SPATIAL DISTRIBUTION OF VEGETATION COMPOSITION AND STRUCTURE IN KAILASH SACRED LANDSCAPE, NEPAL

A THESIS SUBMITTED TO THE

INSTITUTE OF SCIENCE AND TECHNOLOGY

THROUGH RESEARCH CENTRE FOR APPLIED SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY

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FOR THE AWARD OF

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DEAN'S OFFICE
Kirtipur, Kathmandu, Nepal

Institute of Science & Technology
Dean's Office
Kirtip... ...45

Reference No.:

EXTERNAL EXAMINERS

The Title of Ph.D. Thesis : "Spatial Distribution of Vegetation Composition and Structure in Kailash Sacred Landscape, Nepal"

Name of Candidate: Chandra Kant Subedi

External Examiners:

(1) Prof. Dr. Mohan Panthi
Central Department of Botany
Tribhuvan University
NEPAL

(2) Prof. Dr. Gopal Singh Rawat
Wildlife Institute of India
Dehradun, INDIA

(3) Prof. Dr. Udo Schickoff
University of Hamburg
Hamburg, GERMANY

October 13, 2022

Dr. Surendra Kumar Gautam
Asst. Dean

Telephone: 977-1-4330844 Fax: 977-1-4331755 Website: www.tuiost.edu.np E-mail: deaniost7@gmail.com

DECLARATION

Thesis entitled **"Spatial Distribution of Vegetation Composition and Structure in Kailash Sacred Landscape, Nepal"** which is being submitted to the Institute of Science and Technology (IOST) through Research Centre for Applied Science and Technology, Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D.), is a research work carried out by me under the supervision of Prof. Dr. Ram Prasad Chaudhary (Professor Emeritus), Research Centre for Applied Science and Technology, Tribhuvan University.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

....

Chandra Kanta Subedi

RECOMMENDATION

This is to recommend that **Mr. Chandra Kanta Subedi** has carried out research entitled **"Spatial Distribution of Vegetation Composition and Structure in Kailash Sacred Landscape, Nepal"** for the award of Doctor of Philosophy (Ph.D.) in **Botany** under my supervision. To the best of my knowledge, this work has not been submitted for any other degree.

Mr. Subedi has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of Ph.D. degree.

....

Ram Prasad Chaudhary, Ph.D.
Supervisor
Professor Emeritus
Research Centre for Applied Science and Technology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

त्रिभुवन विश्वविद्यालय
TRIBHUVAN UNIVERSITY
व्यावहारिक विज्ञान तथा प्रविधि अनुसन्धान केन्द्र
Research Centre for Applied Science and Technology (RECAST)
कीर्तिपुर, काठमाडौं, नेपाल।
Kirtipur, Kathmandu, Nepal.

पत्र संख्या :-
Ref. No. :-

मितिः 31/05/2022

LETTER OF APPROVAL

On the recommendation of Prof. Dr. Ram Prasad Chaudhary, this Ph.D. thesis submitted by Mr. Chandra Kanta Subedi, entitled **"Spatial Distribution of Vegetation Composition and Structure in Kailash Sacred Landscape, Nepal"** is forwarded by Research Centre for Applied Science and Technology (RECAST) Research Committee to the Dean, Institute of Science and Technology (IOST), Tribhuvan University.

R. nath Yadav

Prof. Dr. Ram Nath Prasad Yadav
Executive Director

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Chandra Kanta Subedi

May 2022

ABSTRACT

Vegetation composition, structure, and function are the primary elements of ecosystem. Ecosystem integrity is the ability of an ecosystem to maintain its organization in the face of changing environmental conditions. The study in structure and composition of vegetation provide baseline for long-term monitoring of plant species diversity and formulate sustainable forest management plan, and conservation efforts. Forest has huge contribution in vegetation composition in Nepal. It plays an important role in the rural livelihoods by providing different ecosystem services. The high dependency of people of Kailash Sacred Landscape, Nepal on natural resources resulting their overexploitation. The systematic study on vegetation composition and structure in the landscape is lacking. Thus, present research attempts to know the variation in the structure and composition of forest vegetation and identify underlying environmental factors along an elevational gradient. This study was carried out in three community forests (two in Darchula and one in Bajhang District) and one forested landscape in Chamelia Valley in Api Nampa Conservation Area, Darchula, all in Sudurpaschim Province, Northwest Nepal.

Quadrat method was used to enumerate vascular plant species and soil sampling. Species richness, abundance, and composition were the response variables and climatic data, soil parameters and anthropogenic variables (disturbance) were predictors. Species richness is the number of species in each quadrat of size 100 m^2; abundance is the occurrence of the species in four subquadrats of the size 25 m^2 measured in the scale of 0 (if absent in all subquadrats) to 4 (if present in all four subquadrats); species composition is the type of species found in each plot. Soil was sampled from the surface layer (10 cm depth). The climatic data were obtained from WorldClim version 1.4. Grazing, trampling, cutting, lopping, and fire recorded in each plot in a categorical scale (0-4) represented the anthropogenic variables. IBM SPSS and R statistical software were used to analyse data. The relationships between different community characteristics of forests and environmental variables were obtained through calculating Spearmen’s rank correlation coefficients; and relationships among community characteristics were obtained through linear regression analysis. Generalized linear model was used to know the effect of different environmental variables on species richness. Canonical correspondence analysis was used to reveal the association between species composition and environmental variables. Non-metric multidimensional scaling

(NMDS) was implemented through package 'Vegan' to determine species composition pattern in different elevational bands. Results obtained through NMDS were fitted with significant environmental variables by using ggplot 2 package.

Species richness was highest in broadleaved forest followed by blue pine and chir pine forests. The species composition was influenced by soil carbon content in broadleaved forest, soil pH in chir pine forest, and potassium in blue pine forest. The size class distribution revealed inverse 'J'-shaped in broadleaved forest and unimodal type in both pine forests. The DBH and height class showed inverse 'J'-shaped distribution pattern in Chamelia Valley. In broad leaved forest, mean height of tree was positively correlated with mean DBH and canopy diameter, and mean canopy was negatively correlated with disturbance factors. Mean DBH and canopy diameter were negatively correlated with density of trees; and mean height was negatively correlated with top canopy and positively with disturbance factor class 2 (fire and cut) in chir pine forest. In blue pine forest, top canopy of tree had negative correlation with low canopy and disturbance factor class 1(grazing and trampling), and low canopy had positive correlation with disturbance factor class 1. A significant linear relationship was established between DBH and height, and DBH and crown diameter in all forest types. The species richness and abundance of vascular plant species along elevation gradient showed hump shaped pattern. Species richness showed significant relationship with elevation, annual precipitation and annual temperature. Species abundance was significantly related with elevation, anthropogenic variables, soil properties, and mean annual temperature. Unimodal type of species richness pattern was exhibited by herbs, shrubs, trees and all plants. Species abundance increased with intensity of cutting and decreased with grazing. As revealed by NMDS, significant relationship was established between species composition with elevation, annual precipitation, mean annual temperature and grazing. There was negative correlation between elevation and tree cutting, annual precipitation and mean annual temperature. The DBH and height class showed inverse 'J'-shaped distribution pattern in Chamelia Valley. Species composition in present study is concurrent with other studies carried out in Nepal Himalaya. However, the range of elevation is varying with other studies. The pine forests are heavily managed and forest along elevation gradient and broadleaved forest are in a state of regeneration. The extent of disturbance and recruitment in the forest is important for forest management strategies in the landscape.

LIST OF ACRONYMS AND ABBREVIATIONS

AAS	:	Atomic Absorption Spectrometer
ANCA	:	Api Nampa Conservation Area
ANOVA	:	Analysis of Variance
CCA	:	Canonical Correspondence Analysis
CF	:	Community Forest
CP/MAS ^{13}C-NMR	:	Cross-Polarization Magic Angle Spinning Carbon-13 Nuclear Magnetic Resonance
DBH	:	Diameter at Breast Height
GLM	:	Generalized Linear Model
Ha	:	Hectare
IBM	:	International Business Machine Corporation
ICIMOD	:	International Centre for Integrated Mountain Development
IPCC	:	Intergovernmental Panel on Climate Change
K	:	Potassium
KATH	:	National Herbarium and Plant Laboratories
KSL	:	Kailash Sacred Landscape
KSLCDI	:	Kailash Sacred Landscape Conservation and Development Initiative
m asl	:	Meter above Sea Level
MDE	:	Mid Domain Effect
MoFE	:	Ministry of Forests and Environment

MoFSC	:	Ministry of Forests and Soil Conservation
N	:	Nitrogen
NMDS	:	Non-metric Multidimensional Scaling
P	:	Phosphorus
PCA	:	Principal Component Analysis
RECAST	:	Research Centre for Applied Science and Technology
SOC	:	Soil Organic Carbon
SOM	:	Soil Organic Matter
SPSS	:	Statistical Package for the Social Sciences
TOSS	:	Total Suppression of Spinning Sidebands
TU	:	Tribhuvan University
TUCH	:	Tribhuvan University Central Herbarium
UN	:	United Nation
UNEP	:	United Nation Environment Programme
VDC	:	Village Development Committee
WCMC	:	World Conservation Monitoring Centre

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CHAPTER 1

1. INTRODUCTION

1.1 Vegetation

Vegetation is an assemblage of plant communities on the earth surface and the ground cover they provide (Burrows, 1990). It is composed mainly of plants with combination of particular morphological characteristics that permit to function effectively in the environment where it grows. The plant species recognized in a particular area determines the floristic composition, while the vegetation structure generally refers to the presence of multiple canopy layers with species having varying stem height, diameter, basal area, age, and canopy cover. Vegetation plays important role in ecosystem maintenance by regulating biogeochemical cycles, providing food and habitat for animals, improving air and water quality, preventing water runoff and soil erosion, and contributing global energy balances. Vegetation includes population of species of local flora, various plant forms, and ecological plant types that are reflected by size, shape and their combination (Box & Fujiwara, 2013). Vegetation is dynamic that develops through different successional stages, and in some environments reaches to climax equilibrium state; but non-equilibrium states are also found in many environments where disturbance produce communities that are a diverse mix of species, and any species may become dominant (Clements, 1936). The vegetation dynamics is influenced by landscape processes such as succession and human disturbances that are interrelated to each other. Considering the vegetation as central object of study, vegetation ecology or synecology emerges as science that deals with the study of plant cover and its relationships with the abiotic and biotic components of the environment. Vegetation ecology is the modern science with important implication in conservation of biodiversity, sustainable use of natural resources and detecting global plant cover change over a period of time (van der Maarel, 2005).

1.1.1 Vegetation composition and structure

Species composition and structure are important attributes to study vegetation. Species composition and general appearance of plants determine the vegetation type of the world. Height, density and dominant plant type are the major descriptors of vegetation in a broader scale. Vegetation is shaped by the influence of different environmental factors such as climate, substrates, soil microorganisms, and disturbances. The life form or growth form of plant is the basic ecological type resulting from the similar morphological responses and environmental conditions that provide a convenient way to describe the vegetation structure. The group of similar size also determines the vegetation structure with similar environmental conditions occupying a particular vegetation layer such as herbs on the forest floor, and shrubs and trees in the forest (Box & Fujiwara, 2013). The vegetation of an area is described by the general appearance plants such as forest, and grassland. On the basis of physiognomy, Box and Fujiwara (2013) classified structure of vegetation as forest (dominated by tall trees with close canopy), woodland (dominated by short or tall trees with open canopy), scrub (dominated by short woody plants with open or closed canopy), shrubland (dominated by shrubs with open or close canopy), savanna (dominated by grass and trees), grassland (dominated by grasses), steppe meadow (dominated by forbs and graminoids), tundra (dominated by graminoids, forbs and dwarf-shrubs), semi-desert (dominated by mosses, lichens and few small herbs), and desert (cryptogams and small herbs).

Forest is the major type of vegetation of the world. Abiotic and biotic component of the environment determine the structure of forest (Behera *et al*., 2012; Mishra *et al.*, 2013). Besides abiotic and biotic component, human disturbances is also responsible to shape forest structure forest (Kareiva *et al*., 2007; Sanderson *et al*., 2002). The forest stand development is determined by disturbance and biological processes significantly (Franklin *et al*., 2002). The structure and composition of forest is responded by fluctuation in the environment and human activities (Gairola *et al*., 2008). The ecological integrity of forest ecosystem and its dynamics and function is maintained by the stand structure, tree size and plant species composition (Elouard *et al*., 1997; Kuuluvainen, 2002; Larsen *et al.*, 2005; Merlin *et al.*, 2015). The study on vegetation structure and floristic composition provides baseline information for long-term monitoring of plant diversity and dynamics that are also useful to make forest management plan and conservation efforts (Krishnamurthy *et al.*, 2010).

1.1.2 Global vegetation distribution

The global vegetation distribution can be treated by geographic region and biome type. However, biome is generally used to treat global vegetation. The distribution of vegetation globally arises by the global circulation of earth's atmosphere. The circulation system near equatorial region characterized by a zone of low pressure and frequent precipitation; high pressure and dry condition in subtropics; and blow of winds from high pressure belts towards inter-tropical convergence zone and towards the pole. The migration of pressure and wind belts in north-south direction with season brings winds and precipitation that give rise to bioclimatic zonation representing geographic framework for the location of biome types. The entire global zonal biomes of vegetation type are presented in Table 1.

Table 1: Main biomes of the world.

SN	Biome	Climate	Climatic variants
1	Tropical rainforest	Equatorial	Semi-evergreen forests, dry evergreen forests/woods, dry scrub (dry equatorial)
2	Tropical deciduous forest and woodlands	Tropical summer-rain	Sclerophyll woodlands, thorn-scrub, savannas
3	Tropical savanna	Tropical summer rain- Subtropical arid	Sclerophyll woodlands, thorn-scrub, savannas, fog desert (coastal fog deserts) Xeric shrub –steppe
4	Warm deserts	Subtropical arid	Fog desert (coastal fog deserts) Xeric shrub –steppe
5	Mediterranean forests, woodlands, shrublands	Continental	Deciduous shrub
6	Temperate rainforest (evergreen broadleaved)	Marine west coast	Coniferous rain forest Giant forest (Continental-Marine west coast
7	Evergreen broadleaved (Laurel) forest	Warm-temperate east-coast	Evergreen mixed forest Sclerophyll woodlands
8	Temperate deciduous (summer green) forest	Typical temperate	Cool-summer and warm temperate deciduous forest
9	Temperate grassland (prairie, steppe)	Temperate continental	Oceanic tussock grasslands
10	Temperate desert	Temperate arid	Oceanic cushion-steppe
11	Boreal forest (evergreen coniferous)	Boreal	Larch forest (Ultra-continental boreal) Deciduous broadleaved forest (Maritime boreal)
12	Polar tundra	Polar	Maritime tundra Moss-lichen cold-desert

Source: Box & Fujiwara (2013)

Kailash Sacred Landscape (KSL) is a transboundary landscape between China (Tibet Autonomous Region), India and Nepal. The landscape has a steep elevational gradient from 400 to above 7,400 m asl (above sea level) that harbors the diverse ecosystems and biomes. The major biomes of the landscape include tropical forest, subtropical forest, montane forest, alpine shrub and meadow (ICIMOD, 2020).

1.1.3 Vegetation pattern in Kailash Sacred Landscape Nepal

KSL Nepal covers four mountainous districts, Baitadi, Bajhang, and Darchula in Sudurpaschim province, and Humla in Karnali province of Nepal. The landscape is covered by 14 different types of vegetation which represent 45.05 % of the total area of the landscape (ICIMOD, 2020) (Figure 1).

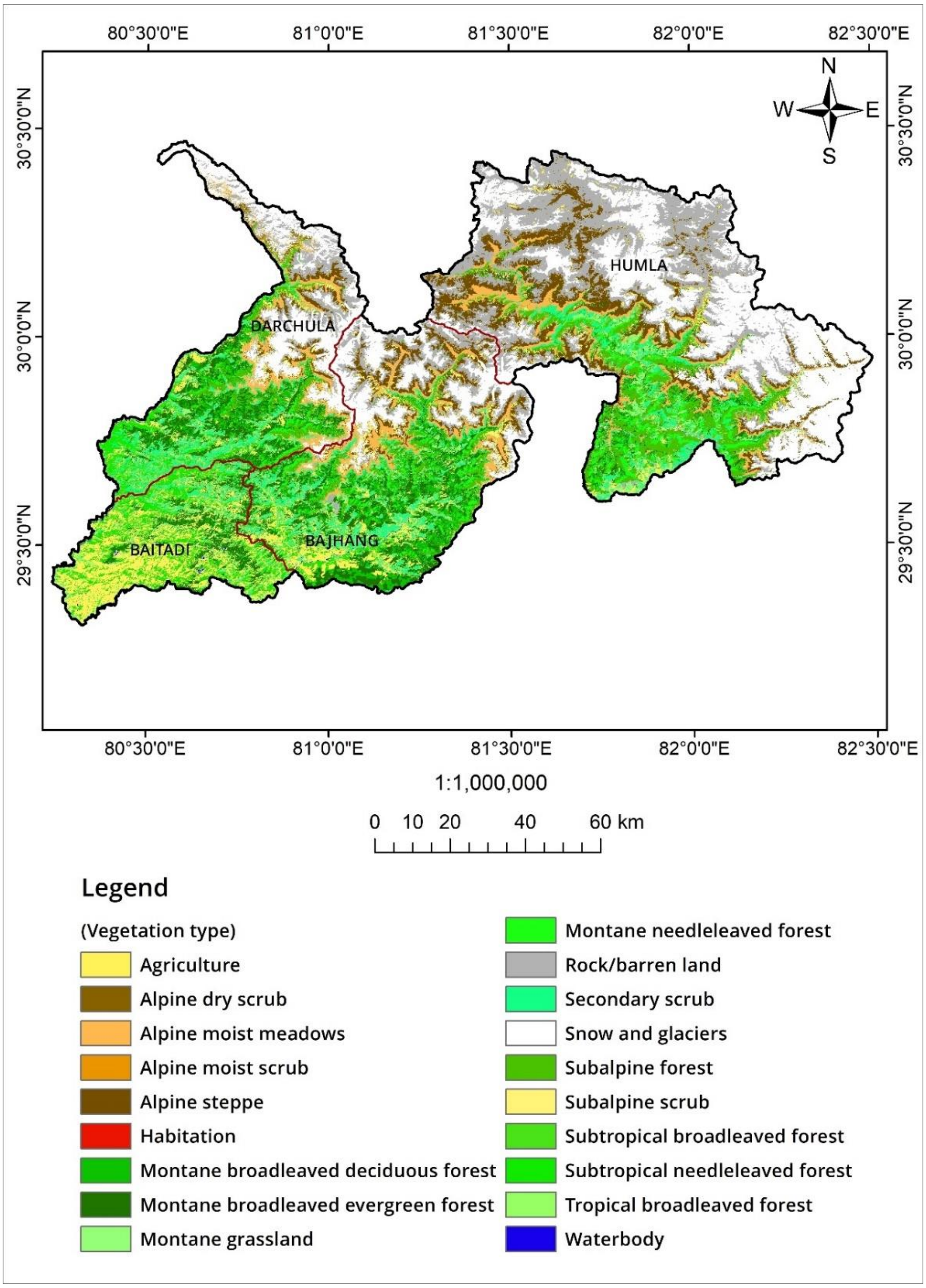

Figure 1: Vegetation types within Kailash Sacred Landscape Nepal (Source: ICIMOD, 2020).

