supply of food and economic needs. Their energy source is mainly the firewood collected from the nearby forests. All the above activities can lead to the degradation of the natural habitats which affect upon the species diversity in different ways (Cousins, 2009; Honnay *et al.*, 2005). In most of the cases, the species diversity declines in the degraded area due to the fragmentation of the natural forests (Tilman *et al.*, 1997; Maitima *et al.*, 2009). These losses are linked with the disturbances and changes in the nutrient cycling processes such as organic carbon in the soil (Maitima *et al.*, 2009), and available nitrogen (Li *et al.*, 2006).

This study aims to find out the effects of most widely used environmental variables such as temperature, precipitation and topography at local as well as regional scales. We have also selected four land use types with an aim to show that species distribution pattern are also the function of land use types. The principle research questions are: (i) How the species richness and composition vary along the altitudinal, precipitational and other topographical indicators?, (ii) How the species are distributed in the different land use types? and (iii) Which types of environmental variables are most suitable to explain the species richness and composition in the Himalaya?

Materials and methods

Study area

The study was conducted in the four river valleys of the two regions of Nepal: Manaslu Conservation Area in Gorkha district and Sagarmatha region in Solukhumbu district (Fig. 1). The study was conducted during 2011 to 2013.

Fig. 1: Map of Nepal showing the study districts Gorkha at the center and Solukhumbu in the east

In Manaslu Conservation Area (MCA), two river valleys *viz.* the Nubri and the Tsum (Fig. 2a) were studied. The Nubri valley starts from the confluence of Budhi Gandaki river and Siyar khola (river) near Lokpa. This valley runs along the Budhi Gandaki river upwards in north-west direction. Our study area started from Gap (2,200 m) to Samagaun (3,700 m) located between 28˚31’48.9” N and 28˚35’22.5” N latitude and between 84˚38’29.6” E and 84˚49’51.9” E longitude. The vegetation on the bank of the river near 2,200 m is broad leaved consisting of species such as *Benthamidia capitata, Michelia kisopa, Pinus wallichiana* and *Quercus semicarpifolia*. Above 2,500 m altitude, there is a dense forest of *Tsuga dumosa*, and above 3,000 m altitude, the forest is changed into larch forest (*Larix himalaica*). At 3,400 m altitude near Shyala, exists a dense forest of *Abies spectabilis* associated with *Hippophae salicifolia* and *Cotoneaster* spp. Similarly, the Tsum valley is oriented towards the north-east along the Siyar khola after the confluence with the Budhi Gandaki river. Our study area is located between 28˚26’19.3” N and 28˚36’56.2” N latitude and between 84˚54’44.3” E and 85˚06’40.4” E longitude. The lower elevation consists of alder (*Alnus nepalensis*) and pine (*Pinus wallichiana*) forests. They are replaced by hemlock (*Tsuga dumosa*) and Himalayan fir (*Abies spectabilis*) at around 3,000 m altitude. The north facing slope of the valley harbors dense vegetation. *Larix himalaica* forest is dominant at around 3,400 m altitude near Rachen Gumba. The north facing slopes possess more vegetation cover than the south facing slopes. *Betula utilis* is found upto 3,800 m altitude near Kalung. Most of the south-facing slopes consist of open meadows intersected by small human settlements such as Chumling, Gho, Chhekampar and Nile.

Fig. 2a: Map of Gorkha district with plots overlaid on Nubri river valley on the left and Tsum river valley on the right

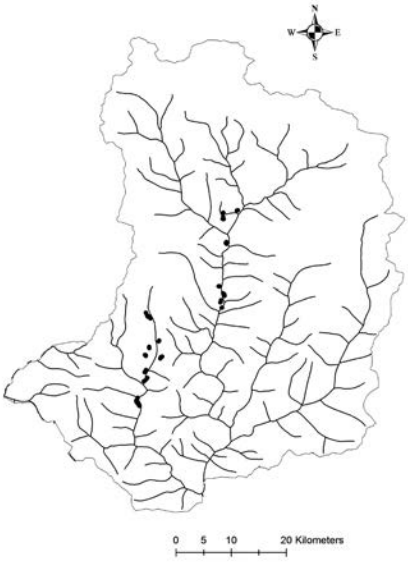

Fig. 2b: Map of Solukhumbu district with plots overlaid on Dudhkunda river valley on the left and Dudhkoshi river valley on the right

In Sagarmatha region, we studied the Dudhkoshi and the Dudhkunda (Fig. 2b) river valleys. The region is famous for the world's highest mountain, Sagarmatha (Mt. Everest, 8,848 m) and the Sagarmatha National Park. The Dudhkoshi river valley runs northwards along the bank of Dudhkoshi river. The studied plots are located between 27˚40'18.1" N and 27˚49'48.3" N latitude and between 86˚42'3.2" E and 86˚44'25.2" E longitude. The plots located at 2,200 m at Surke and Nakchung and those at Muse and Sengma at 2,600 m elevation are outside the Sagarmatha National Park whereas the rest of the plots are within the boundaries of the Park. The vegetation of the site starts from *Schima-Castanopsi*s and alder (*Alnus nepalensis*) at 2,200 m and is replaced by *Pinus-Rhododendron* at mid elevation (3,000 m) and is further replaced by Silver fir-birch-rhododendron at Khumjung (3,800 m). The study area at Dudhkund valley is located between 27˚30'39.9" N and 27˚39'49.1" N latitude and between 86˚34'34.5" and 86˚37'01.6" E longitude, and lies towards the west of Dudhkoshi river valley; the two valleys are separated by a chain of mountains. The Dudhkund valley does not fall inside the Sagarmatha National Park area. The plots, laid at 2,200 m and 2,600 m elevation, are near the settlements and the forests are managed by the local Community Forest User Groups (CFUGs). The forests above 3,000 m elevation are managed by the Government as national forest. The crop fields are not found at and above 3,000 m altitude except one at Taksindu. The study started at Boldok-Kholaghari (2,200 m). Going upwards from Phera (2,600 m), Taksindu (3,000 m) and Sarkaripati (3,400 m), our highest plot was located near Sasarbeni (3,800 m). The vegetation at 2,200 m is *Schima-Castanopsis-Alnus*, *Pinus* and then followed by *Pinus-Quercus-Rhododendron* at mid-elevation. *Abies spectabilis* forest can be noticed at Sasarbeni (3,800 m).

Study design

Five elevation levels were investigated with a regular elevation interval of 400 m starting from 2,200 m to 3,800 m. At each elevation level, four land use types were considered *viz.* (i) natural forest, (ii) exploited forest, (iii) meadow and (iv) crop field (Scheidegger *et al.*, 2010). The category of the land use types were based on the visual observation in accordance with the methods of FAO (Gregorio and Jansen, 2000). The crop fields are cultivated areas where the vegetative cover is created by anthropogenic activities, and so become bare during off-crop season. The meadows are isolated patch or wide area of grazing land where the tree species are less than 20%, and they are also affected by anthropogenic activities such as livestock grazing and grass collection. The natural forests are far from the human settlements which are rarely intervened by anthropogenic activities. The exploited forests comprise the vegetation not planted by humans but influenced by their actions. This does not require human activities to be maintained in the long-term as compared to the crop fields.

All the four land use types were assessed for species records on both sides of the river. Two sample plots (25 m x 2.5 m) were selected randomly per land use type at each elevation level (e.g. 2,200±50 m) on the one side of the river, and the same number were replicated on the another side of the river (Scheidegger *et al.*, 2010). Each plot was divided into 5 m x 2.5 m sub-plots for species record. Thus, each elevation level consisted of eight sample plots (Fig. 3). Crop fields were not found at the elevations of 3,400 m and 3,800 m except a few in some valleys. A total of 148 plots were sampled during the study period of 2011 – 2013.