The major physiognomic units, floristic units, dominant species and their altitudinal range of each vegetation type (ICIMOD, 2020) are presented below:

1. Tropical broadleaved forest: It is distributed below 1,000 m asl and represented by Sal Forest dominated by *Shorea robusta,* and Khair-Sissoo Forest dominated by *Acacia catechu,* and *Dalbergia sissoo.* The other associated tree species found in these forests are *Anogeissus* spp., *Lagerstroemia* spp., *Indopiptadenia oudhensis, Hymenodictyon excelsum.*

2. Subtropical broadleaved forest: Sal Forest (*Shorea robusta, Terminalia alata*), Toona – *Engelhardia* forest (*Toona ciliata, Engelhardia spicata, Albizia* spp.), and *Macaranga pustulata* (*Macaranga pustulata, Debregeasia* spp.) forests are the major forest types included under this vegetation category. Sal forest is distributed between 1,000-1,400 m asl and reaches upto 1, 500 m asl in drier slope along river valley. Toona (*Toona ciliata*) – *Engelhardia* and *Macaranga pustulata* forest are also the floristic units of this vegetation that are distributed from 800 to 1,200 m asl.

3. Subtropical needleleaved forest: Usually this forest is monospecific forest dominated by Chir pine (*Pinus roxburghii*). However, *Glochidion velutinum* is associated with it in some forests. It is distributed from 900 to 1,800 m asl.

4. Montane broadleaved evergreen forest: It is distributed from 1,400 to 3,300 m asl and dominated by different species of oak (*Quercus* spp.) in different altitudinal ranges. The dominant species include *Q. leucotrichophora* associated with *Myrica esculenta* (1,600-2,200 m asl); Q. *floribunda,* associated with *Symplocos chinensis* (2,000-2,600 m asl); *Q. lanuginosa* and *Q. lanata* (1,400-2,200 m asl); *Q. semecarpifolia* associated with *Thamnocalamus falconerii* (2,600-3,300 m asl); *Q. leucotrichophora* associated with *Neolitsea pallens,* and *Machilus* spp. (1,500-2,200 m asl).

5. Montane broadleaved deciduous forest: *Aesculus – Acer* forest (characterized by domination of *Acer villosum* and *Aesculus indica* associated with *Betula alnoides, Juglans regia,* and *Carpinus* spp.), Alder Forest (*Alnus nepalensis* and *Alnus nitida)* and *Populus ciliata* forest that are distributed from 1,500 to 3,000 m asl are the floristic units of this vegetation.

6. Montane needleleaved forest: It includes Deodar (*Cedrus deodara*) forest (1,600-2,200 m asl), Cypress (*Cupressus torulosa*) forest (1,800-2,400 m asl), Hemlock (*Tsuga* *dumosa*) forest (2,600-3,200 m asl), Blue pine (*Pinus wallichiana*) forest (1,800-3,300 m asl), and Silver Fir (*Abies pindrow*) forest (2,100-3,300 m asl).

7. Secondary scrub: It is represented by mixed scrub, *Lantana* scrub, *Rhus* scrub and *Dodonea viscosa* associated with *Berberis asiatica, Prinsepia utilis, Rubus niveus, Cocculus laurifolius* distributed from 800 to 3,000 m asl, *Pyracantha crenulata, Rhus parviflora, Woodfordia fruticosa* distributed from 800 to 3,300 m asl and Euphorbia scrub (*Euphorbia royleana*) and Olea spp. (*Olea cuspidata*) distributed up to 1,200 m asl.

8. Montane grassland: Grasslands on steeper slopes and hay meadows (managed pastures) distributed upto 3,300 m asl represents montane grasslands vegetation type. The dominant species of the grassland includes *Themeda anathera, Chrysopogon gryllus, Cymbopogon distans, Andropogon munroi, Cymbopogon jwarancusa*.

9. Subalpine forest: It includes Oak – Fir mixed forest (*Q. semecarpifolia – Abies spectabilis*) distributed from 3,000 to 3,500 m asl in association with *Pinus wallichiana, Juniperus communis, Taxus wallichiana*; Birch – Rhododendron forest (*Betula utilis - R. campanulatum*), distributed from 3,300 to 3,600 m asl; Fir (*Abies spectabilis*) dominated forest distributed from 3,300 to 3,600 m asl, and maple mixed forest dominated by *Acer caesium* from 2,700 to 3,300 m asl.

10. Subalpine scrub: It is Krummholz formed by *R. campanulatum* at an elevation of 2,700 m asl to 4,000 m asl.

11. Alpine Moist Scrub: The major plant communities of this vegetation are *Salix-Lonicera* (*Salix denticulata, S. lindleyana, Lonicera myrtillus*) distributed from 3,400 to 5,000 m asl; Rhododendron scrub (*Rhododendron anthopogon, Cassiope fastigiata, Cotoneaster microphylla*) distributed from 3,800 to 4,200 m asl; and *Salix – Myricaria* (*Salix denticulata, Myricaria elegans*) distributed from 3,000 to 3,800 m asl.

12. Alpine Dry Scrub: It is represented by *Caragana – Lonicera* Scrub (*Artemisia* spp., *Caragana versicolor, Lonicera spinosa, Astragalus* spp., *Potentilla fruticosa, Rubus nivale, Rosa sericea*), *Ephedra* Scrub (*Ephedra gerardiana*), *Juniper* scrub (*Juniperus communis*) and *Eurotia* scrub (*E. serratoides*) distrributed from 2,100-5,000 m asl.

13. Alpine moist meadows: Mixed herbaceous formations (*Potentilla atrisanguinea, Geranium wallichianum*), *Danthonia* meadows (*Danthonia cachemyriana*), *Kobresia* meadows (*Kobresia nepalensis*), and marsh meadows (*Blysmus compressus, Carex* spp.) distributed from 3,400 to 4,500 m asl are the major communities of alpine moist meadows found in the landscape.

14. Alpine steppe: *Stipa – Carex* (*Stipa orientalis, S. purpurea, Carex* spp., *Leymus secalinus*), dry alpine mixed formations (*Potentilla argyrophylla, Lancea tibetica, Artemissia* spp., *Festuca* spp.), desert steppe (*Orinus thoroldii, Stipa glariosa, Artemissia wellbyi*), Alpine Cushionoid (*Areneria* spp., *Thylacospermum caespitoides*), and Marsh Meadows (*Blysmus compressus, Carex* spp.) are the broad communities under alpine steppe. It is found between 4,000- 4,800 m asl.

1.2 Rationale

The study of patterns and processes of global distribution of biodiversity is one of the most important objectives for ecologists and biogeographers of the world. Study of floristic composition through inventory of species in a particular area is prerequisite in community ecology that enables researcher for modeling species diversity and distribution patterns. The floristic composition and species diversity is also important to understand the forest dynamics (Gentry, 1990). Study on vegetation types and composition help to design future monitoring schemes to assess the effects of global changes (Dvorskỳ *et al.,* 2010). The mountain regions covering about 24% of total global land area (UNEP-WCMC, 2002) have been impacted rapidly due to climate changes in recent decades (IPCC, 2021).

Since 8.6% of total land is available for cultivation in the Kailash Sacred Landscape (KSL), Nepal (Chaudhary *et al.*, 2010), people of this region are highly dependent on natural resources mainly those of forests for their livelihoods that result in the overexploitation of the resources alarmingly (Kunwar *et al.*, 2013). The Government of Nepal declared Darchula District, which is a part of KSL Nepal as sheep pocket area. Thus, grazing along with other anthropogenic disturbances put pressure on natural resources mainly forests and rangeland in the area. The decrease in forest cover by 9% and increase in cropland by 12% in KSL Nepal during the period of 20 years (1990-2009) indicates forest dependency (Uddin *et al.*, 2015). KSL Nepal falls in Himalayan biodiversity hotspot. It is characterized by different bioclimatic zones and ecosystems, and harbors globally significant populations of wide variety of plants and animals, and is also rich in cultural heritage (Zomer & Oli, 2011). The area is regarded as a data deficit area in terms of climate and biodiversity, and existing vegetation data are truly not representative of whole area. Despite its richness in the biodiversity, very few scientific studies have been carried out in this region. Some new records of plant species of different life form for Nepal and the world recently being described from this area (Subedi *et al.*, 2018; Rana *et al.*, 2018, 2021; Ghimire *et al*., 2021) indicate that systematic study of floristic composition and structure of vegetation is urgently needed in the Landscape. Knowledge on forest structure and composition is important for management and developing conservation strategies (Gutiérrez & Huth, 2012) but such studies are lacking in the Landscape. The information on vegetation composition and structure of forest in KSL Nepal is lacking. The present study aims to enumerate the vegetation of community forests and national forest of KSL Nepal. The collected information on vegetation composition and structure serves as baseline information for community forest user groups and district forest authority. Thus, the findings of this study will contribute to conservation and sustainable utilization of forest resources thereby developing forest management strategy.

1.3 Research hypotheses

The environment plays crucial role in determining vegetation globally. Since different plant species have different environmental requirements, the plant communities vary along space (Whittakar, 1956). This study hypothesized that the structure, species richness, and species composition in a forest is determined by abiotic factors such as climate (rainfall and precipitation), soil properties, topography and anthropogenic activities.

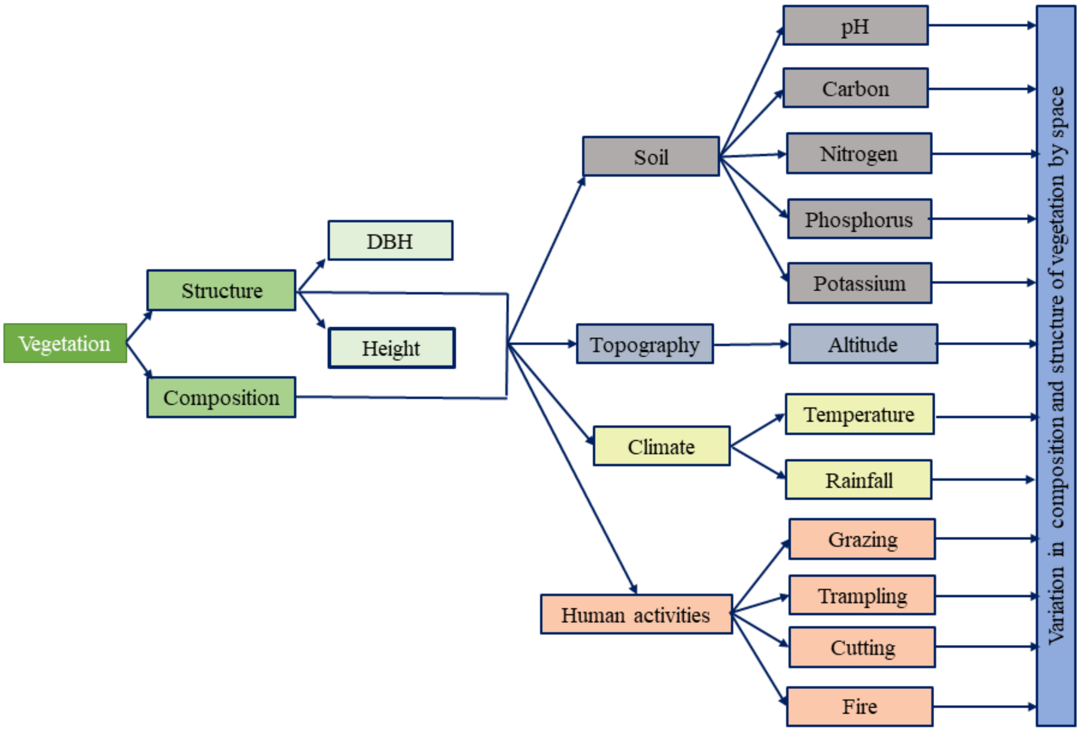

Figure 2: Conceptual framework.

1.4 Objectives

General Objective

This research assesses the structure and composition of vegetation that vary with major forest types (broadleaved forest and pine forests) and along an elevational gradient in the landscape.

Specific objectives

The specific objectives are:

- To know the vegetation composition and structure in different forest type and along elevational gradient;
- To know the role of soil nutrients on species composition and richness;
- To know the role of climatic factors on species composition and richness; and
- To know the role of anthropogenic activities on species composition and richness.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Vegetation composition and structure

The floristic composition, physiognomy and structure of vegetation are important variables that help to classify plant community into different groups (Keith & Sanders 1990; Wolf, 1998). These variables can also serve as the baseline to know the dynamics of primary and secondary forest (Gould *et al.*, 2006). In a forest, vegetation structure is measured in terms of canopy height, over story tree cover, canopy layering and density (Kormos *et al.*, 2018). The size class distribution of forest community is one of the attributes to show the structure of community. The size class distribution representing population structure of trees based on seedlings, saplings and mature trees gives insight into the regeneration of species and their future stability. Size class distribution of population in terms of diameter at breast height (DBH) and height, mean stem density and basal area value of the forest can be used to know the intactness of forest, type of management practices, regeneration, and recruitment status (Banda *et al.*, 2006; Hundera & Gadissa, 2008). The main structure of the forest community is constituted by the dominant tree species. The structure provides basis for developing sustainable conservation strategies for the management of forest by the local community (Giriraj *et al.*, 2008; Sharma *et al.*, 2009).

Study on vegetation in Nepal began with the exploration of plant species from different regions of the country in the early 19th century. Miehe *et al.* (2015) divided the history of plant exploration in Nepal into three periods *viz*: early collection (1802-1849), the interim period (1850-1948), and the modern era (1949-present). Scottish botanist Francis Buchanan-Hamilton was the first collector of plant species, who spent one year (1802-1803) in Kathmandu valley and collected plant specimens from Kathmandu valley and surrounding areas. He documented 1,120 plant species. The second and third exploration of early collection was made by Edward Gardner (1817-1820) and Nathaniel Wallich (1820-21) who collected plants from Gosaikund and Kathmandu. After nearly three decades of Wallich collection, J.D. Hooker in 1848 visited Nepal for one month and collected herbarium specimens from far eastern Nepal. Very few explorations were made during interim period. Only short excursion was made across the border in west Nepal by J. Scully in 1876 and J.F. Duthie in 1886. I.H. Burkill visited

Kathmandu valley in 1907 and visited Trishuli valley with J. Manners-Smith. Few high-altitude plants were collected by G. Beauverd in East Nepal. L. Dhwoj and K. Sharma made extensive visit throughout Nepal and collected hundreds of most conspicuous and alpine plants between 1927 and 1937. B.L. Gupta, Bis Rama and L. Dhwoj visited West Nepal in 1929 and collected plat specimens from there. F.M. Bailey collected plant specimens from Kathmandu valley and also sent collectors to West and Central Nepal between 1935 and 1936. In 1948, M.L. Benerji collected specimens from Tamur valley. Since the restriction to foreigners to visit Nepal eased, more than 200 expeditions have been made during modern era. The expedition was organized by different institutions/universities from Nepal, Japan, UK, India, France, and other countries. There were altogether 14 expeditions in Far Western, 30 in Mid-Western, 49 in Western, 82 in Central, and 64 in Eastern region (Miehe *et al.*, 2015).

Giri *et al.* (1999) studied vegetation composition, biomass production and regeneration in *Shorea robusta* forest and *Shorea – Terminalia* forest in Royal Bardia National Park, Nepal. The upper caopy of both the forest was dominated by *Shorea robusta* and *Terminalia alata*. The number of tree species was reported more in *Shorea – Terminalia* forest than in *Shorea robusta* forest. *Buchanania latifolia, Lagerstroemia pawiflora, Dillenia pentagyna, Mallotus philippensis, Careya arborea, Bauhinia malabarica, Casearia tomentosa,* and *Garuga pinnata* were common low canopy species in both forests. The biomass was high in *Shorea – Terminalia* forest than *Shorea robusta*. The regeneration of capacity was higher for *Shorea robusta* than for *Terminalia alata*.

Zomer *et al.* (2001) studied tropical monsoon forest in Makalu Barun Conservation Area, eastern Nepal and identified different forest communities *viz*: sub-montane semi-deciduous broadleaf tropical forest dominated by *Shorea robusta*; low-montane semi-deciduous needle leaf forest dominated by *Pinus roxburghii*; and low-montane evergreen broadleaf sub-tropical monsoon forest.

Vegetation composition and biomass production in riverine forest of Royal Bardia National Park was studied by Giri *et al.* (2001). Deciduous riverine forest was dominated by *Acacia catechu* and *Dalbergia sissoo* and evergreen riverine forest was dominated by *Syzygium cumini*, *Mallotus philippensis*, *Ficus racemosa* and *Schleichera oleosa*. The other codominated species included *Adina cordifolia*, *Bombax ceiba*, *Trewia nudiflora*, and *Holoptelea integrifolia*. The understorey vegetation comprised of *Smilax aspera*, *Clerodendron viscosum*, *Colebrookea oppositifolia*, and saplings of

Murraya koenigii and *S. cumini*. *Desmostachya bipinnata*, seedlings of *C. viscosum*, *S. cumini*, *M. koenigii* and *M. philippensis* were ground vegetation.

Kunwar & Chaudhary (2004) studied the status, vegetation composition, and biomass of forests of Arun valley, east Nepal and identified 10 forest communities from tropical to subalpine region. The forest communities included *Shorea – Semecarpus* dominated by *Shorea robusta*, *Semecarpus anacardium*, *Schima wallichi*, *Lagerstromia parriflora*, *Adina cordifolia*; *Shorea - Aegle* dominated by *Shorea robusta*, *Aegle marmelos*, *L. parriflora*, *Hollarena antidysentrica*; *Shorea - Syzygium* dominated by *Shorea robusta*, *Syzygium cumini*, *L. parriflora*, *S. wallichi*, *Leucosceptrum cranum*; *Bombax - Erythrina* dominated by *Bombax ceiba*, *Erythrina stricta*, *Castanopsis hystrix*, *S. wallichi*; *Schima - Castanopsis* dominated by *S. wallichi*, *C. hystrix*, *Rhododendron arboreum*, *Rhus parviflora*, *Macaranga denticulata*; *Castanopsis – Eurya - Cardamon* dominated by *C. hystrix*, *Amomum subulatum*, *Viburnum mullaha*, *Eurya cerasifolia*; *Alnus – Cardamon* dominated by *Alnus nepalensis*, *A. subulatum*, *Dichora febrifuga*, *Eupatorium adenophorum*; *Castanopsis – Eyrya* dominated by *C. hystrix*, *C. indica*, *E. cerasifolia*, *A. nepalensis*, *Lyonia ovalifolia*; *Daphniphyllum – Eurya* dominated by *Quercus lamellosa*, *Q. glauca*, *Daphiniphyllum himalense*, *E. cerasifolia*, *V. mullaha*; *Castanopsis – Viburnum* dominated by *C. hystrix*, *V. mullaha*, *Q. lamellosa*, *Holoptelia integrifoila*; *Castanopsis – Eurya* dominated by *C. hystrix*, *V. mullaha*, *E. cerasifolia*, *A. cordifolia*, *Q. lamellosa*; *and Rhododendron – Eurya* dominated by *R. arboreum*, *E. cerasifolia*, *Q. glauca*, *Edgeworthia gardnerii* and *L. ovalifola*. The above ground biomass was highest in *Daphniphyllum – Eurya* followed by *Castanopsis - Viburnum* forest. The biomass content was found less in *Shorea robusta* dominated community.