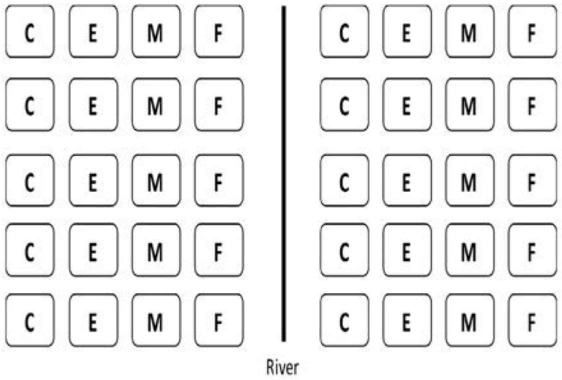

Fig. 3: Schematic diagram of sampling plot design of the study per land use type in all elevation (C= crop field, E = exploited forest, M = meadow, F = forest and the straight line at the center represents the river)

All the species within each plot were recorded. If the same species occurred in the next plot, it was recorded as "1" (in the presence of the species). The species recorded in the first plot but not in the second plot were recorded as "0" (in the absence of the species). Two replicate plots of the same land use type were later merged into one. Each plot was visited twice in order to record as many species as possible. To reduce the sampling bias caused by spatial auto-correlation, the replicate of each plot was established at least 50 m away from the first plot (Magurran, 2004).

Data source

Plant species records as response variable

Most of the flowering plant species were identified in the field by using the books written by Polunin and Stainton (1984) and Stainton (1988). The specimens unidentified in the field were identified at the National Herbarium and Plant Laboratories (KATH), Godawari, Lalitpur. The voucher specimens were submitted to the KATH Herbarium.

For nomenclature of the species, we followed the Angiospermic Phylogenetic Group (APG III) system (Chase *et al.*, 2009). In the case of the unresolved names (according to APG III), the nomenclature of Press *et al.* (2000) was adopted. On the other hand, the nomenclature of Iwatsuki (1998) and Fraser-Jenkins (2008, 2011) were used in the case of pteridophytes. The individual species' presence/absence data in each studied plot were used as the response variable in the current study.

Environmental variables as predictor variables

The following sets of environmental variables were selected as predictor variables (Table 1).

I. The first set of predictor variables included the microclimate (temperature and humidity) data recorded by the logger installed in the field, from 2011 to 2013. The HOBOs (Onset Computer Corporation, Bourne, MA 02532, USA) were used to record air humidity and air temperature 2 m above the ground level in each plot. The HOBOs recorded data in every 30 minutes interval. The soil temperatures were recorded at 10 cm below the ground level using Button (Maxim Integrated, San Jose, CA 95134, USA) in each plot. The soil temperature data were recorded after every 3 hours. The mean, minimum and maximum values of the year-round data were derived using the recorded data afterwards (Table 1). The non-available (NA) values of the data were replaced by the mean of the respective variables so that there would be no loss of data rows in the data frame.

II. The second set of predictor variables included the bioclimatic variables extracted from the Worldclim-Global climate data (Hijmans *et al.*, 2005). The data were obtained in 30 arc seconds (0.93 km x 0.93 km= 0.86 sq. km.) resolution. The latitude and longitude of each plot recorded with the help of Garmin 60S GPS were supplied in the DIVA GIS ver. 7.5.0. The software extracted the interpolated values of the bioclimatic variables from the WORLD CLIM database for each plot. Out of the 19 bioclimatic variables as defined by the USGS Data Series 691 (O'Donnell and Ignizio, 2012), only 10 less correlated variables were chosen for further analysis (Table 1).

III. The third set of data contained the information of the topography of the studied area, and were directly recorded in the field. Garmin GPS 60S was used to record the elevation of the plots. Brunton Compass was used to record the aspect while Clinometer was used to record the slope angle of the sample plots. The land use types, the regions and the valleys were considered as the categorical variables and all the others were taken as the ratio variables (Table 1).

The above set of variables contained large number of variables. The Hmisc (Harrell *et al.,* 2016) Package was used to check the collinearity among the environmental variables. The Pearson correlation coefficient was used to describe the relationships between the variables. The highly correlated variables ($r \geq 0.7$) were taken for analysis (Dormann *et al.*, 2013).

Data analysis

Initial data recording and management were done using MS Excel and MS ACCESS. The further analyses were performed on the R ver. 3.1.2 (R Core Team, 2015).

R-package vegan (Oksanen *et al.*, 2015) was used for the multi-variate ordination analysis. Detrended Correspondence Analysis (DCA) was performed for the species data (Hill and Gauch,

Table 1: The list of environmental variables selected from three sets

Set	Variable acronym	Contained information
(1) Loggers' data	MaxT.H	maximum air temperature recorded by HOBO
	MaxT.iB	maximum soil temperature recorded by iButton
	MeanT.iB	mean soil temperature recorded by iButton
	MinT.iB	minimum soil temperature recorded by iButton
	MaxH.H	maximum air humidity recorded by HOBO
	meanH.H	mean air humidity recorded by HOBO
	MinH.H	minimum air humidity recorded by HOBO
(2) Bioclimatic	BIO1	annual mean temperature
	BIO3	Isothermality of temperature
	BIO5	maximum temperature of warmest month
	BIO6	minimum temperature of coldest month
	BIO8	mean temperature of wettest quarter
	BIO10	mean temperature of warmest quarter
	BIO14	precipitation of driest month
	BIO15	precipitation seasonality
	BIO17	precipitation of the driest quarter
	BIO19	precipitation of the coldest quarter
(3) Spatial	REG	two regions (Manaslu and Sagarmatha)
	VAL	four valleys
	HABIE	exploited forest
	HABIF	natural forest
	HABIM	meadow
	ALTG	recorded elevation
	ASP	aspect
	SLOP	slope angle

1980) showing the gradient length of the first ordination axis higher than 2.5 standard units. Therefore, we used the Constrained Ordination Method, the unimodal model of the Canonical Correspondence Analysis (CCA) (Ter Braak, 1986).

The inertias of all the predictors were compared among each other in order to find out the amount of variances explained by them. The diversity indices like Shannon-Wiener, Simpson and Inverse Simpson indices were calculated using "vegan" R Package (Oksanen *et al.*, 2015).

Generalized Linear Model (McCullagh and Nelder, 1989) with quasi-poisson distribution for counts were used to evaluate the relationships between the species richness as response variable and different environmental predictors. The model was fitted against the null model to check for its robustness and performance. The second order polynomial function was also tested, but Fisher's alpha was not significant. Thus, we proceeded with the first order linear model.

Results and discussion

The study revealed 790 vascular plant species of 337 genera within 114 plant families. The highest number of species were recorded for Asteraceae (84 spp.) followed by Rosaceae (52 spp.), Poaceae (50 spp.) and Fabaceae (38 spp., Fig. 4).

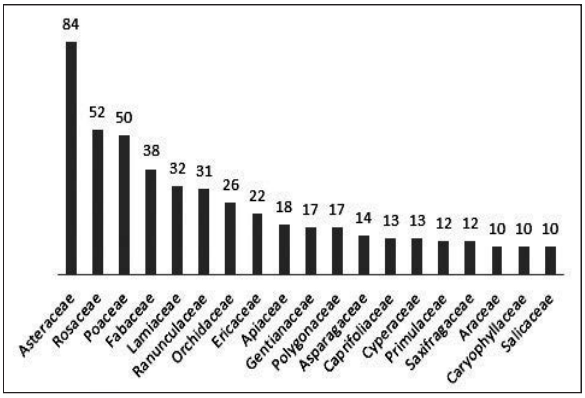

Fig. 4: Bar diagram showing the representative families, number of species on the Y-axis and families on the X-axis (families representing more than 10 spp. are included)

Species composition

The Detrended Correspondence Analysis (DCA) of the species values against the plots studied was performed. All of the DCA axes were more than 2.5 standard units; therefore, the data were further analyzed using CCA. The species data were further constrained separately by the logger data, bioclimatic data and topographical variables for CCA analysis. The performances of the variables are presented in Table 2.

The CCA plots show the effect of the environmental variables on the species composition (Fig. 5, 6 and 7). The distribution of the species were found to be affected by the temperature along the CCA axis-1 and the humidity along the CCA axis-2 (Fig. 5) This clearly showed that the temperature and humidity were controlling environmental factors for the distribution of the species (Table 2). In terms of percentage, the variation explained by the CCA axis-1 and the CCA axis-2 were ~41.8% and ~27.7%, respectively; thus, 69% of the variation were explained by the two CCA axes (Table 3).