Study on vegetation composition and biomass production in community forest was done in Sikre VDC, Kathmandu (Pandey & Bajracharya, 2010). Considering the important value index, the forest was dominated by *Alnus nepalensis*, *Pinus roxburghii*, and *Schima wallichi*. The other associated trees included *Albizia julibrissin*, *Castanopsis indica*, *Eurya accuminata*, *Myrica esculenta*, *Lyonia ovalifolia*, etc. *Hypericum uralum*, *Berberis aristata*, *Melastoma melabathricum* were shrubs and ground vegetation represented by *Capillipedium assimile*, *Eupatorium adenophorum* and *Biden pilosa*. The highest above ground biomass in the forest was contributed by *C. indica* followed by *M. esculenta* and *S. wallichi*.

Floristic composition and diversity in Upper Manaslu Conservation Area was carried out by Chhetri & Bhattarai (2013). They recorded 161 species plants belonging to 44 families. The major plants included *Abies spectabilis*, *Acer acuminatum*, *Acer campbelli*, *Betula utilis*, *Hippophae salicifolia*, *Pinus wallichiana*, *Lonicera angustifolia*, *Rhododendron arboreum*, *Rhododendron barbatum*, *Sorbus foliolosa*, *Tsuga dumosa* were tree; *Berberis aristata*, *Berberis erythroclada*, *Caragana brevispina*, *Cotoneaster frigidus*, *Ephedra gerardiana*, *Hippophae tibetana*, *Juniperus communis*, *Juniperus recurva*, *Lonicera lanceolata*, *Rhodendron anthopogon*, *Rhododendron nivale*, *Rosa macrophylla* shrubs; and *Aconitum ferox*, *A. spicatum*, *Actaea spicata*, *Anaphalis triplinervis*, *Artemisia dubia*, *Astilbe rivularis*, *Bistorta amplexicaulis*, *Carex filicina*, *Corydalis juncea*, *Fragaria nubicola*, *Fritillaria cirrhosa*, *Iris stantonii*, *Kobresia nepalensis*, *Meconopsis regia*, *Parnassia nubicola*, *Podophyllum hexandraum*, *Polygonatum verticillatum*, *Primula denticulata*, *Senecio wallichi*, *Swertia angustifolia*, *Thalictrum foliosum*, *Viola biflora*, etc. were herbs.

Comparative study on structure, composition and diversity of plants of different life form in community and government managed forest in Udayapur District, Nepal was carried out by Paudel & Sah (2015). They identified 46 species as overstorey and 63 species as understorey in both forests. Based on stems/ha, the major tree species constitute overstorey of community forest were *Shorea robusta*, *Semecarpus anacardium*, *Cleistocalyx opperculatus*, *Buchnania latifolia*, *Flacourtia indica*, and *Shorea robusta*, *Terminalia myriocarpa*, *Bauhinia vahlii*, *Bauhinia purpurea*, *Syzygium* sp., *Terminalia tomentosa*, *Trichilia connaroides* in government managed forest. The species composition was more heterogeneous in community forest than government forest.

Bürzle *et al.* (2017) studied the treeline ecotone vegetation of Rolwaling Himal, Nepal to know the ecology of treeline vegetation types. They recorded 103 species of vascular plants in the treeline ecotone. They broadly classified vegetation into two group *viz*. *Betula utilis-Abies spectabilis* forests and *Dasiphora arbuscula-Rhododendron anthopogon* dwarf shrub heaths including five communities. *Betula utilis-Abies spectabilis* forests comprised of *Synotis alata-Abies spectabilis*, *Ribes glaciale-Abies spectabilis*, and *Boschniakia himalaica-Rhododendron campanulatum* community and *Dasiphora arbuscula-Rhododendron anthopogon* dwarf shrub heaths group comprised of *Pedicularis cf. microcalyx-Rhododendron anthopogon*, and *Anaphalis royleana-Rhododendron anthopogon* community.

The composition and structure of vegetation in Himalayan region have been studied by several workers. Hussain *et al.* (2008) studied composition and community in 23 forests stand along altitudinal gradient (1,500-3,000 m asl) in Kumaon Himalaya. They recorded 63 tree, 56 shrubs, 91 herbs and 21 grasses in 23 forest stands. The TWINSPAN analysis identified five group of tree species belonging to 19 communities in relation to environmental variables. The first group comprised of *Acer caecium*, *Aesculus indica* and *Betula alnoides*. Second group consisted of *Quercus semecarpifolia*, *Toona serrata*, *Dodecademia grandiflora* etc. *Abies pindrow, Juglans regia*, *Betula utilis*, *Rhododendron barbatum*, *Tsuga Dumosa*, *Prunus cornuta*, *Acer cappodicum* form third group. The fourth and fifth group comprised of *Cedrus deodara*, *Quercus lanuginosa*, *Q. glauca*, *Pinus roxburghii*, *Quercus leucotricophora*, *Pyrus pasiha*, *Pinus wallichiana* and *Litsea umbrosa*, *Rhododendron arboreum*, *Alnus nepalensis*, *Ilex dipyrena*, *Lindera pulcherrima*, *Lyonia ovalifolia*.

Study on structure, composition and diversity of temperate broadleaved forest along altitudinal gradient in Garhwal Himalaya was studied by Sharma *et al.* (2009). *Persea duthiei*, *Daphniphyllum himalense*, *Quercus leucotricophora*, *Betula alnoides*, *Lyonia ovalifolia*, *Alnus nepalensis*, *Ulmus wallichiana* were reported from upper altitude (2,100 m asl); *Daphniphyllum himalense*, *Rhododendron arboreum*, *Quercus leucotricophora*, *B. alnoides*, *A. nepalensis*, *Persea odoratissima*, *L. ovalifolia*, *U. wallichiana* in middle altitude (1,700 m asl); and *Q. leucotricophora*, *L. ovalifolia*, *Rhododendron arboreum*, *P. odoratissima*, *Myrica esculanta* in the lower altitude (1,550 m asl).

Kharkwal & Rawat (2010) conducted vegetation analysis in subtropical forest of Kumaon Himalaya at an altitude of 1,600 to 2,600 m asl. They reported that *Quercus leucotrichophora* (Banj-Oak forest), *Q. floribunda* (tilonj-oak forest), *Q. semecarpifolia* (kharsu-oak forest), and *Pinus roxburghii* (chir-pine forest) are dominant tree species. The codominant tree species were: *Myrica esculanta* and *Rhododendron arboreum* in chirpine forest; *Fraxinus micrantha*, *M. esculenta*, *Cornus oblonga* in Banj-oak forest; *Q. leucotrichophora*, *Rhododendron arboreum* in tilonj-oak forest; and *Cedrus deodara*, *Cupressus torulosa*, *Q. floribunda* and *Acer oblongum* in kharsu-oak forest.

The study on forest structure and regeneration along the altitudinal gradient (1,600-2,400 m asl) in Binsar Sancturry, Uttarakhanda Himalaya (Majila & Kala, 2010) revealed three types of forest communities *viz.* chirpine forest dominated by *Pinus roxburghii* at lower altitude (1,600-1,900 m asl); oak-chirpine with the domination of *Q. leucotricophora* and *P. roxburghii* at middle altitude (1,900-2,100 m asl); and oak forest dominated by *Q. floribunda* and *Q. leucotrichophora* at high altitude (2,100-2,400 masl). *Cornus capitata* and Q. *glauca* were tree and *Myrsine africana*, *Berberis asiatica* and *Rhus parviflora* were shrubs associated in pine forest. The tree and shrub species associated in oak-chirpine forest included *Cornus macrophylla* and *M. africana*, *Rubus ellipticus*, *Hypericum patulum*, *B. asiatica* respectively. *Acer cappadocium, Euonymus tingens, Fraxinus micranthus* and *Lyonia ovaliofolia* were associated trees and *Myrcine africana*, *Berberis aristata*, *Arundinaria falcata, Daphne papyracea* and *Hypericum patulum* were shrubs in oak forest.

Shaheen *et al.* (2012) studied speies composition and community structure in western Himalayan moist temperate forests in Kashmir. They recorded 122 species belonging to 43 families. The communities were dominated by *Abies pindrow* and *Pinus wallichiana* in the high altitudinal range (1,700-2,600 m asl) and *Q. dilatata*, *Q. incanna*, and *Machilus odoratissima* were associated with conifers in the lower altitude (1,500-2,000 m asl). The shrub layer was comprised of *Viburnum grandiflorum*, *Sarcococca saligna*, *Berberis lycium*, and *Dryopteris stewertii*. The ground vegetation was dominated by *Poa alpina*, *P. stewartii*, *Trifolium repens*, *Fragaria nubicola*, *Plantago major* and *Viola canescens*. The regeneration pattern (counting cut stumps, seddlings and saplings number) indicated deterioting forest structure in the study area.

Study on vegetation composition in montane forest ecosystem in Pakistan recorded 209 species of vascular plants (Ilyas *et al.*, 2012). They categorised plant communities into eight group *viz.* 1) *Cedrus-Indigofera-Thymus*, 2) *Cedrus-Viburnum-Pteridium*, 3) *Olea-Plectranthus-Micromeria*, 4) *Pinus roxburghii-Plectranthus-Rumex*, 5) *Pinus wallichiana-Indigofera-Galium*, 6) *Pinus wallichiana-Viburnum-Leucas*, 7) *Populus-Debregeasia-Nasturtium*, and 8) *Quercus-Indigofera-Amaranthus*. They suggested for the sustainable management of biodiversity of the area for present and future generations with the participation of local people and different stakeholders.

Gairola *et al.* (2011) studied composition of species in herbs, shrubs and tree layers in five different forest type dominated by *Abies pindrow*, *Acer acuminatum*, *Aesculus* *indica*, *Quercus floribunda*, and *Quercus semecarpifolia*, in Mandal-Chopta area West Himalaya. *Rhododendron arboreum*, *Lyonia ovalifolia* and *Sorbus cuspidata* were associated tree species; *Daphne papyracea*, *Gaultheria nummularioide, Rubus foliolosus, Senecio kunthianus* were shrubs; and *Agrimonia pilosa*, *Ainsliaea aptera, Anaphalis triplinervis, Bergenia ciliata, Erigeron multiradiatus*, *Fragaria nubicola, Galium asperifolium, Gentiana capitata, Impatiens sulcata*, *Potentilla fulgens, Rumex nepalensis, Taraxacum officinale*, *Viola biflora* were herbs layer found in *Quercus semecarpifolia* forest. In *Quercus floribunda* forest, the tree layer is comprised of *Quercus floribunda*, *Rhododendron arboreum*, *Lyonia ovalifolia*, and *Persea duthiei*; Shrub layer is comprised of *Cotoneaser microphyllus, Cyathula tomentosa, Daphne papyracea*, *Elsholtzia fruticosa*, *Senecio kunthianus*, *Thamnocalamus falconeri*; and herbs comprised of *Agrimonia pilosa, Ainsliaea aptera, Cirsium wallichii*, *Elsholtzia pilosa*, *Erigeron multiradiatus*, *Fragaria nubicola*, *Galium asperifolium*, *Gentiana capitata*, *Impatiens sulcata*, *Origanum vulgare*, *Parochetus communis*, *Plantago depressa*, *Potentilla fulgens, Primula denticulata*, *Rumex nepalensis, Swertia cordata, Viola biflora*. The tree layer of *Acer acuminatum* forest is comprised of *Abies pindrow, Aesculus indica*, *Diospyros montana*, *Lyonia ovalifolia*, *Neolitsea pallens*, *Persea duthiei*, *Quercus floribunda*, *Rhododendron arboreum*, and *Lyonia ovalifolia*. *Plectranthus striatus, Rubus foliolosus*, *Sarcococca saligna*, *Thamnocalamus falconeri* were shrubs and *Cirsium wallichii*, *Corydalis cornuta*, *Fragaria nubicola*, *Geranium nepalense*, *Impatiens sulcata*, *Origanum vulgare, Oxalis corniculata*, *Parochetus communis*, *Pilea umbrosa*, *Potentilla fulgens*, *Primula denticulata*, *Pteracanthus alatus*, *Rumex nepalensis*, *Salvia nubicola*, and *Viola betonicifolia* were herbs. The *Abies pindrow* dominated forest is comprised of tree species such as *Acer acuminatum, Quercus floribunda*, and *Rhododendron arboreum*; Shrubs such as *Ficus hederacea, Rosa brunonii*, *Rubus niveus*, *Thamnocalamus falconeri*, *Thamnocalamus spathiflora*; and herbs such as *Anaphalis triplinervis*, *Cirsium wallichii*, *Fragaria nubicola, Gentiana capitata*, *Hypericum elodeoides*, *Origanum vulgare*, *Potentilla fulgens, Primula denticulata*, *Ranunculus laetus*, *Rumex nepalensis*, and *Swertia cordata*. *Acer acuminatum*, *Betula alnoides*, *Persea duthiei*, *Quercus floribunda* were tree species reported in *Aesculus indica* forest. *Daphne papyracea*, *Ficus hederacea*, *Hedera nepalensis*, *Rubus ellipticus*, *Thamnocalamus falconeri*, and *T. spathiflora* were shrubs; and *Fragaria nubicola, Galinsoga parviflora, Galium asperifolium, Origanum vulgare, Parochetus communis, Pilea umbrosa*, *Plantago depressa*, *Primula denticulata*, *Ranunculus laetus*, *Rumex nepalensis*, and *Viola betonicifolia* were herbs in *Aesculus indica* forest.

Community structure on timberline ecotone of *Betula utilis* (Birch), *Abies spectabilis* (silver fir), *Quercus semecarpifolia* (kharsu oak) and *Abies*-*Quercus* (mixed) in Kedarnath Wildlife Sanctuary in western Himalaya was studied by Rai *et al.* (2012). Trees in the timberline ecotone were sparsely distributed. *Rhododendron arboreum* and *S. foliolosa* were reported from all communities while *Taxus wallichiana* was in kharsu oak community. The shrub species included *Rubus niveus*, *Spiraea bella*, *Rosa sericea*, *R. campanulatum*, *Viburnum grandiflorum*, *Cotoneaster acuminatus*, and *Lonicera myrtillus* reported in all communities; *Berberis jaeschkeana*, *Rhododendron barbatum*, *Salix denticulata*, and *Thamnocalamus spathiflorus* reported in birch, kharsu oak and mixed community; *Rhododendron lepidotum* in birch community; and *Ribes glaciale*, in birch, silver fir and kharsu community; and *Spiraea canascens* in birch community. The dominant herb species included *Fragaria nubicola*, *Impatiens sulcata*, *Polygonum amplexicaule*, *Senecio alatus*, *Smilacina purpurea*, *Strobilanthes atropurpureus*, *Trachydium roylei*, and *Viola biflora* in birch community; *Circaea alpina*, *Fragaria nubicola*, *Galium rotundifolium*, *Polygonum amplexicaule*, *Polygonum chinense*, *Triplostigea glandulifera*, and *Viola biflora* in silver fir community; *Circaea alpina*, *Fragaria nubicola*, *Polygonum amplexicaule*, *Polygonum chinense*, *Primula sessilis*, *Selinum vegenatum*, *Triplostigea glanduliferaI*, and *Viola biflora* in kharsu oak community; and *Circaea alpina*, *Fragaria nubicola*, *Polygonum amplexicaule*, *Polygonum chinense*, *Triplostigea glandulifera*, and *Viola biflora* in mixed community.

Sharma & Kant (2014) studied floristic composition, diversity and structure of woody vegetation in subtropical Kandi belt, Jammu and Kashmir, India. They recorded 112 species comprising 65 trees and 47 shrubs. The northern dry mixed deciduous forest dominated with *Mallotus philippensis* associated with *Aegle marmelos, Albizia lebbeck*, *Bauhinia variegata, Bombax ceiba, Cassia fistula*, *Crataeva adansonii, Dalbergia sissoo, Ficus palmata, Flacourtia indica, Grewia optiva, Lannea coromandalica, Mangifera indica, Melia azedarach, Mitragyna parviflora, Ougenia oogeinensis, Phyllanthus emblica, Syzigium cumini,* and *Toona ciliata.* Shrub species included *Abutilon indicum, Capparis sepiaria, Carissa opaca, Colebrookia oppositifolia, Dodonaea viscosa, Justicia adhatoda, Nerium indicum, Punica granatum* and *Woodfordia fruticosa*. Himalayan subtropical scrub was dominated by *Acacia modesta*, followed by *Zizyphus mauritiana* and *Flacourtia indica*. *Aegle marmelos, Albezia lebbeck, Bauhinia variegata, Casseria tomentosa, Cassia fistula, Crataeva adansonii, Dalbergia sissoo, Ehretia laevis, Grewia optiva, Lannea coromandelica, Mallotus philippensis, Ougenia oogeinensis, Phyllanthus emblica, Premna barbata, and Wrightia tomentosa.* Shrubs of this forest type comprised of *Capparis sepiaria, Carissa opaca, Colebrookia oppositifolia, Dodonaea viscosa, Justicia adhatoda, Lantana camara, Mimosa rubicaulis, Punica granatum, Randia tetrasperma, Woodfordia fruticosa,* and *Zizyphus oxyphylla*. Himalayan subtropical pine forest was dominated by *Pinus roxburghii*. The other associated tree species included *Acacia catechu, Butea monosperma, Cassia fistula, Dalbergia sissoo, Ficus benghalensis, Ficus palmata, Lannea coromandelica, Mallotus philippensis, Phyllanthus emblica,* and *Syzigium cumini*. The shrubs comprised of *Carissa opaca, Colebrookia oppositifolia, Dodonaea viscosa, Euphorbia royleana, Justicia adhotoda, Nyctanthes arbro-tristis, Rubus ellipticus, Woodfordia fruticose,* and *Wendlandia heynii*.