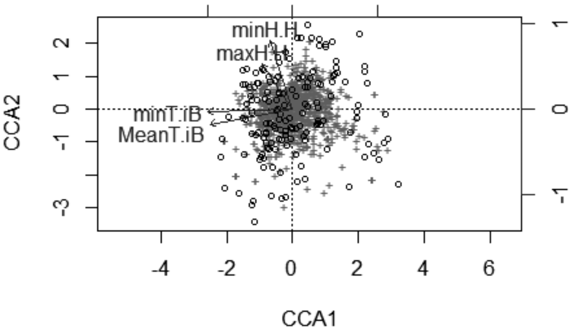

Fig. 5: CCA plot showing the species composition constrained by humidity and soil temperature; the crosses indicating the species, the circles indicating the plots and the arrows showing the predictors

The precipitation seasonality (BIO15) possesses the longest gradient length to shape the species distribution. Isothermality (BIO3) refers to the percentage of the mean diurnal range divided by the annual temperature. Thus, the growing days and length of the days which shape the temperature pattern has also significant contribution for species distribution. Precipitation of the driest month (BIO14) is another contributor for species distribution. Annual mean temperature (BIO1), mean temperature of coldest month (BIO6), mean temperature of the warmest quarter (BIO10) and mean temperature of the wettest quarter (temperature combined with the precipitation, BIO8) were found to have the significant effect on the species composition in the study areas (Table 2 and Fig. 6).

Table 2: The test statistics expressed by the environmental variables while constraining the species composition (by "margin" i.e. each marginal term analyzed in a model with all other variables)

Variable Set	Code	Df	Chi Square	F	Pr(>F)	Significance codes
Loggers	MeanT.iB	1	0.1385	1.7665	0.001	***
	MinT.iB	1	0.1450	1.8498	0.001	***
	MaxH.H	1	0.1187	1.5135	0.002	**
	MinH.H	1	0.1303	1.6617	0.001	***
	Residual	143	11.2110			
Bioclimatic	BIO1	1	0.1259	1.6474	0.001	***
	BIO3	1	0.1664	2.1761	0.001	***
	BIO6	1	0.1078	1.4100	0.001	***
	BIO8	1	0.1132	1.4808	0.001	***
	BIO10	1	0.1185	1.5506	0.001	***
	BIO14	1	0.1617	2.1150	0.001	***
	BIO15	1	0.1458	1.9071	0.001	***
	Residual	140	10.7033			
Spatial	REG	1	0.2408	3.2757	0.001	***
	VAL	1	0.2368	3.2217	0.001	***
	HABI	3	0.5225	2.3695	0.001	***
	ALTG	1	0.3770	5.1288	0.001	***
	ASP	1	0.1242	1.6903	0.001	***
	SLOP	1	0.1109	1.5089	0.001	***
	Residual	139	10.2174			

Significance codes: '***' for P=0.001, '**' for P=0.002

The CCA axes of the bioclimatic variable were found to have performed less than the CCA axes obtained from the logger data. The CCA axis-1 was found to have explained 24.39% of the variation followed by the CCA axis-2 (20.19%), the CCA axis-3 (14.82%) and the CCA axis-4 (12.24%). Thus, a total of 72% of the variation was found to be explained by these four axes (Table 3).

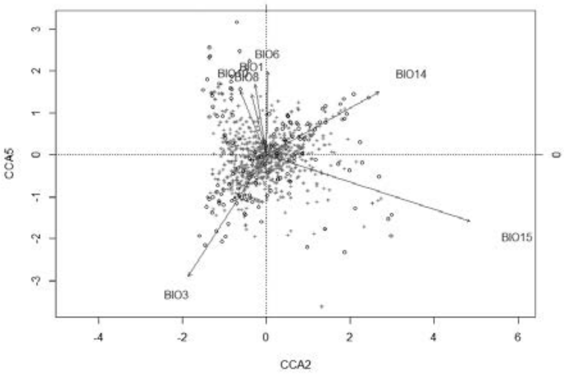

Fig. 6: CCA plot showing the species composition constrained by the bioclimatic variables; the crosses indicating the species, the circles indicating the plots and the arrows showing the predictors

The results obtained by constraining species with the annual temperature and precipitation mean and their derivatives show that not only the mean, minima and maxima of the temperature and precipitation are important but also their combined effect are equally important to shape the distribution of the species in the given environmental hyper-volume (Hutchinson, 1957). The predictor variables constructed with the derivatives of temperature and precipitation alone and combined have the physiological role in the germination, growth and proliferation (Wright *et al.*, 2006). Soil temperatures are important for the physiology of the cell, water availability and nutrient uptake from the soil (Korner, 2003). Temperature is related with the energy balance as well (Scherrer *et al.*, 2011). Topographical variables also show significant effect upon the species composition (Fig. 7, Table 2).

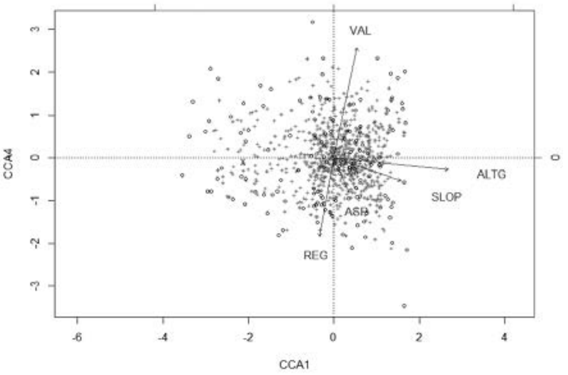

Fig. 7: CCA plot showing the species composition as shaped by the topographical variables; the crosses indicating the species, the circles indicating the plots and the arrows showing the predictors

Elevation (ALTG) was found to be one of the significant variables for the species composition in our study (Table 2). It is a surrogate of a number of environmental factors,e.g. temperature, which in turn stands for energy, water etc. Slope angle (SLOP) and aspect of the plots were also found to be significant contributors for the species composition (Table 2). More than 60% of the variation was found to be explained by the three CCA axes produced by constraining species composition with the topographical variables. The CCA axis-1 explains ~25% followed by the CCA axis-2 (~21.8%) and the CCA axis-3 (~15.2%) (Table 3).

The valleys (VAL) were also found to be significant for species composition (Table 2). The Sagarmatha region receives more annual precipitation (average 1,640.95 mm) as compared to the MCA region (average 545.36 mm, Hijmans *et al.*, 2005). The valleys in the Sagarmatha region are geographically nearer to the Bay of Bengal, the origin of the monsoon rain system, and are less rain-shadowed by the high mountains. In contrast, the MCA valleys are geographically farther from the Bay of Bengal and rain-shadowed by Mt. Ganesh (7,422 m).

Species richness

For each environmental variable, annual model was first created and was tested with the first order Generalized Linear Model (GLM). Transect-wise species richness was taken as response variable which regressed against different environmental variables as predictor. These included land use types (LUT), elevation (ALTG), precipitation seasonality (BIO15), annual precipitation (BIO12), slope angle (SLOP) and aspect (ASP) of the plots. These developed models were tested

Table 3: Percentage of variation explained by the CCA axes when species richness were constrained with the predictor variables

Data set	Constrained inertia	CCA axes	Eigenvalues	Percentage variation explained	Cumulative variation %
Loggers' Set	0.750	CCA1	0.3132	41.77	
		CCA2	0.2076	27.68	69
		CCA3	0.1223	16.31	86
		CCA4	0.1072	14.30	100
Bioclimatic Set	1.258	CCA1	0.3068	24.39	
		CCA2	0.2539	20.19	45
		CCA3	0.1864	14.82	59
		CCA4	0.1539	12.24	72
		CCA5	0.1512	12.02	84
		CCA6	0.1081	8.60	92
		CCA7	0.0975	7.75	100
Spatial Set	1.744	CCA1	0.4344	24.97	
		CCA2	0.3780	21.72	47
		CCA3	0.2643	15.19	62
		CCA4	0.2277	13.09	75
		CCA5	0.1937	11.13	86
		CCA6	0.1073	6.17	92
		CCA7	0.0846	4.86	97
		CCA8	0.0542	3.11	100

Table 4: Test statistics of the generalized linear model (GLM) of species richness against the individual environmental variables

Code	Predictors	Resid. df	Resid. dev.	Deviance	F	Pr(>F)	Significance codes
LUT	Land Use Types	144	1460	75445	2608.9	< 2.20E-16	***
ALTG	Elevation	146	1357	75547	8574.1	< 2.20E-16	***
BIO15	Precipitation Seasonality	146	1373	75532	8460.7	< 2.20E-16	***
BIO12	Annual Precipitation	146	1462	75443	7934.5	< 2.20E-16	***
SLOP	Slope Angle	146	1464	75441	7928.0	< 2.20E-16	***
ASP	Aspect	146	1467	75437	7895.5	< 2.20E-16	***

Significance codes: '***' for $P \leq 0.001$

among each other by using "*F*" statistics. Over-dispersed residual of errors were standardized after application of "quasipoisson" family of distribution of error. The significant environmental variables with deviance and "*F*" values are indicated in Table 4. The graphics of some more interpretable and statistically significant variables are shown in Fig. 8a–8d.