Species richness, regeneration and community composition of deciduous forests covering Thano forest range, Asarori forest range, and Selaqui-Jhajra forest range of Doon Valley, Western Himalaya, India was studied by Mandal & Joshi (2014). The distribution analysis indicated that the Thano forest range was dominated by *Shorea robusta* in association with *Terminalia alata*, *Cassia fistula* and *Bombax ceiba*. The shrub species comprised of *Adhatoda zeylanica*, *Solanum hispidum*, *Flemengia bracteata*, *Murraya koenigii*, *Azanza lampas*, *Carissa opaca*, and *Lantana camara* and herbs comprised of *Vernonica cinerea*, *Phyllanthus virgatus*, *Mosla dianthera*, *Mazus rugosus*, *Hygrophila angustifolia*, *Asparagus aspera*, and *Spilanthes paniculata*. Asarori forest range was dominated by *S. robusta* and *Adina latifolia*, *Bauhinia variegata*, *Casearia tomentosa*, *C. fistula*, *Ehretia laevis*, *Ficus benghalensis*, *Litsea glutinosa*, *Mallotus philippensis*, *Miliusa velutina*, *Ougeinia oojeinensis*, *Syzgium cumini*, and *Terminalia bellirica* were codominant species. *L. camara*, *Ardisisa solanacea*, *Urena lobata*, *Desmodium gangeticum*, *Clerodendrum viscosum*, *Colebrookia oppositifolia* and *Aerva sanguinolenta*, *Euphorbia hirta*, *Justicia diffusa*, *Lindernia ciliata*, *Phyllanthus urinaria*, *Setaria glauca*, *Fimbristylis dichotoma*, *Oplismenus compositus*, *Euphorbia hirta*, *Triumfetta rhomboidei*, *Cynoglossum lanceolatum*, *S. paniculata*, *Syndrella vialis*, and *Triumfetta rhomboidei*. *S. robusta* was also dominant tree species in Selaqui-Jhajra forest range and other codominant tree species included *Anogeissus latifolia*, *Bauhinia variegata*, *Caseaseria tomentosa*, *Cordia dichotoma*, *Ehretia laevis*, *Flacourtia indica*, *Miliusa velutina*, *M. philippensis*, *Syzygium cumini*, and *T. alata*. *Ardisia solanacea*, *Asparagus adscendens Bambusa arundinacea C. viscosum*, *L. camara*, *M. koenigii*, *Opuntia dillenii*, *Randia uliginosa*, *Salix tetrasperma*, and *Urena lobata*, were shrubs and *Achyranthes aspera*, *Setaria glauca*, *Tridax procumbens*, *Zingiber roseum*, *Polygonum plebejum*, *Portulaca Pilosa*, *Phyllanthus urinaria*, *A. aspera*, and *Sida rhombifolia*. Species richness of tree was highest in Asarori forest range followed by 14 in Selaqui-Jhajra range and eight in Thano forest range. The species richness of herbs ranged from 27 species in Thano forest range and 49 species in Asarori forest range and 24 species of shrubs at Thano range and 21 species in Selaqui-Jhajra range and Asarori forest range respectively.

Sharma *et al.* (2016) studied the variation in vegetation (tree) composition in five major forests type *viz. Abies* forest, *Cedrus* forest, *Pinus* forest, *Quercus* forest, and *Betula* mixed forest in ridge top forests of Garhwal Himalaya. *Acer caesium*, *Aesculus indica*, *Betula utilis*, *Cedrus deodara*, *Pinus wallichiana*, *Prunus cornuta*, *Sorbus cuspidata*, and *Taxus wallichiana* were associated with *Abies spectabilis* in *Abies* forest. *Cedrus* forest was dominated by *Cedrus deodara* and associated tree species included *Picea smithiana*, *Pinus wallichiana*, and *Populus ciliata*. *Pinus* forest was dominated by *Pinus wallichiana* in association with *Acer caecium*, *Cedrus deodara*, and *Picea smithiana*. *Quercus semecarpifolia* dominated *Quercus* forest comprised of *Abies spectabilis*, *Prunus cornuta*, *Rhododendron arboreum*, and *Sorbus cuspidata*. *Betula* mixed forest is comprised of *Abies spectabilis*, *Acer caesium*, *Betula utilis*, *Lyonia ovalifolia* and *Pinus wallichiana*.

2.2 Role of environmental factors on vegetation composition

Plant species diversity and composition is regulated by numerous abiotic and biotic factors and their interactions (Angelo & Daehler, 2013; Behera *et al.*, 2012; Bunn *et al.*, 2010; Kareiva *et al.*, 2007; Kluge *et al.*, 2017; Mishra *et al.*, 2013; Sanderson *et al.*, 2002). The study of interactions of living organisms with abiotic and biotic factors of the environment is the fundamental aim of ecology. The basic knowledge provided by fundamental ecological research is important for the management of natural world. In order to identify present state of ecological research and their relevance for conservation of biodiversity and ecosystem function, Sutherland *et al.* (2013) provided 100 fundamental ecological questions. Among them, how environmental factors influence species composition and diversity is one of the questions that reflect state of ecology today. The relationship between vegetation and environment is dynamic and highly affected by time scale. Ecologists have attempted to study different determinants that control the distribution and variation in vegetation composition over a century (Iason *et al.*, 2005). The vegetation types are predicted by environmental factors (Greve *et al.*, 2011). Earlier studies documented the role of environmental and edaphic factors and recent studies emphasized the role of anthropogenic disturbances in shaping the structure and composition of vegetation and their dynamics. The relative effect of biotic and abiotic factors and their variation with different environmental conditions determine the species composition in a plant community (Lavergne *et al.*, 2010). It has been reported that abiotic factors tend to explain more variation of species composition in colder sites but biotic component explains more variation in the warmer sites (Klanderud *et al.*, 2015; Laughlin & Abella, 2007).

2.2.1 Climatic factors

Climatic factors that include light, temperature, precipitation, humidity, wind, fire, atmosphere, etc. are responsible for determining climatic condition of an area. Climate is highly correlated with the species richness and considered as prominent driver and first level predictor for species richness and composition (Hawkins *et al.*, 2003; McCain, 2007). Climatic factors, especially microclimatic factors, have dominant role on the development of forest structure and associated vegetation in a forest community in Northern India (Behera *et al.*, 2012; Mishra *et al.*, 2013). Establishment of savannah, sal mixed and dry miscellaneous forest community influenced by the microclimatic condition such as air temperature, absolute humidity, ambient carbondioxide and photosynthetically active radiation. The dry miscellaneous forest community mainly is affected by air temperature, soil temperature and absolute humidity (Behera *et al.*, 2012). Variation in climatic conditions affects productivity within a particular area, determines carrying capacity of the environment, and thus species composition, diversity and their population size (Acharya *et al.*, 2011; Hawkins *et al.*, 2003; Körner, 2007).

The climatic factors such as temperature, rainfall, humidity alone or in combination have role in composition and diversity of plants. It is well established that climatic factors such as temperature and precipitation collectively control the growth and development of natural vegetation thereby structuring the floristic composition and diversity of plant species in an area (Fang & Yoda, 1991; Rundquist & Harrington, 2000; Svenning & Skov, 2005). The total annual precipitation and mean annual temperature explained more variation in species composition in Andean forests (Blundo *et al.*, 2012).

Temperature facilitates biological activities related to ecosystem productivity by regulating water resources of plants. Thus, temperature as an energy-related variable among others such as water related variables like precipitation and humidity, is the most influential factor affecting plant species diversity in Bhutan Himalaya (Kluge *et al.*, 2017). Peters *et al.* (2016) reported that temperature is main predictor of richness and diversity of species covering larger communities that is fundamental importance for identifying ecological and evolutionary mechanisms to find consequences of global warming in long-term. Miehe *et al.* (2015) classified vegetation of Nepal based on different climatic zones *viz*. tropical, subtropical, temperate, cool and cold. Each climatic zone is determined by mean annual temperature, mean annual temperatures of coldest month and mean annual temperature of warmest month.

Rainfall is the most important variable that can predict the distribution of different terrestrial vegetation types, *viz*. evergreen forests, mosaic forest/savanna, closed deciduous forest, deciduous woodland, deciduous shrubland, closed grassland, open grassland with sparse shrubs, open grassland, sparse grassland and desert in continental scale in Africa (Greve *et al.*, 2011). Vegetation density in the Himalaya is highly influenced by the available moisture and temperature (Olen *et al.*, 2016). Panthi *et al.* (2007) reported moisture as the most important determinant of species richness and composition in trans-Himalayan inner valley of Manang, central Nepal ranging in elevation from 3,000 to 4,000 m asl. *Pinus wallichiana*, *Juniperus indica*, *Abies spectabilis*, *Betula utilis* and *Salix* species are the dominant tree species along the trans-Himalayan inner valley of Manang. *B. utilis* was preferred to grow on north facing slope with high moisture content and *Juniperus indica* was common in dry south facing slope (Panthi *et al.*, 2007). Kunwar *et al.* (2019) identified environmental variables such as slope, aspect, temperature, precipitation, radiation, disturbance, elevation, and use pressure as the socioeconoomic variable influence the vegetation composition and structure of forest vegetation in KSL Nepal. The canonical correspondence and correlation analyses indicated that vegetation and species composition was significantly affected by elevation, slope, and temperature.

2.2.2 Edaphic factors

Edaphic factors comprise physical (such as texture and thickness) and chemical properties (such as pH, humus, soil organic matter, carbon, nitrogen, phosphorus, potassium, and magnesium) of soil. Soil properties of an area determine the vegetation structure, composition, and richness. Sánchez-González & López-Mata (2005) in Sierra Navada, Mexico found that the species richness was highest in mixed forest at an altitude between 2,900-3,200 m with high organic matter as compared to scrub-oak forest with at an altitude from 2,750 to 2,850 m. The physical and chemical characteristics of soil determine the forest quality that has role on sustainable forest management. Thus, soil quality can be used as indicator for sustainable forest management (Schoenholtz *et al.*, 2000). The chemical properties of soil that can be used as indicator include organic matter, organic carbon, availability of nitrogen, phosphorus, and potassium, and pH value. The change in organic carbon pool to a given depth can be used as an indicator of soil quality change due to grazing. Organic matter content has been suggested as the first level indicator of soil quality. Total nitrogen and organic nitrogen are used as indicator for grassland and grazing respectively. Water relation, nutrient supply, biological activities of soil are attributes of soil physical characteristics (Schoenholtz *et al.*, 2000). The soil organic matter (SOM) is one of the important components for global carbon cycle which is determined by the vegetation composition of a particular area. Total suppression of spinning sidebands (TOSS) cross polarization under magic angle spinning (CPMAS) ^{13}C NMR spectra revealed that, Carbonyl C dominated under oak forest, *O*-alkyl C under manzanita, and alkyl C was under coniferous vegetation (Quideau *et al.*, 2001). The soil organic matter, total nitrogen, silt and clay content, chlorine, calcium ion, magnesium ions and electrolytic conductivity of soil have strong correlation with vegetation composition (He *et al.*, 2007). A dominant role of nitrogen, phosphorus and potassium was reported to shape the structure of Cerrito vegetation in Brazil (Goodland & Pollard, 1973).

Soil organic matter and soil nutrient mainly nitrogen, phosphorus and potassium have significant role on composition of vegetation assemblages mainly diversity and distribution (Liu *et al.*, 2012; Tilk *et al.*, 2017; Zhang *et al.*, 2007). Liu *et al.* (2012)

remonitored the vegetation and soil characteristics of 144 permanent plots in Niujiazhuang catchment in middle Taihang Mountains of north China in 1986 and 2008. The soil characteristics that affect vegetation composition in the permanent plots included soil thickness, humus thickness, rock content, soil organic matter, and total N, P, and K. They found that dominant role of nitrogen was replaced by phosphorus within two decades interval for composition of vegetation. Soil properties especially moisture and soil nutrients were strongly linked with the topographic features, such as aspect, slope position, elevation and inclination (Desta *et al.*, 2004), thereby influence the species composition and structure of vegetation. Merunková & Chytrý (2012) found soil moisture, soil nutrients and soil pH as the main determinants of floristic composition in upland grassland of Czech Republic. Soil pH is an important predictor that explains diversity and distribution pattern of vegetation at local or regional scales (Rahbek & Graves, 2001; Zellweger *et al.*, 2016). There was significant correlation between vegetation composition, edaphic factors and topographic factors (Liu *et al.*, 2012).

2.2.3 Topography

The landscape features such as topography, landscape position, slope gradient and elevation influence the distribution of plant communities. Topography is the physical features of earth that includes elevation, slope and its direction. These factors influence the microhabitat of plants and shape up the composition and structure of plant community. Topography influences soil characteristics, water availability, material redistribution and seed dispersal that has direct impact on plants distribution pattern in the mountain area (Fu *et al.*, 2004; Xu *et al.*, 2008). The topographic variables such as elevation, slope and aspect in the mountain have direct impact on species composition and abundance of plant species (Liu *et al.*, 2012). The microenvironment of hill slopes is determined by the intensity and duration of sunlight that often is linked with soil moisture and affects the species composition in the mountains (Ferrer-Castán & Vetaas, 2003; Måren *et al.*, 2015; Paudel & Vetaas, 2014; Yadav & Gupta, 2006). It is considered that north-east facing slope is cooler and moister and south-west facing slope is warmer and drier in the Himalaya that brings variation in structure and composition of vegetation (Singh & Singh, 1992). The orientations of slope and land use pattern are also important factors for structuring woody species in the trans-Himalaya zone of Nepal Himalaya. Paudel & Vetaas (2014) showed that there was significant difference in species composition between northeast and southwest facing slope. The composition was governed by relative radiation index. The southwest facing slope receive greater intensity and radiation as compared to northeast facing slope that suppot different species composition. North facing slope had more species and higher density than south facing slope in trans-Himalayan region in Manang District, central Nepal (Måren *et al.*, 2015; Panthi *et al.*, 2007). The composition and distribution of forests type in KSL Nepal was significantly affected by elevation and aspect. The canonical correspondence analysis (CCA) and correlation analysis indicated that elevation and aspect along with temperature were the most significant variables for affecting vegetation and species distribution (Kunwar *et al.*, 2019).

2.3 Vegetation pattern along elevation gradient

The elevation gradient has received little attention than latitudinal gradient to biogeographers, and ecologists of the world (MacArthur, 1972). Elevation gradient is a unique situation to study species richness that has geophysical and general climatic trends change within a very short distance (Körner, 2007; Lee *et al.*, 2013). After knowing its significance, many studies focused on elevational pattern of plant species change in different parts of the world (Jones *et al.*, 2011; Lomolino, 2001). Elevation gradient along with different living and nonliving factors influence the distribution of plant species. It is the major ecological factor for shaping the spatial pattern of species richness (Brown, 2001; Lomolino, 2001; Zimmerman *et al.*, 1999). It also can provide powerful information about the range and restriction of plant and animal species distribution influenced by environmental conditions and to understand the evolutionary dynamics and adaptations (Grinnell, 1924). The elevation pattern of species richness is strongly influenced by climate and floristic overlap of the floras of tropical and temperate region (Li & Feng, 2015).

The land area changes, and climatic trends are the phenomenon that changes with elevation. The shrinkage of land area can be observed with increasing elevation. The climatic trend in elevation includes decreasing atmospheric pressure, reduction in atmospheric temperature, increasing solar radiation, and ultraviolet radiation. However, precipitation, wind velocity, and seasonality are generally not related with elevation (Körner, 2007). A positive correlation was found between tree species richness with rainfall, temperature, moisture index, and evapotranspiration along elevation gradient in eastern Himalaya, India (Acharya *et al.*, 2011).

The number of species and their composition varies systematically along the elevational gradient in different parts of the world. McCain & Grytnes (2010) identified four common types of elevational pattern of species richness *viz*. (i) decreasing, (ii) low plateau, (iii) low plateau with mid elevation peak, and (iv) mid elevation peak. The decreasing pattern reveals the decline in number of species monotonically with increasing elevation. The decreasing pattern was reported by Aiba & Kitayama (1999) in Mount Kinabalu, Borneo, Trollan and Lynghaugtinden mountain in northern Norway (Grytnes, 2003), five mountains of Faroe Islands (Fosaa, 2004). The monotonic decrease in species richness mainly due to reduce in temperature and consequent decrease in productivity (Rahbek, 1995). Low plateau pattern shows the high richness at lower portion of elevation gradient and decreases along high gradient. This pattern is common among birds (McCain, 2009). Low plateau with mid elevation peak demonstrates high richness across low elevation with maximum diversity at high elevation. Such type of pattern is mainly exhibited by reptiles (McCain & Grytnes, 2010). The mid elevation peak or humped shaped relationship have high diversity at intermediate elevation i.e., more species richness at mid elevation than base and top of the mountain. The review of literature on species richness revealed that the hump shaped pattern peaked at mid elevation was the typical pattern among all (Rahbek, 2005). Humped shaped relationship at intermediate elevations have widely reported in different parts of the world: Nepal Himalaya (Bhattarai & Vetaas, 2003; Grytnes & Vetaas, 2002), eastern Himalaya, India (Acharya *et al.*, 2011), eastern Himalaya, Bhutan (Kluge *et al.*,2017), in the Northern slopes of Qilianshan Mountains, Gansu, China (Wang *et al.*, 2002), Western Himalaya (Oommen & Shanker, 2005), Mount Kinabalu, Sabah, Borneo (Grytnes & Beaman, 2006), in the Gaoligong Mountains, south-east Tibet, China (Wang *et al.*, 2007), Baekdudaegan Mountains, South Korea (Lee *et al.*, 2013). The study of tree species richness along altitudinal gradient of Mt. Boker, a table shaped mountain in southwestern Cambodia did not follow any pattern of species richness as described by McCain & Grytnes (2010) where the altitudinal gradient shows nearly constant pattern of tree species richness (Zhang *et al.*, 2016).

McCain & Grytness (2010) summarized different hypothesis related to altitudinal species richness pattern in global scale *viz*. climatic hypothesis, spatial hypothesis, and spatial constraint hypothesis. The climatic hypothesis based on variation in abiotic factors such as temperature (decreases along increasing altitude), precipitation (increases with elevation), productivity (unimodal), humidity and cloud cover. The spatial hypothesis includes species area relationship (more species at the base and less at the mountaintops) and spatial constraint hypothesis (mid domain effect brings mid elevation peak). Besides these hypotheses some biological process such as ecotone effect, competition, mutualism, habitat heterogeneity and habitat complexity also explained species richness pattern.

The review of literature on species richness revealed the hump-shaped pattern peaked at mid elevation was the typical pattern among all (Rahbek, 2005), and agrees with the prediction of mid domain effect (MDE) (Colwell & Hurtt, 1994). The species richness pattern followed mid domain model prediction in temperate and subtropical areas in the western Himalaya (Oommen & Shanker, 2005). The environmental and geometric factors contributed of hump-shaped species richness pattern in Braulio Carrillo National Park, Costa Rica, and adjacent areas (Brehm *et al.*, 2007). The speciess richness was associated with the combined interaction of mid domain effect and climatic factors, mainly mean annual precipitation and temperature (Lee *et al.*, 2013). Theoretical models have suggested the role of geomorphology in shaping the species distribution in mountains and resulting in the hump-shaped patterns of species richness along elevational gradients (Bertuzzo *et al.*, 2016).

2.4 Anthropogenic effects on vegetation

Vegetation composition and diversity change over time due to succession and environmental changes. The major drivers of changes on biodiversity include climate change, demographic change, and land use and land cover change (Chettri *et al.*, 2015). Based on the global population Ellis & Ramankutty (2008) identified eighteen anthropogenic biomes in the world. Human beings alter the earth's land use and land cover for their purpose that directly affect biodiversity worldwide (Sala *et al.*, 2000). The rate of urbanization is also responsible for land use and land cover change (Estoque & Murayama, 2013; Haase & Nuissl, 2010). The world's population is increasing, although the growth rate is different for different regions (Roser *et al.*, 2013). Mainly mountain peoples' dependency on forest for energy, food, medicine, non-timber forest products (Shaheen *et al.*, 2012) adversely affect integrity, diversity and productivity of forests and other vegetation.