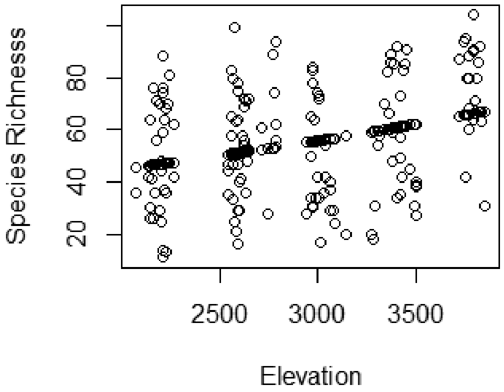

Fig. 8a: Species richness versus elevation of the plots

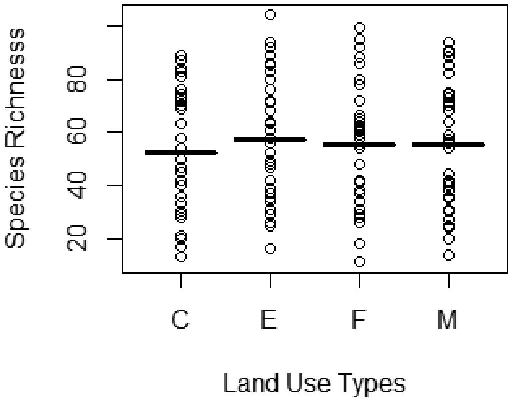

Fig. 8b: Species richness versus land use types

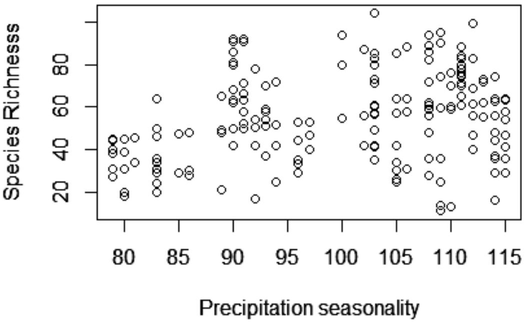

Fig. 8c: Species richness versus precipitation seasonality

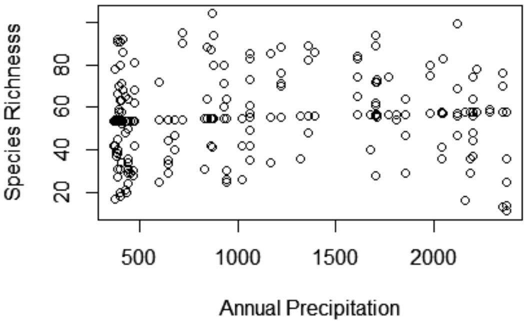

Fig. 8d: Species richness versus annual precipitation

Note: In Fig. 8b, C = crop field, E = exploited forest, F = natural forest and M = meadow; in Fig. 8c, units are precipitation coefficients and in Fig. 8d, precipitation is in mm.

The species richness increased with the increase in the elevation of the plots studied. The previous studies in Nepal showed the unimodal richness pattern with elevation (Baniya *et al.*, 2010; Grau *et al.*, 2007; Vetaas and Grytnes, 2002). Those studies analyzed long elevation gradients whereas this study considered relatively short elevation gradient between 2,200 m and 3,800 m above the mean sea level. The short gradient in our study was not sufficient to test the species richness humps. However, there are studies which show the plateau of species richness of birds at high elevation (Patterson *et al.*, 1998). An elevation limit of species occurrence is expected for high mountains e.g., the Himalaya, always covered with snow and the permafrost. The hump shaped unimodal distribution of species richness are expected for such restriction in the absence of any environmental gradients (Colwell and Lees, 2000; Colwell *et al.*, 2004) or isolation from other zonal communities (Lomolino, 2001). However, hump is a union of linear segments at local scale. The result was obtained from only 1,600 m elevation. Thus, the result from this study could be a local phenomenon rather than the large-scaled unimodal pattern found by the earlier researchers. This interpretation resembles quite similar to that of Baniya *et al.* (2012).

Four land use types namely (i) crop field, (ii) meadow, (iii) exploited forest, and (iv) natural forest were studied. The exploited forests were more species-rich, followed by the meadow, the natural forest and the crop field. The soil use intensity and fragmentation are thought to be loss of biodiversity (Cousins, 2009; Honnay *et al.*, 2005; Maitima *et al.*, 2005). This explains the less richness in the crop field. The species richness in the exploited forest is described by the intermediate disturbance hypothesis (Connell, 1978) and some empirical studies (Townsend and Scarsbrook, 1997).

In our study, the species richness was found to have increased significantly with the increase in the annual precipitation and seasonality (Fig. 8c and 8d). Precipitation seasonality is the coefficient of variation of the monthly precipitation. The four valleys studied have different precipitation seasonality, which is explained by this study. The different valleys receive varying degree of precipitation shaping different scale of species richness and their pattern (O'Brien, 1993; Pauses and Austin, 2001).

The species richness and composition pattern are also affected by the slope and aspect of the sampling plots (Nuzzo, 1996). The south-facing and steeper slopes are drier than the north-facing slopes, and more number of species is expected towards the wet areas (Kassas and Zahran, 1971; Pook and Moore, 1966). The temperature is also significantly affected by the aspects in the mountain environments at point-scale (Kroner, 2003; Parker, 1991). The variation in the slope and aspect, thus, result in the variation of the soil moisture, nutrient cycling and availability of energy dissipation (Mohammad, 2008) resulting in different composition and richness (Carmel and Kadmon, 1999).

Conclusion

Altogether 790 vascular plant species belonging to 114 families were recorded from six river valleys studied. Asteraceae (84 spp.) was the most dominant family among them. The three sets of environmental variables were used to study their effect on the species composition and species richness of vascular plants. The loggers recorded the microclimate data of each plot. Soil temperature and humidity of the plots affected the plants composition significantly. Out of 19 bioclimatic variables only seven showed significant effect on the plant composition. Annual mean temperature (BIO1), isothermality of the temperature (BIO3), minimum temperature of the coldest month (BIO6), mean temperature of the wettest quarter (BIO8) were the temperature related variables. Precipitation of the driest month (BIO14) and precipitation seasonality (BIO15) also were significant variables. The topography of the plots (elevation, aspect and slope) affected the vascular plant composition significantly. Nearly 50 percents of the variations were explained by two axes of the CCA in all three sets of environmental variables. Four land use types were considered during the study. These land use types also affected the species richness and composition significantly. The results of the study are in accordance with the previous studies. However, the unimodal hump of the species richness distribution was not revealed due to shorter elevation gradient in this study.

Acknowledgements

We are grateful to the CDB-WSL Project run by the Central Department of Botany, Tribhuvan University, Nepal for providing the fund and logistics for the field trip. We are also thankful to the Swiss Federal Institute for Forest, Snow and Landscape Research, WSL, Switzerland for providing us scholarships for data management and processing. This study was funded by the Swiss National Science Foundation (JRP

IZ70Z0_131338/1 to CS). The first author is indebted to the Ministry of Forests and Soil Conservation, the Government of Nepal for granting him a three-year study leave to accomplish the study. Our sincere thanks go to Dr. Keshab Raj Rajbhandary, Dr. Khem Raj Bhattarai and Rita Chhetri for identification of plants at the National Herbarium and Plant Laboratories (KATH), Godawari. The employees of KATH and Wilder Places Treks, Kathmandu are duly acknowledged. We appreciate the contribution of Ms. Laxmi Sankhi, Ms. Srijana Shah and Mr. Hem B. Katuwal in data collection during the field-work. We acknowledge Dr. Chitra Baniya for sharing his ideas and analysis methods while developing this paper.

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