Deforestation brings adverse effect on different ecosystem goods and services that it provides and livelihoods of forest dependent people throughout the world. The major drivers of deforestation include agricultural expansion, infrastructure development, wood extraction and fires in different parts of the world (Evans, 2016; Vinya *et al.*, 2011). Curtis *et al.* (2018) classified global dominant drivers of deforestation and their percentage contribution over the period of 2001 to 2015. Their result revealed that 27% of global forest loss was due to commodity driven deforestation (conversion of forestland or shrub land to agriculture, mining or infrastructure) followed by forestry operations (26%), shifting agriculture (24%) and wild fire (23%).

Forest is the most important natural resources and source of livelihoods especially for rural communities of Nepal. The dependency of local people on forest resources and their unsustainable illegal harvesting, infrastructure development, forest fire, natural calamities, encroachment, over grazing, lack of governance and ambiguous policy have identified as the major divers of deforestation of Nepal (Chaudhary *et al.*, 2016). Uddin *et al.* (2015) studied the changing land cover and fragmenting forest in KSL Nepal. They studied the forest fragmentation of 20 years period (1990-2009) and found that there was 9% decrease in forest cover and 12% increase in cropland. They predicted further 4% decrease in forest cover and 5% increase in cropland by 2030. They also analysed and predicted core forest fragmentation in the landscape. The core forest area was decreased by 10% during 1990 to 2009 and 10.6% decrease in core forest by 2030.

Anthropogenic activities such as extraction of forest resources, burning, looping, grazing, trampling are the common activities in the forests and grasslands of Himalaya including Nepal (Carpenter, 2005; Li *et al.*, 2012; Zomer *et al.*, 2001) that affect the composition and structure of plant species and facing conservation challenges. Grazing of cattle has negative effect on regeneration of tree species and under canopy species in treeline ecotone in western Himalaya (Rai *et al.*, 2012). The increasing level of disturbance resulted sharp decline in tree density, basal area, and species richness in subtropical dry deciduous and temperate forests in the Central Himalaya (Pokhriyal *et al.*, 2012). Variation in species richness, distribution pattern and regeneration potential of forest was related to human impact in the forest ecosystem (Bhuyan *et al.*, 2003; Malik *et al.*, 2016). Anthropogenic disturbances significantly affect forest vegetation and soil characteristics in a semiarid trans-Himalayan valley (Måren *et al.*, 2015). Human disturbance mainly for resource extraction had impacts on vegetation composition, and structure in terms of species richness, diversity, tree density, evenness, and basal area (Kumar & Shahabuddin, 2005; Thapa & Chapman, 2010). The richness of trees, shrubs and herbs decreased with the increasing level of disturbance in tropical forest of eastern Himalaya (Gogoi & Sahoo, 2018). In another study Kumar *et al.* (2009) reported that species diversity value was highest in highly disturbed forest followed by undisturbed and moderately disturbed forests in temperate zone; highly disturbed and moderately disturbed forest had same value in subtropical region; and high diversity value in highly disturbed forest than moderately disturbed forest in tropical zone in Garhwal Himalaya.

The potential responses of vegetation to global warming includes ecotonal shifts, changes in composition and structure, phenology and growing season, growth and productivity, changes in landscape and interaction with human activity (Theurillat & Guisan, 2001). It is predicted that the global temperature and precipitation has been rising continuously (IPCC, 2021). The vegetation of world is considered sensitive to climate change that altered the characteristics of vegetation (Krishnaswamy *et al.*, 2013; Parmesan, 2006). The climate change is an important driver of vegetation change that consistent with global warming for elevational shifts of species distribution, biodiversity change and biotic homogenization over the period of more than four decades in Quebec Canada (Savage & Vellend, 2015). The global meta-analysis indicated that there was a significant shift of plant species ranges due to climate change. Garamvölgyi & Hufnagel (2013) identified tree line advancement, reduction in alpine vegetation belt, drought, forest diebacks, shifting from coniferous to decidious forest as main trends of vegetation change in Europe and Eurasia. The global climate change significantly alters the phenology of plants by earlier spring flowering and earlier spring green-up (Cleland *et al.*, 2007). Shrestha *et al.* (2012) examined the vegetation phenology changes in the Himalayas, and found there was advancement in the start of growing season, and length of growing season and no change was reported in end of growing season. The history (i.e., large-scale dispersal limitation) equally with climate strongly controlled the species composition and diversity of plants (Svenning & Skov, 2005). Himalayas are vulnerable to climate change than other parts of the world (Xu *et* *al.*, 2009). The rate of warming greater than the global average (Shrestha *et al.*, 2012) affects biodiversity and treeline position in the Himalaya (Xu *et al.*, 2009).

2.5 Research gap

The composition and structure of vegetation influence the sustainability and functioning of landscape. Composition refers to the identity of plant species comprising the community and structure as the different canopy layer and size distribution based on DBH and height. These aspects of vegetation are poorly studied in the KSL, Nepal. While reviewing the literature, it is clear that many researchers have been considered different life forms of plants species in a community as the structure of vegetation. However, a holistic approach, including the role of different environmental factors for shaping the structure and composition of vegetation in the landscape, is lacking. This research work attempts to know the underlying environmental factors for structuring the vegetation, and composition of plant species in the landscape.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Study area

The present study was carried out in the Kailash Sacred Landscape (KSL), Nepal (MFSC, 2016) (Figure 3). KSL Nepal is one of the six conservation landscapes of Nepal that covers an area of 13,289 square kilometer in northwest Nepal, and comprises Baitadi, Bajhang, and Darchula Districts of Sudurpaschim Province, and Humla District of Karnali Province. It extends between 29° 22’ N to 30° 45’N latitudes and 80° 15’ E to 82° 10’ E longitudes. Elevation ranges from 390 m above sea level (m asl) in Baitadi to 7,336 m asl (Mt. Nalakankad) in Humla. The climatic conditions of the landscape are characterized by high rainfall and humidity. The average rainfall is 2,129 mm. Average maximum and minimum temperature recorded of the area is 18.6°C and 7.7°C respectively (Chaudhary *et al.*, 2010). Geologically, Tibetan sediments dominate the northern most part; gneiss, schist, limestone, sediments, granite, and pegmatite are found in the high Himalayan zone; and phyllite, quartzite, gneiss, granite, and schist are found in middle mountain zone of KSL Nepal (Chaudhary *et al.*, 2010). Api Nampa Conservation Area (ANCA) (Darchula District) and a part of Khaptad National Park (Bajhang District) are two protected areas that fall within KSL Nepal.

KSL Nepal harbors globally significant diversity of plants and animals and is rich in cultural heritage and natural resources (Zomer & Oli, 2011). It lies at the interjection of Western Himalayan, Eastern Himalayan and Central Asiatic floristic zones. It is a part of Himalayan biodiversity hotspot (Mittermeier *et al.*, 2004) comprising of five ecoregions *viz*. Himalayan subtropical broadleaved forest, Himalayan subtropical pine forest, western Himalayan broadleaved forest, western Himalayan subalpine conifer forest and western Himalayan alpine shrub and meadows (Olson *et al.*, 2001).

Out of 35 forest type of Nepal at least 18 types of forest occur in this area (Stainton, 1972). There are altogether 14 endemic plant species documented from the area (Chaudhary *et al.*, 2010; Rana *et al.*, 2018).

The subtropical needle-leaved forest (dominated by *Pinus roxburghii*), montane broadleaved evergreen forest (*Quercus* spp.) and montane needle-leaved forest (*Pinus wallichaina*) contributed 15.31 % out of total 45.05% vegetation cover in the KSL

Nepal (ICIMOD, 2020). Thus, vegetation sampling in the landscape was conducted in Paripatal Mahila Community Forest (montane broadleaved evergeen forest) and Kirmadhe Sinnadi Community Forest (subtropical needle-leaved forest) in Darchula District, and Kailash Kachaharikot Mahila Community Forest (montane needle-leaved forest) in Bajhang District representing all three types of forest, and Chamelia Valley in Darchula District representing government managed forests (Figure 3 & Figure 4).

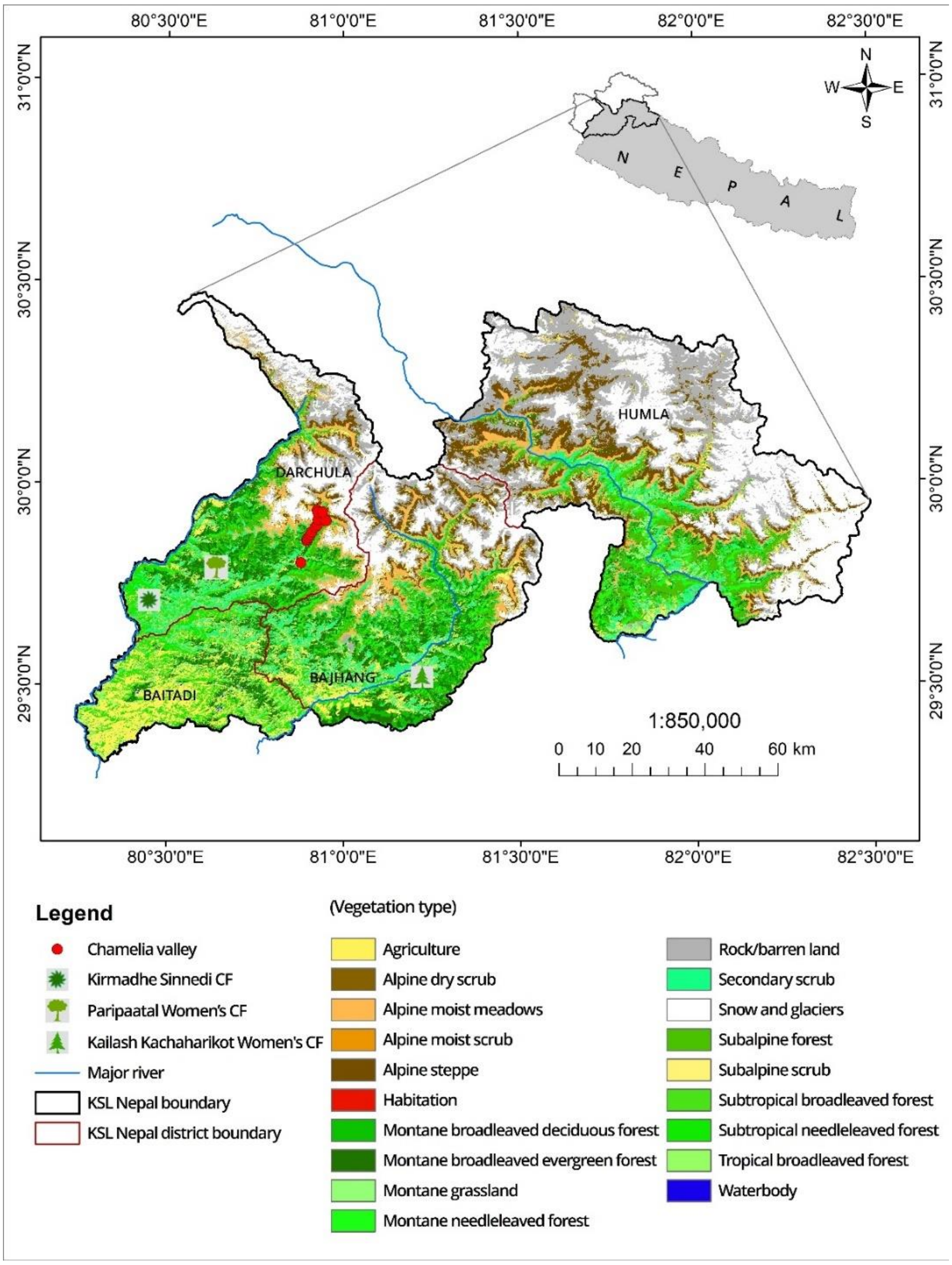

Figure 3: Map showing the study area for vegetation sampling (Source: ICIMOD, 2020).

3.1.1 Paripatal Mahila Community Forest

Pariptal Mahila Community Forest (CF) (hereafter broadleaved forest) located in Naugad Rural Municipality, ANCA, Darchula District (Figure 3 and Figure 4b). It covers an area of 29 hectare (ha). It is dominated by broadleaved tree species such as *Quercus lanata* and *Lyonia ovalifolia*. The other associated tree species of the forest include *Pyrus pashia*, *Ilex dipyrena, Carpinus betulus*. *Berberis asiatica*, *Cotoneaster frigidus*, *Deutzia compacta*, etc. are shrubs and *Strobilanthes capitata*, *Hedera nepalensis*, *Taraxacum parvulum*, *Stellaria semivestita*, *Ainsliaea latifolia* etc. are few herbs found in the forest. Elevation of the forest area ranges from 1,922 to 2,350 m asl. The slope varies between 2° to 33° and is oriented towards northeast.

The forest is an example of success story of community participation in the improvement of forest condition. According to local people, the forest was heavily destroyed due to unsustainable utilization of forest resources in the past. It has regenerated after handing over the forest to community in 2050 BS (1993 AD).

The primary source of energy for heating and cooking is fuelwood. Households are allowed to to collect fuelwood and litter once a year from the forest. Households collect forest products from multiple sources such as from government managed forests and private forests that help to reduce pressure on community forests. They also harvest non-timber forest products mainly medicinal plants such as *Swertia chirayita* and few terrestrial orchids (*Goddyera* species). Community is allowed to graze their animals in the forest. The forest is also en route to pastureland. Visible sign of grazing was frequent in the forest. Besides, sign of lopping and cutting (illegal) was also observed in the forest.

3.1.2 Kirmadhe Sinnadi Community Forest

Kirmadhe Sinnadi CF (hereafter chir pine forest) located in Malikaarjun Rural Municipality, Darchula District, covers an area of 50.76 ha. Elevation in this CF ranges from 1,808 to 1,958 m asl, slope is between 5° to 2° and the forest is oriented towards east and west. The forest is dominated by *P. roxburghii* (chir pine). Other associated tree species of the forest include *Quercus lanata, Rhododendron arboreum* and *Myrica esculenta.* The shrubs in the forest include *Ageratina adenophora, Berberis asiatica, Rubus ellipticus*, etc. *Anaphalis triplinervis*, *Carex filicina*, *Erigeron karvinskianus*, *Galium elegans*, *Gonostegia hirta*, *Taraxacum parvulum*, etc. are herbs found in the forest.

Many of the households are dependent on the community forest for fuelwood, litter, and fodder. Timber, vegetables, fruits, and materials for roofing are other forest products collected from the community forest. Besides community forest, the households depend upon government management forest, religious forest and private land to meet their demands. The members of the community forests are allowed to collect fodder and fuel wood from the forests throughout the year. They collect litter from forest only during Asar (June) to Asoj (September). They are allowed to harvest timber only once a year. During Falgun (February) and Chaitra (April), they collect litter and conduct control burning in the forest. The CFUG does not conduct any other forest management practices. The communities graze their cattle in the forest. The sign of forest fire and cutting was also visible on the forest floor during our visit.

3.1.3 Kailash Kachaharikot Mahila Community Forest

Kailash Kachaharikot Mahila CF (hereafter blue pine forest) located in Jayaprithvi Municipality, Bajhang District, covers an area of 20 hectares. Elevation ranges from 1,800 to 2,100 m asl, slope is between 20° to 35° and the forest is oriented towards south and west. The forest is dominated by *P. wallichiana*. *Lyonia ovalifolia*, *Rhododendron arboreum*, *Symplocos pyrifolia* were other associated tree species in the forest. The shrubs comprised of *Daphne papyracea*, *Indigofera heterantha*, *Prinsepia utilis*, *Rubus ellipticus*, *Spiraea bella*, etc. and *Centella asiatica*, *Myrsine africana*, *Oplismenus compositus*, *Origanum vulgare*, *Taraxacum parvulum*, etc. were herbs.

The forest users extracted fuelwood, litter, fodder, timber, vegetables, fruits, and materials for roofing from the community forest. The members of the community forests are allowed to collect fodder and fuel wood from the forests throughout the year. They collect litter from forest only during Asar (June) to Asoj (September). They are allowed to harvest timber only once a year. During Falgun (February) and Chaitra (April), they collect litter and control burn in the forest.

3.1.4 Chamelia Valley

The Chamelia Valley is narrow ‘V’ shaped valley. The sampling sites of the valley extends between 29° 48’ 8.6” N to 29° 55’ 57.3” N latitudes and 80° 53’0.9” to 80° 57’ 17.4” E longitudes. The elevation ranges from 2,000 m asl to 3,800 m asl. The slope ranges from 5° to 45° mostly oriented to north direction. Based on the dominant tree species four different types of forest was found in the study area. They were: Low temperate mixed broadleaved forest (2,000 – 2,300 m asl), Temperate mixed broadleaved forest (2,400 – 2,600 m asl), Upper temperate mixed broadleaved forest (2,700–3,200 m asl) and Birch – Rhododendron forest (3,300-3,800 m asl).

Low temperate mixed broadleaved forest is comprised of *Neolitsea pallens*, *Acer* spp., *Juglans regia*, *Celtis australe*, *Buxus wallichiana*, etc. The understory is comprised of *Urtica ardens*, *Sarcococca saligna*, *Girardinia divesifolia*, *Deutzia compacta*, *Leycesteria formosa*. The ground vegetation is composed of *Anisomeles indica*, *Boehmeria ternifolia*, *Cyathula tomentosa*, *Cheilanthes rufa*, *Galium asperuloides*, *Lysionatus serrotus*, *Pilea umbrosa*, *Viola biflora*, *Impatiens bicornuta*, *Stellaria media*, *Thalictrum foliolosum*, *Strobilanthus urtisifolius*, *Holboellia latifolia*, *Galium asperuloides*, *Ageratum conyzoides*, etc.

Temperate mixed broadleaved forest is dominated by *Ulmus wallichiana*, *Acer cappadocicum*, *Euonymus porphyreus*, *Prunus nepaulensis*, *Saurauria nepaulensis*, *Corylus jacquemontii*. The shrub layer in the forest comprises of *Arundanaria falcata*, *Urtica ardens*, *Rosa macrophyla*, *Spirea bella*, *Sarcococca saligna*, *Viburnum mullaha*. The ground vegetation is comprised of *Aechmanthera gossypina*, *Arisaema flavum*, *Asparagus racemosus*, *Clematis connata*, *Cyathula tomentosa*, *Geranium nepalense*, *Hedera nepalensis*, *Impatiens sulcata*, *Nepeta erecta*, *Leucas lanata*, *Pilea umbrosa*, *Prenanthus brunoniana*, *Smilax aspera*, *Thalictrum foliolosum*, etc.

Upper temperate broadleaved forest is comprised of *Tsuga dumosa*, *Quercus semecarpifolia*, *Euonymus fimriatus*, *Prunus nepaulensis*, *Rhododendron barbatum*, *Ulmus wallichiana*, *Acer pectinatum*, *Viburnum erubescens*, *Syringa emodi*. The mid canopy of the forest is dominated by shrubs species such as *Rubus biflorus*, *Ribis gliciale*, *Rosa macrphyyla*, *Salix hylematica*, *Indigofera* sp., *Viburnum cotinifolium*, *Jasminum humile*, *Arundanaria falcata*, etc. The ground vegetation included *Aconogonum rumicifolium*, *Arabidospsis himalaica*, *Arisaema consanguineum*, *Arisaema flavum*, *Bidens pilosa*, *Bistorta amplexicaulis*, *Calenthe tricarinata*, *Clematis connate*, *Galium paradoxum*, *Fragaria nubicola*, *Halenia elliptica*, *Impatiens sulcata*, *Impatiens urticifolia*, *Myriactis nepalensis*, *Polygonatum vertisilatum*, *Thalictrum cultratum*, *Trigonella emodi*, etc.

The Birch-Rhododendron forest is dominated by *Betula utilis* and *Rhododendron campaulatum*. The other tree species included *Quercus semecarpifolia*, *Sorbus macrophylla*. The shrub layer is comprised of *Ribis gliciale*, *Rosa sericea*, *Lonicera webbiaba*, *Salix hylematica*, etc. The ground vegetation is comprised of *Aconogonum rumicifolium*, *Astilbe rivularis*, *Bistorta affinis*, *Cardamine violacea*, *Cheilanthes rufa*, *Cynoglossum ambile*, *Fragaria nubicola*, *Galium paradoxum*, *Juncus* sp., *Parasenecio chenopodifolius*, *Parnassia nubicola*, *Potentilla atrosanguinea*, *Rumex acetosa*, *Thalictrum cultratum*, *Swertia petiolata*, etc.

The forest along the valley was government managed forest. It is en route to pastureland. Herders and thousands of medicinal plant collectors use this trail. Visible sign of grazing, trampling and cutting was seen along the trail where herders established their shelter. The herders establish their hurt in Khayakot (2,000 m asl), Simar (2,800 m asl) and Dhauloodar (3,400 m asl) and let their cattle's graze for few days. Thus, the disturbance was quite visible in the vegetation sampling plots around these areas. A huge destruction of forest was observed in Dhauloodar where Yar-tsa-gunbu (*Ophiocordyceps sinensis*) collectors establish their shelter during harvesting months (June-July).

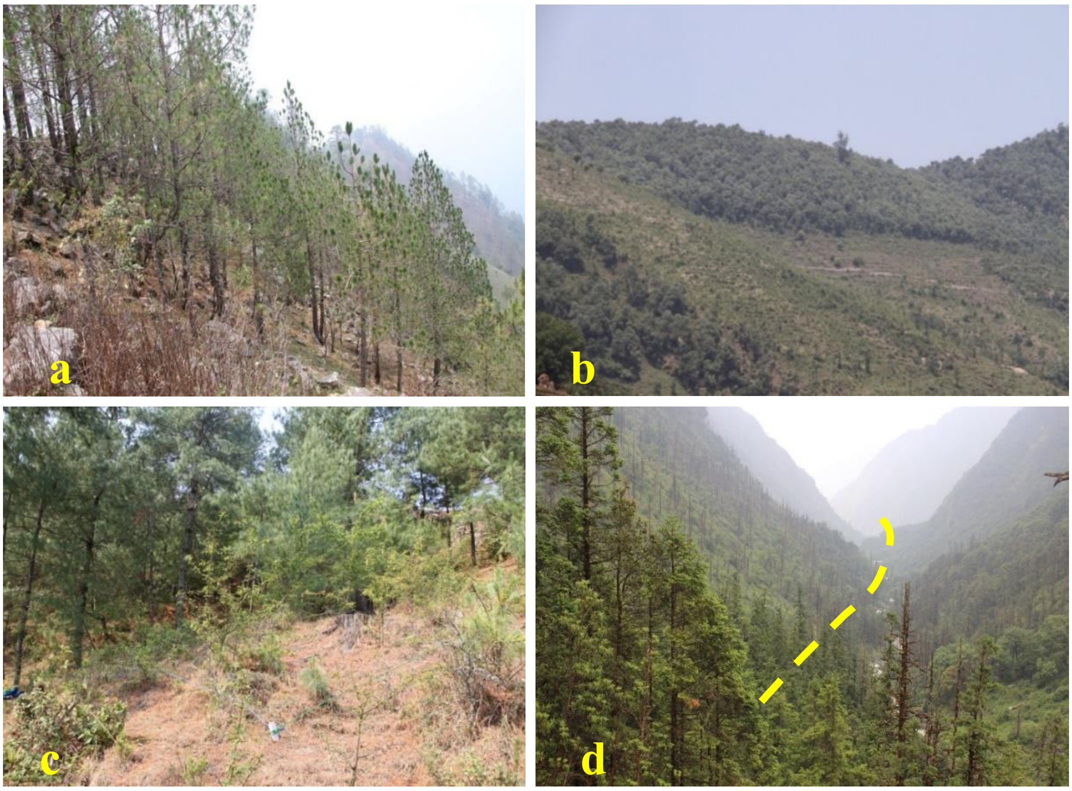

Figure 4: Sampling sites (a. Kirmadhe Sinnadi CF, b. Paripatal Mahila CF, c. Kailash Kachaharikot Mahila CF, d. Chamelia Valley).

3.2 Field methods

3.2.1 Plot establishment

Fieldworks in three community forests (CFs) were carried out in May to June 2016 to collect vegetation data and soil samples. The boundaries of all three CFs were delineated using Global Positioning System (GPS) device (Garmin Oregon 650) and transferred on to Google Earth map and overlaid on grid of 20 m × 25 m size. Sample forest plots were randomly selected and verified in the field. Based on the area of forest, altogether, ten plots were established in chir pine forest, six in broadleaved forest and four in blue pine forest. Each plot was further divided into twenty 5 m × 5 m subplots for collecting data (Figure 5). The location (longitude and latitude) of each plot was recorded using a portable GPS receiver (eTrex Vista, Garmin), elevation was measured by using altimeter (Suunto), and Slope and aspect were recorded with a clinometer (Suunto) (Appendix 1).

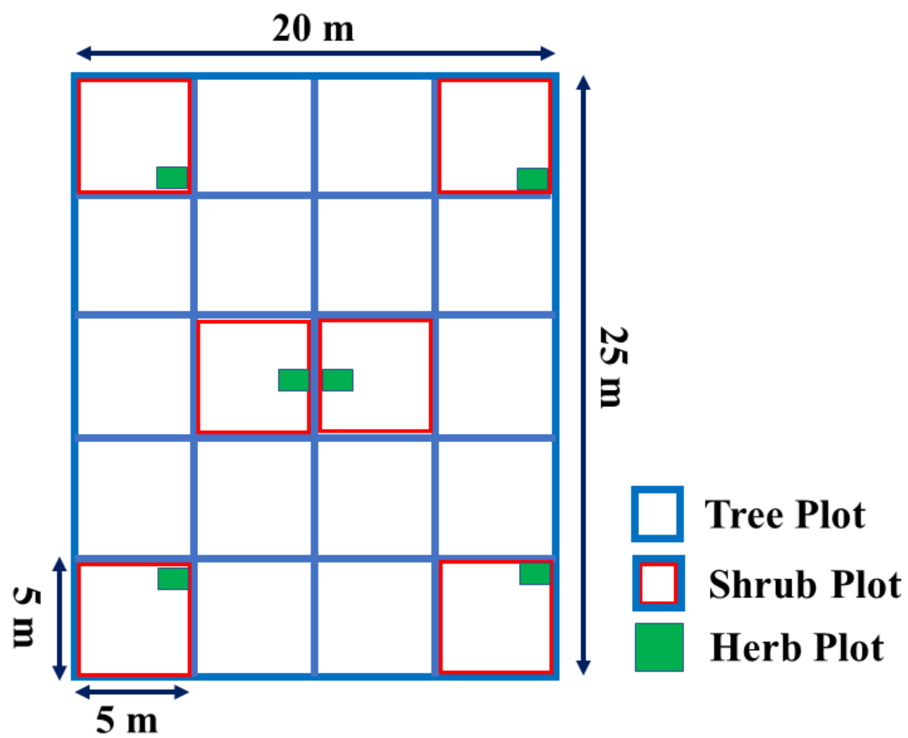

Figure 5: Vegetation sampling design in different forest types.

Field work in Chamelia Valley was carried out between June and August 2015. Quadrat sampling was adopted along an altitudinal gradient (2,000-3,800 m asl) to collect data. The size and numbers of quadrats were determined in the field as per the availability of space in the study area. Quadrats were laid at an interval of 100 m elevation from

Khayakot (2,000 m asl) to Shiyela (3,800 m asl) along the valley. At each elevation, we laid transect of 160 meters long comprising of six quadrats of size 10 m × 10 m (Figure 6). Each quadrat was divided into four 5m×5m subquadrats to sample shrubs, and four 1m×1m subplots for sampling of herbs. The quadrats were 20 m apart. In total, 114 quadrats were studied in 19 transects. In each plot, elevation, longitude, latitude, slope, and aspect was recorded (Appendix 2). The elevation was measured by using altimeter (Suunto), longitude and latitude by a portable GPS receiver (eTrex Vista, Garmin) and slope and aspect by compass (Sunto).

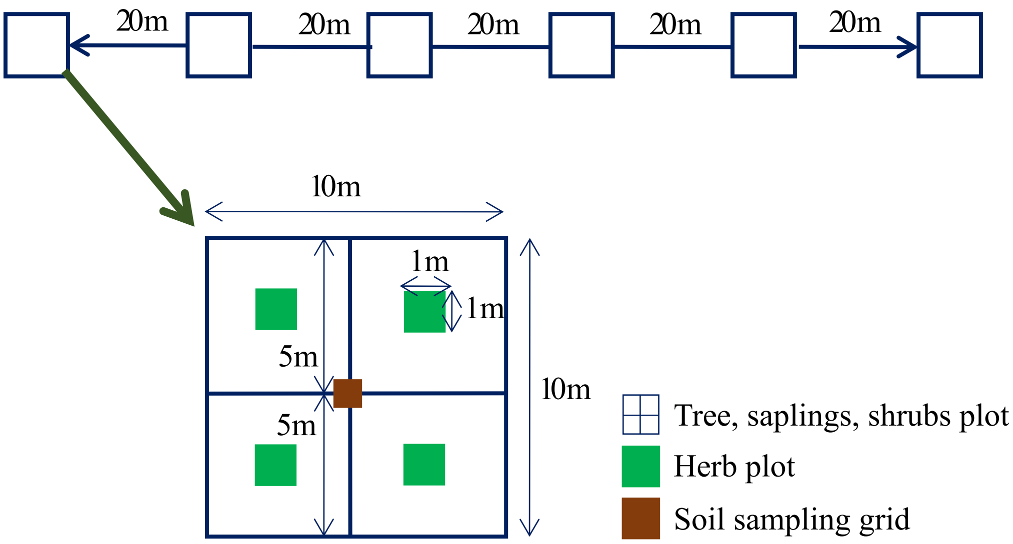

Figure 6: Sampling design in Chamelia valley.

3.2.2 Vegetation sampling

On the basis of diameter at breast height (DBH) and height (H) of the individual, plant species were categorized into: tree (≥10 DBH and H ≥1.3 m), saplings (< 10 cm DBH and H >1.3 m) and seedlings (H<1.3 m) (Newton, 2007). The tree species were recorded in the entire 20 m×25 m plot. DBH of each individual tree was measured at 1.3 m height from the ground using Million diameter tape (YAMAYO) (Figure 7) and its height with a Vertex IV (Haglof Sweden) (Figure 7). The tree crown diameter was measured from 2 times the mean of the four crown radii (north, south, east and west). The crown radii were measured four cardinal directions from ground projections of crown edge to the stem centre, with the person viewing the edge of the canopy standing perpendicularly to the line to the bole (Pretzsch *et al.*, 2015). The number and percentage cover of shrubs were recorded in six 5 m×5 m sub-quadrats, four of which were fixed at the corners of the tree plot and two at the center. Similarly, six 1 m×1 m sub-sub quadrats nested within the sub-quadrat, were used to record herbaceous vegetation. The number of herb species and an ocular estimate of their percent cover were recorded.

Data on trees species composition along Chamelia Valley were recorded in the 10 m×10 m quadrat, shrubs on 4 smaller sub-quadrats of size 5 m×5 m and herbs in the centre of each sub-quadrat within smaller sub-subquadrats of size 1 m × 1 m (Figure 6). Newton (2007) was followed to categorize tree, saplings and seedlings habits. DBH of each individual tree was measured using Million diameter tape (YAMAYO) and its height with a clinometer (Sunto) (Figure 7). The number of seedlings and saplings of tree species observed in the quadrat was counted and recorded. The presence and absence of different species of herbs and shrubs were recorded.

Figure 7: Measurement of DBH and height of tree.

3.2.3 Anthropogenic variables

The anthropogenic variables recorded in this study were: grazing, trampling, cutting, lopping, and fire. They were visually estimated in each studied plot/quadrat on scale ranging from 0 (no visible sign of disturbance) to 3 (nearly 100% disturbance).

3.2.4 Plant collection and identification

Standard Floras and botanical field guides such as Polunin & Stainton (2000); Stainton (1997) were used to identify plants in the field. Unidentified plant specimens were collected and maintained by following Forman & Bridson (1989). They were identified with the help of available literature (Polunin & Stainton, 1984; Sharma & Kachroo, 1983; Watson *et al.*, 2011) and by consulting herbarium specimens housed at Tribhuvan University Central Herbarium (TUCH) and National Herbarium and Plant Laboratory (KATH). Press *et al.* (2000) was followed for nomenclature of plant species.

3.2.5 Climatic data

Temperature and precipitations were the climatic data used in this study. These were obtained from WorldClim version 1.4 (http://www.worldclim.org) (Hijmans *et al.*, 2005), and categorized as annual precipitation and annual temperature for the analysis.

3.2.6 Soil sampling and analysis

Soil samples were collected from the top 20 cm of surface soil from a 20cm×20cm grid that was set up at the center of each quadrat. The collected soil samples were stored in zip-lock plastic bags (Carter & Gregorich, 2007) and transported to Kathmandu where they were air dried and sieved through a 2 mm mesh. Soil chemical analysis was carried out in Soil and Water Analysis Laboratory, Kathmandu University, Dhulikhel, Nepal; and Soil Science Division, National Agriculture Research Council, Khumaltar, Laitpur, Nepal. The soil was analysed by following Pradhan (1996). Soil pH was measured by the Probe method; soil organic carbon (SOC) by dry combustion method; total nitrogen (N) by Kjeldhal method; available phosphorus (P) by modified Olsen's bicarbonate method; and available potassium (K) by Ammonium Acetate followed by Atomic Absorption spectrophotometer (AAS) method.

Figure 8: Soil sampling.

3.3 Statistical analysis

International Business Machine Corporation (IBM) Statistical Package for the Social Sciences (SPSS) 20 was used for data analysis of different community forests. The relationship between different community characteristics of forest and environmental variables was obtained by using Spearmen's rank correlation. Relationships between different community characteristics were obtained by linear regression analysis. The regression coefficients and equations were obtained through fitted line on the scattered plot, and F and p values were obtained through Analysis of Variance (ANOVA). Principal component analysis (PCA) was used to combine all the disturbance variables (grazing, trampling, cut, harvesting and fire) through dimension reduction process to obtain combined measure of disturbance. In broadleaved forest, two PCA factors were obtained explaining 74.1% of variance: PCA factor 1 (51.7% variance) explained grazing (0.833) and trampling (0.790) as main associated variables; and PCA factor 2 (22.4% variance) explained lopping (0.635) and cut (0.424) as associated variables. In chir pine forest, two PCA factors explained 56.5% of variance: PCA factor 1 (31.32% variance) explained grazing (0.841) and trampling (0.858) as main associated variables; and PCA factor 2 (25.23% variance) explained tree cut (0.807) and fire (0.734) as the main associated variables. In blue pine forest, two PCA factors explained 55.2% of variance: PCA factor 1 (35.25% variance) explained grazing (0.801) and trampling (0.851) as main associated variables, and PCA factor 2 (19.95% variance) explained tree cut (0.782), harvesting (0.517) and fire (0.539) as main associated variables.

Generalized linear model (GLM) was used to determine the effect of different environmental factors (soil pH, carbon, nitrogen, phosphorus and potassium) and forest type on species richness. In the model, species richness was used as a dependent variable and all environmental variables as independent variables. Here, Poisson distribution was assumed as data were not over-dispersed. To find out the variations within different significant variables, we used Tukey's post-hoc test. R 4.0.0 (R Development Core Team, 2019) was used to carry out all tests.

Multivariate analysis was executed by using Canoco 5.12 (ter Braak & Šmilauer, 2012) to determine the factors associated with species composition in different forest types. Since the gradient length was very long (4.09), canonical correspondence analysis (CCA) (Šmilauer & Lepš, 2014) was implemented to reveal the associations between species composition in different forest types and soil characteristics *viz.* soil pH, carbon, nitrogen, phosphorus and potassium. The significance of the predictors was tested by using Monte Carlo permutation test (n=499). The rare species was down weighted to reduce their effect on the results.

R statistical software (R Development Core Team, 2019) was used to analyze data obtained from elevation gradient. Species richness, abundance and composition were three terms to analyse the data. Plant species richness refers to the number of species in each quadrat. Abundance refers to occurrence of each species in four subquadrats in the scale of 0 (if absent from all subquadrats) to 4 (if present in all four subquadrats). Species composition refers the type of species encountered in each quadrat (Timsina et al., 2016). Spearmen's rank correlation was used to determine the relationships among different environmental variables. GLM was used to determine the effect of different environmental variables such as elevation, grazing, cutting, soil characteristics (pH, SOC, total N, P, K), annual precipitation and mean annual temperature on species richness. In the model, we first determined the effect of elevation and if found significant, it was used as covariate in subsequent analyses.

Patterns in plant species composition in different elevational bands were analysed by using non-metric multidimensional scaling (NMDS) ordination method. NMDS was run to the whole samples by species data matrix by using the Bray-Curtis dissimilarity distance as a default. NMDS is an indirect gradient analysis that uses up to certain random numbers until the convergent value of stress obtained. NMDS ordination was implemented through the package 'Vegan' with a function "metaMDS" (Oksanen *et al.*, 2019). Significant environmental variables were over-fitted into the model. Final NMDS result with sample plots of varied abundance sample scores were fitted with significant environmental variables by using gg (Grammer of Graphics) plot2 package (Wickham, 2016).

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 Floral diversity

There were altogether 97 species of vascular plants recorded in three community forests. Sixty-three species of plants belonging to 40 families and 59 genera were reported in broadleaved forest (Appendix 3). Based on life form, 14 species were tree, 18 shrubs and 31 were herbs. There were altogether 31 plant species belonging to 28 genera and 20 families in chir pine forest (Appendix 4), and 38 plant species belonging to 37 genera and 20 families in blue pine forest (Appendix 5). Based on the life form, 22 herbs, four shrubs and five trees were recorded in the chir pine and 20 herbs, 13 shrubs and five tree species were in blue pine forest.

In total, we recorded 231 plant species consisting of 158 herb species belonging to 55 families, 37 shrub species belonging to 22 families and 36 tree species belonging to 23 families (Appendix 6) along Chamelia Valley. The most species rich family were Asteraceae and Rosaceae represented by 15 species each, and largest genus included *Acer*, *Anemone*, *Arisaema*, *Rhododendron*, *Swertia* and *Viburnum* each represented by three species.

4.1.2 Species richness and abundance

Species richness of plants in different forest types in this study are presented in Figure 9. Plant species richness was recorded highest in broadleaved forest followed by blue pine and chir pine forests. The mean species richness values broadleaved forest, blue pine forest and chir pine forest were 15, 10, and 5 per 500 square meters, respectively.

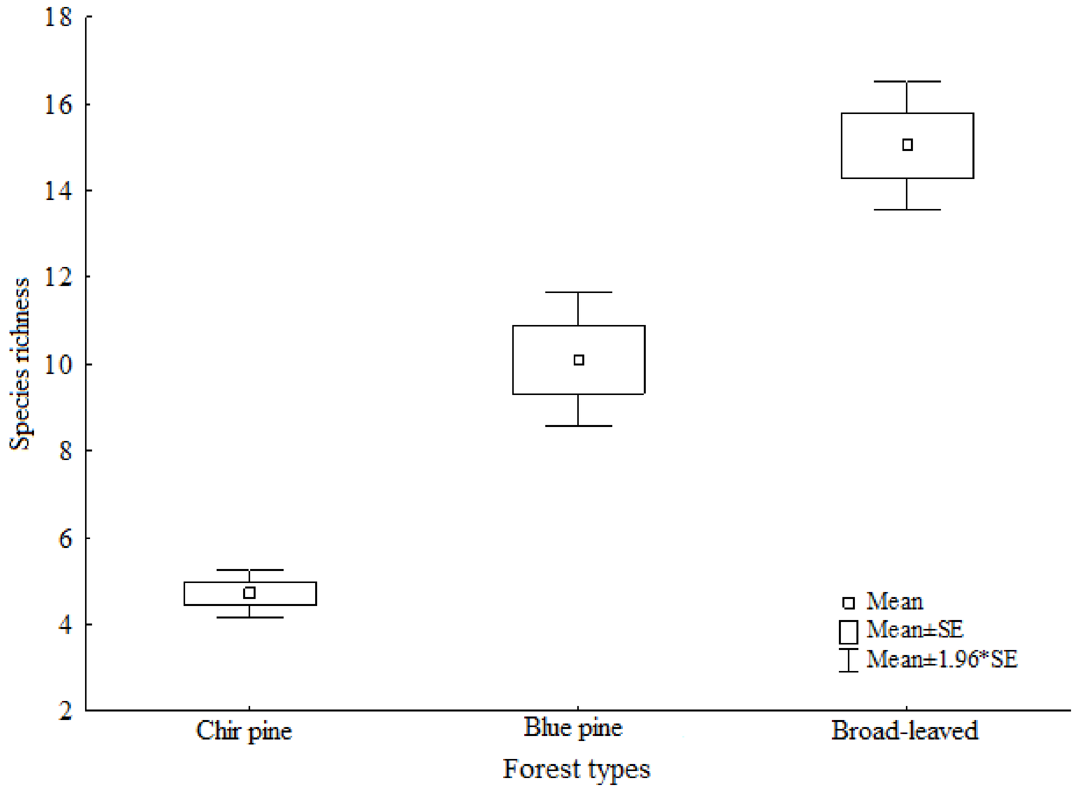

Figure 9: Species richness in different forest types.

The species richness and abundance of vascular plant along the elevation gradient revealed hump shaped (Unimodal) pattern (Figure 10). However, at the real observation the highest vascular plant species richness was at 2,500 m asl and species abundance at 2,300 m asl (Figure 10).

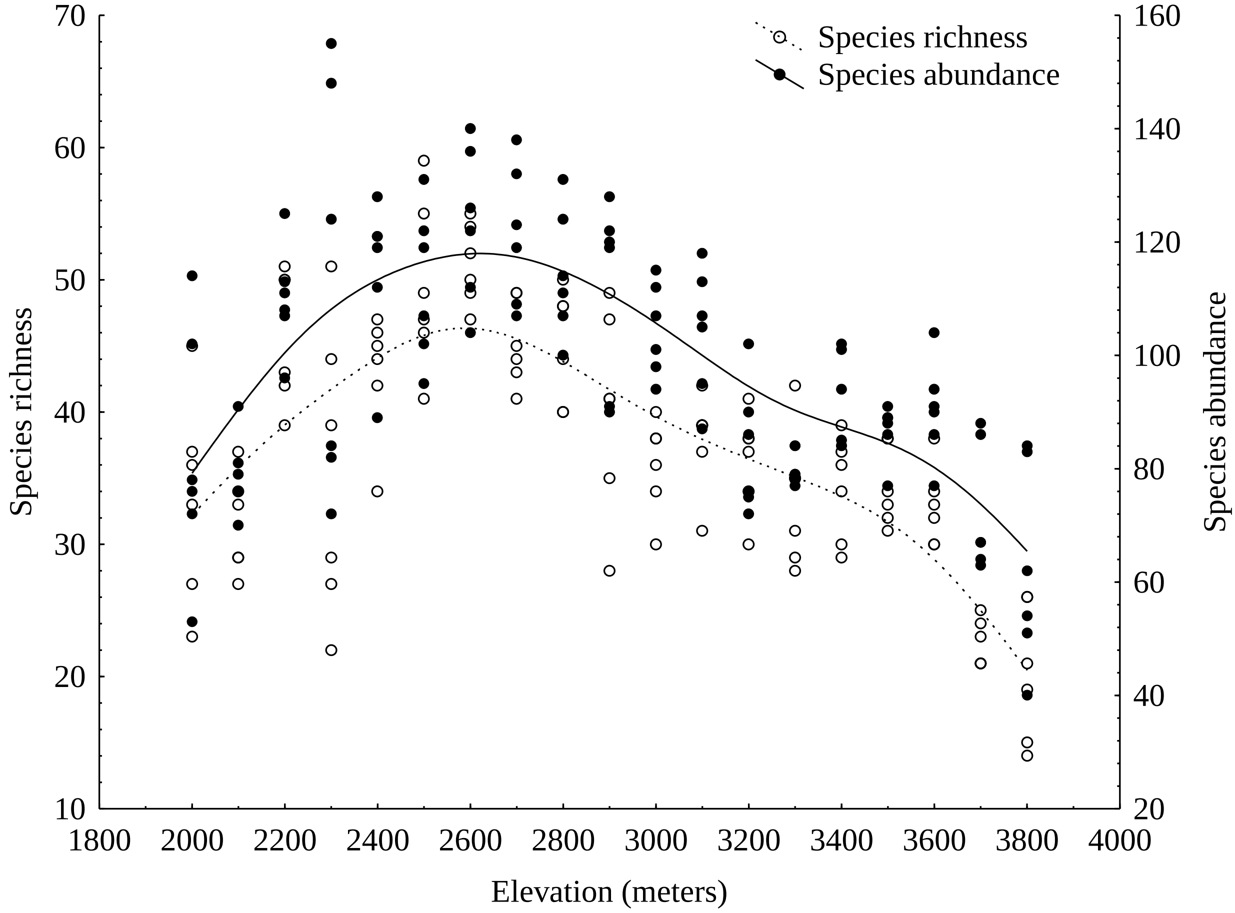

Figure 10: Relationship between species richness and species abundance of vascular plant species with elevation.

4.1.3 Role of environmental factors on species richness and abundance

The relationship between species richness of associated plant species with different forest types and soil characteristics is presented in Table 2. A significant relationship was found between species richness and soil pH ($R^2 = 0.710$, p = <0.001). On the other hand, there was no significant relationship between species richness and other soil characteristics such as carbon, nitrogen, phosphorus and potassium.

Table 2: Results of generalized linear model (GLM) and canonical correspondence analysis (CCA) to show the relationships between species richness and composition of associated plant species with forest types, soil pH, carbon, nitrogen, phosphorus and potassium.

	Df	Species richness		Species composition	
		p-value	R^2	p-value	R^2
pH	1	**<0.001**	0.710	**0.002**	0.126
Carbon	1	0.817	-	**0.002**	0.096
Nitrogen	1	0.350	-	**0.002**	0.064
Phosphorus	1	0.113	-	**0.002**	0.033
Potassium	1	0.803	-	**0.002**	0.042
Forest type	2	0.583	-	**0.002**	0.230

Table 3: Results of generalized linear model (GLM) showing the relations of different environmental variables with species richness and species abundance. Significant p-values are marked by bold type face.

	Df	Species richness		Species abundance	
		p-value	R^2	p-value	R^2
Elevation	1	**<0.001**	0.224	**<0.001**	0.161
Grazing	3	0.543	-	**<0.001**	0.048
Cutting	3	**0.029**	0.033	**<0.001**	0.036
pH	1	0.572	-	0.402	-
Carbon	1	0.259	-	0.851	-
Nitrogen	1	0.164	-	**0.043**	0.007
Phosphorus	1	0.092	-	**0.01**	0.012
Potassium	1	0.057	-	**0.016**	0.01
Annual precipitations	1	**0.031**	0.017	**0.004**	0.015
Mean annual temperature	1	**0.001**	0.043	**<0.001**	0.033

The increase in intensity of vegetation cutting significantly increased species abundance (Figure 11). The species abundance also significantly increased with soil nutrients, annual precipitation and mean annual temperature (Table 3). On the other hand, it decreased with increasing grazing intensity (Figure 12).

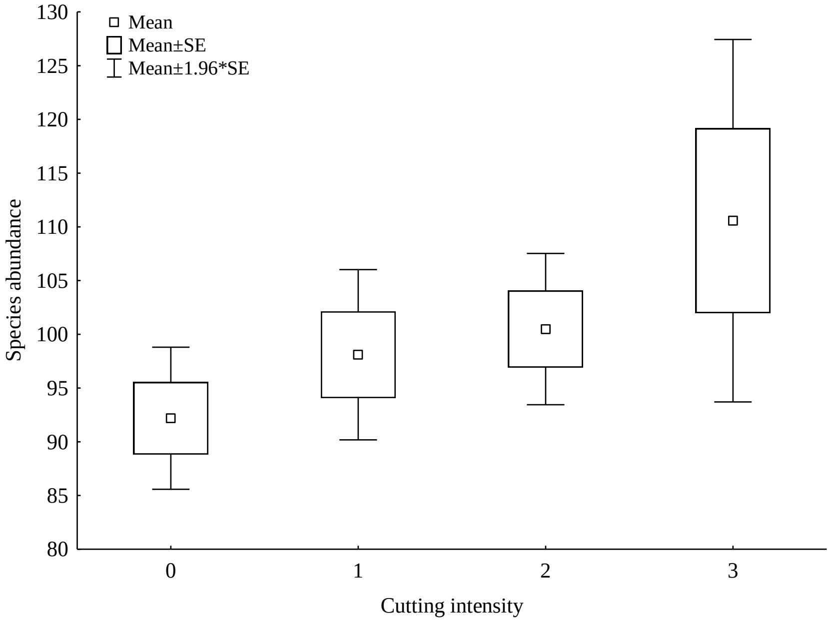

Figure 11: Relationship between species abundance of vascular plant species and cutting intensity.

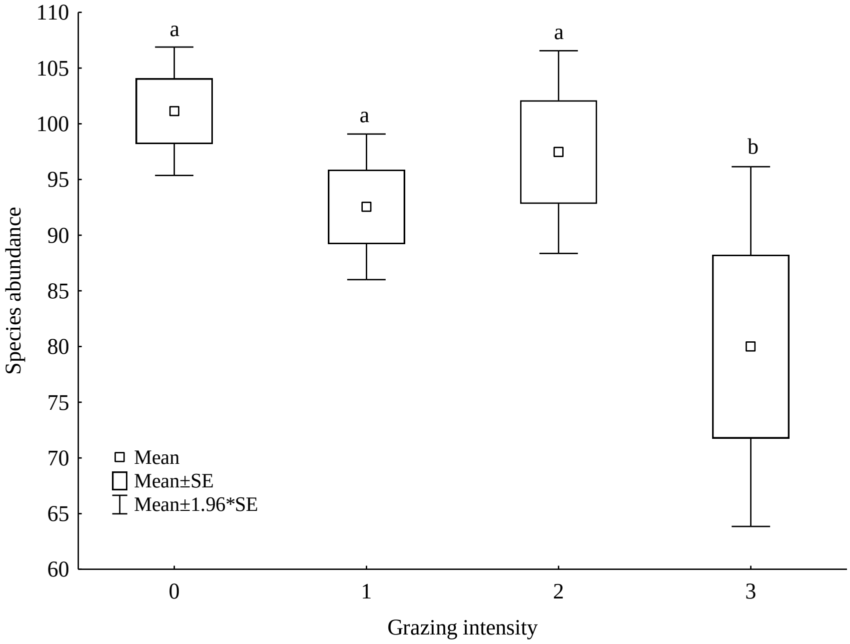

Figure 12: Relationship between species abundance of vascular plant species and grazing intensity.

4.1.4 Species richness pattern along elevation gradient

The plant species richness pattern of different life forms of plants and total species richness along elevational gradient is presented in Figure 13. Species richness pattern of herbs, tress and all plants exhibited unimodal (hump shaped) pattern [The R squared values were found to be 0.83(for herbs), 0.63(shrubs), 0.93(trees), and 0.93(all plants)]. The highest number of species was recorded in 2,500- 2,700 m asl elevation band.

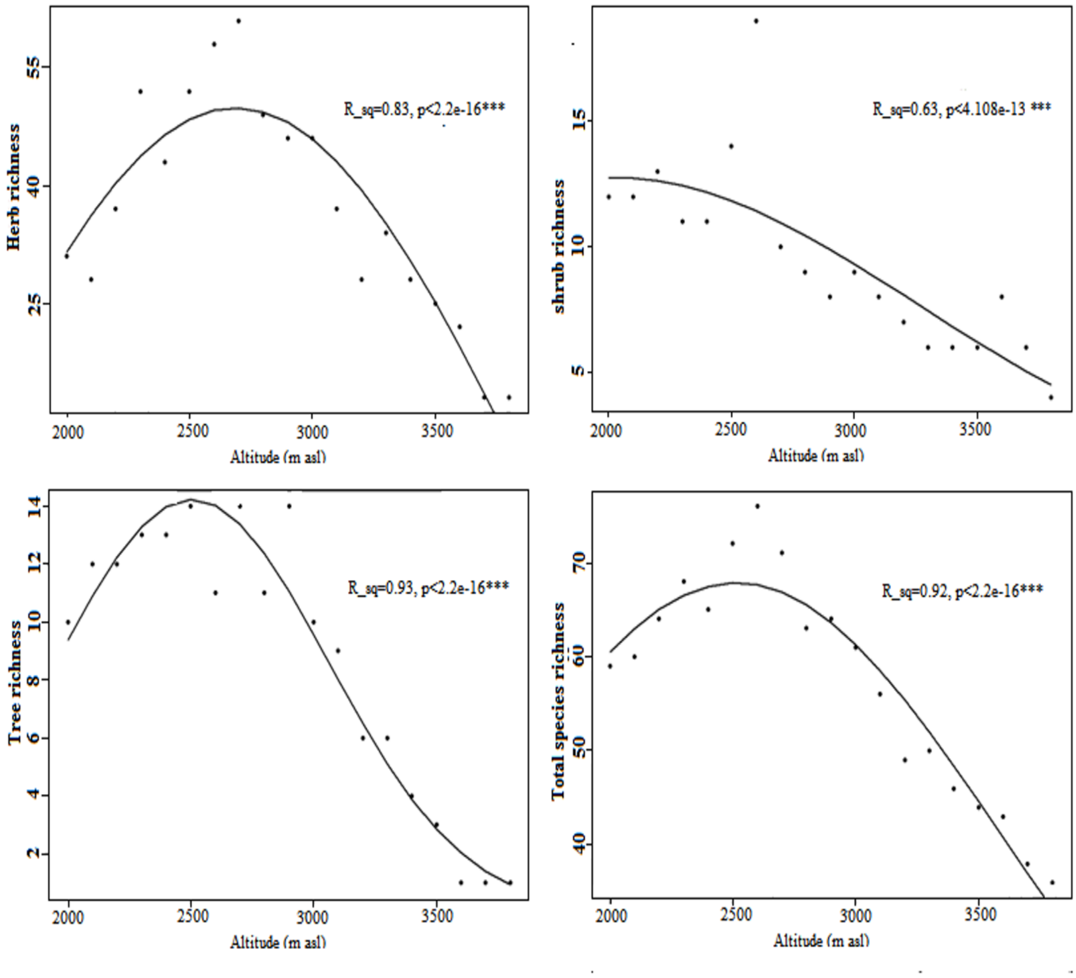

Figure 13: Species richness pattern along elevational gradient.

4.1.5 Species composition

The relation of different vascular plant species and their composition in different forest types is presented in Figure 14 (see also appendices 3, 4, and 5 for details). There were distinctly different plant species associated with different forest types. *Quercus lanata*, *Lyonia ovalifolia*, *Pyrus pashia*, *Ilex dypyrena*, *Carpinus betulus*, *Rhododendron arboreum*, *Eurya acuminata*, *Symplocos pyrifolia* were the major tree species in the broadleaved forest. The shrub layer was mainly comprised of *Daphne papyracea, Jasminum humile, Smilax aspera, Indigofera atropurpurea, Rosa macrophylla, Viburnum mullaha, Berberis aristata, Hypericum uralum, Cotoneaster firgidus, Pyracantha crenulata*, and *Spiraea bella*. The ground vegetation mainly included *Ophiopogon intermedius, Galium asperifolium, Viola pilosa, Strobilanthes capitata*, *Goodyera biflora*, *Rubia manjith*, *Oplimensus compositus*, *Lysimachia congestiflora*, *Anaphalis busua*, and *Oxalis corniculata*.

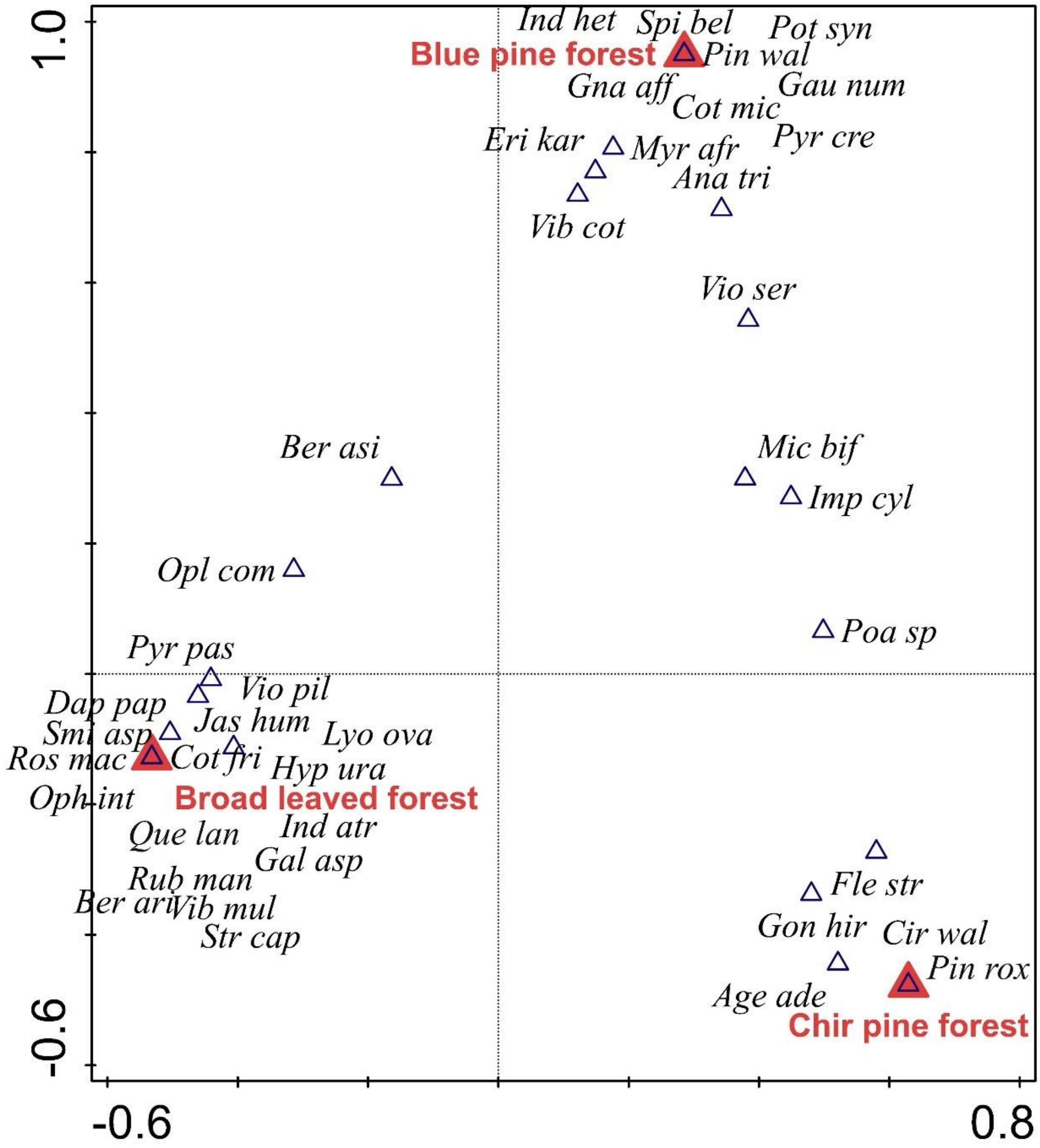

Figure 14: Relationship between different species in forest types. The 1st canonical axis explained 18.98 % and the 2nd 11.56 % of the total variation in the data set (see annexes 3, 4, and 5 for abbreviation).

P. wallichaiana, *Lyonia ovalifolia* and *Symplocus paniculata* were tree species reported in the blue pine forest. *Cotoneaster microphylla, Spirella bella*, *Potentilla sundaica*, *Indigophera heterophylla*, *Pyracantha crenulata*, *Myrsine africana*, *Rubus ellipticus*, *Daphne paparacea*, *Smilax aspera*, and *Viburnum erubescens* were some common shrubs. The ground vegetation was mainly comprised of *Gnaphallium affine*, *Gaultheria nummularioides*, *Centella asiatica*, *Erigeron karvinskianus*, *Myrsine* *africana*, *Fleminga strobilifera*, *Imperata cylindrica*, *Galium elegens*, *Gonostegia hirta*, *Micromeria biflora*, *Origanum vulgare*, *Oxalis corniculata*, and *Viburnum cotinifolium*.

The chirpine forest comprised of *P. roxburghii*. The understory of this forest was poor as compared to other forests. *Berberis asiatica*, *Hedysarum kumaonense*, *Rubus paniculatus* and *Rubus ellipticus* were shrub species and *Flemingia strobilifera*, *Gonostegia hirta*, *Ageratina adenophora*, *Anaphalis busua*, *Commelina benghalensis*, *Erigeron karvinskianus*, *Galium elegans*, and *Cirsium wallichii* were herb species found in the forest.

4.1.6 Role of environmental factors on species composition

The species composition in different types of forests was significantly influenced by soil characteristics, *viz.* pH, carbon, nitrogen, phosphorus, and potassium (Table 2, Figure 15). Most of the plant species preferred sites with high carbon, nitrogen and phosphorus content of the soil. Plants growing in such sites were *Berberis aristata*, *Oplismenus compositus*, *Smilax aspera*, *Rubia manjith*, *Indigofera atropurpurea*, *Viburnum mullaha*, *Daphne papyracea*, *Ophiopogon intermedius*, *Jasminum humile*, *Viola pilosa*, *Hypericum uralum*, *Galium asperifolium, and Cotoneaster frigidus.* Species like *Cirsium wallichii*, *Ageratina adenophora*, *Flemingia strobilifera*, *Gonostegia hirta* preferred high soil pH. Plant species, such as *Pyracantha crenulata*, *Cotoneaster microphyllus*, *Indigofera heterantha*, *Myrsine africana*, *Erigeron karvinskianus*, *Spiraea bella*, *Potentilla sundaica*, and *Gaultheria nummulariodes* preferred high potassium content of the soil.

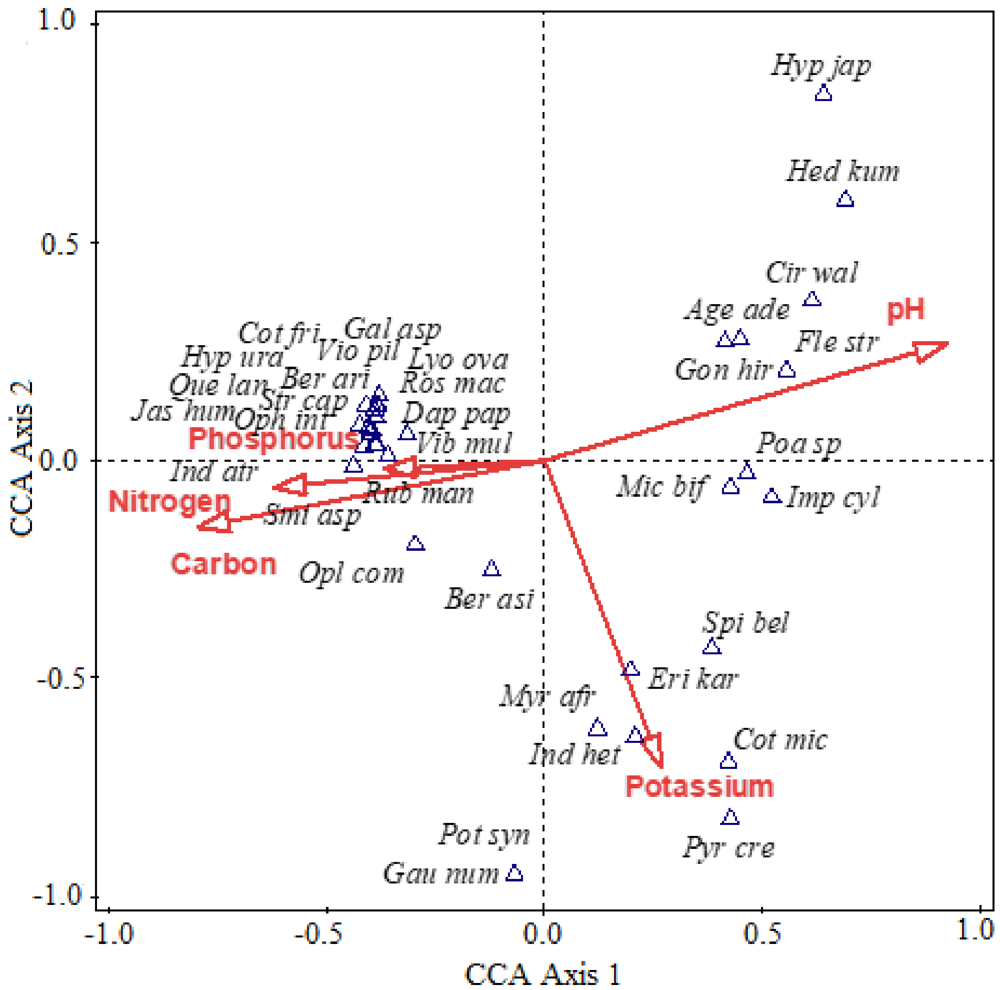

Figure 15: Relationship between different and significant environmental factors. The 1st canonical axis explained 14.23 % and the 2nd 5.21 % of the total variation in the data set (see Annexes 3, 4, and 5 for abbreviations).

The stress value of 0.2 on the whole sample by species dataset from elevation gradient was obtained to confirm convergence of NMDS ordination. The vector fitting of environmental variables on species dataset revealed that elevation, mean annual precipitation, annual temperature, and grazing were significant along elevation gradient (Table 4, Figure 16). High NMDS1 score value of 0.967 ($p< 0.001$, $R^2 = 0.93$, Table 3) was governed by elevation. Mean annual temperature and annual precipitation were significantly negative with the NMDS1 ($p=0.001$, $R^2 = 0.906$ and $p=0.001$, $R^2 = 0.868$ for both variables, respectively). The compositional abundance of plant species was high towards the high annual precipitation and high amount of mean annual temperature gradients at lower elevations (negative end of NMDS1). High compositional abundance of fewer species towards high elevation (positive end of NMDS1). Compositional abundance of small number of species was high abundance at negative end of NMDS2 which was a grazing gradient (p=0.039, R2 = 0.060). On the other hand, the compositional abundance was high towards positive end of NMDS2 i.e plots with no grazing and cutting (Table 4, Figure 16).

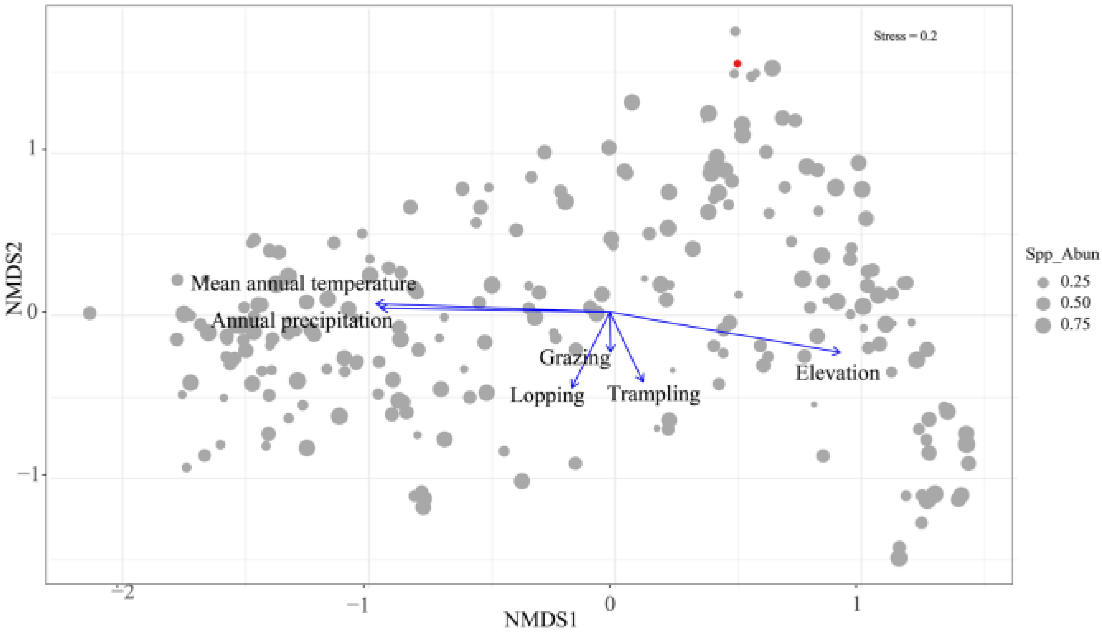

Figure 16: Effect of different environmental variables on composition of all plant species analysed by NMDS. Only significant variables are shown in the figure.

Table 4: Results of vector's fitting environmental variables on the samples by species dataset. Bold marked values are significant.

Variables	NMDS1	NMDS2	p-value	R^2
Elevation	0.967	-0.256	**0.001**	0.935
Grazing	0.011	-1.000	**0.039**	0.060
Cutting	-0.962	0.274	0.053	-
pH	-0.299	0.954	0.782	-
Carbon	0.995	0.096	0.939	-
Nitrogen	-0.140	-0.990	0.677	-
Phosphorus	-0.311	0.950	0.243	-
Potassium	0.905	-0.425	0.063	-
Annual precipitations	-1.000	0.026	**0.001**	0.868
Mean annual temperature	-0.999	0.054	**0.001**	0.906

4.1.7 Forest Structure

The DBH and height distribution revealed different shape in different type of forests (Figure 17and Figure 18). The proportions of small-sized tree individuals were high and that of greater size trees were low in broadleaved forest indicating inverse J-shaped distribution. On the other hand, the proportion of medium-sized tree were high and proportion of small and large-sized individuals were low in blue pine and chir pine forests indicating unimodal type (hump-shaped) distribution.

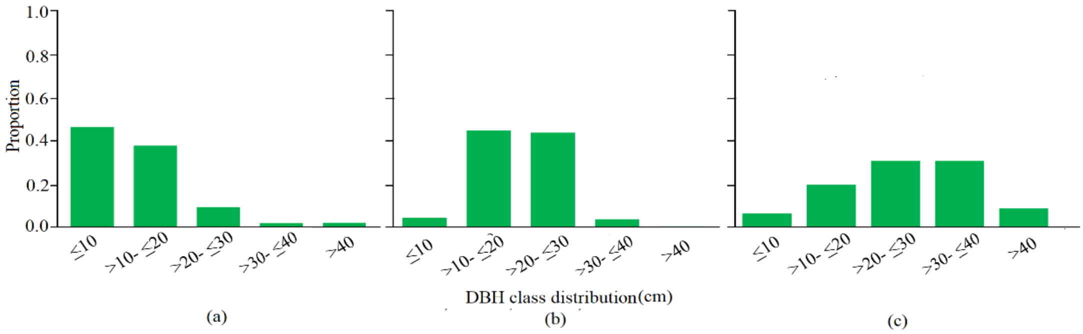

Figure 17: DBH class distribution of different community forests: (a) Broadleaved forest, (b) Chir pine forest, and (c) Blue pine forest.

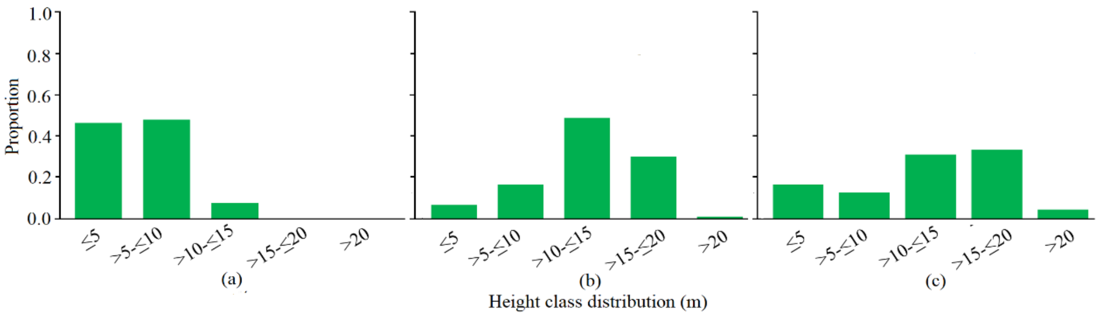

Figure 18: Height class distribution of different community forests: (a) Broadleaved forest, (b) Chir pine forest, and (c) Blue pine forest.

The DBH and height class distribution of forest along elevation gradient in Chamelia Valley is presented in Figure 19 and Figure 20 respectively. Both DBH and height class distribution showed inverse J shaped structure having greater proportion of small size individuals. It also showed that there was gradual decrease in number of tree individuals with high DBH and height class along lower to higher elevation.

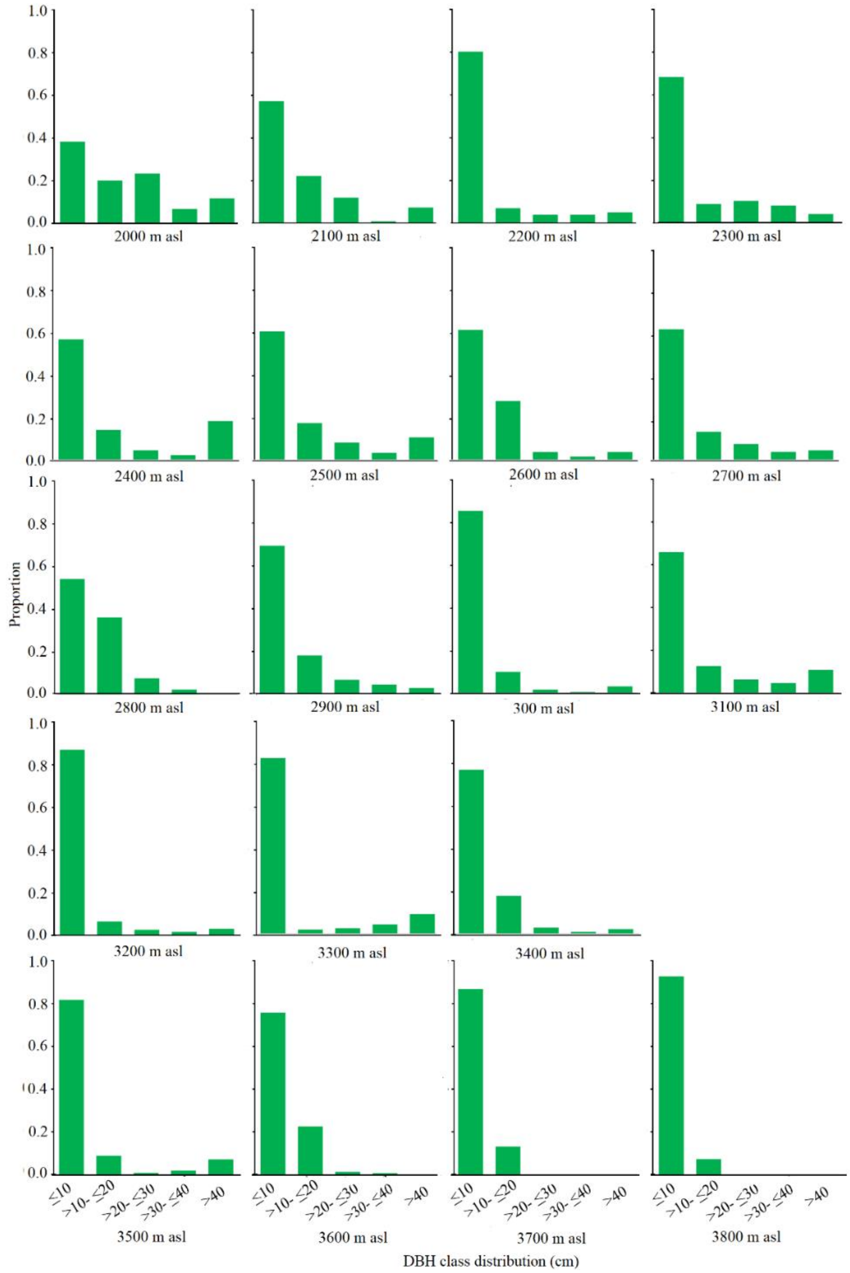

Figure 19: DBH class distribution of trees along elevational gradient.

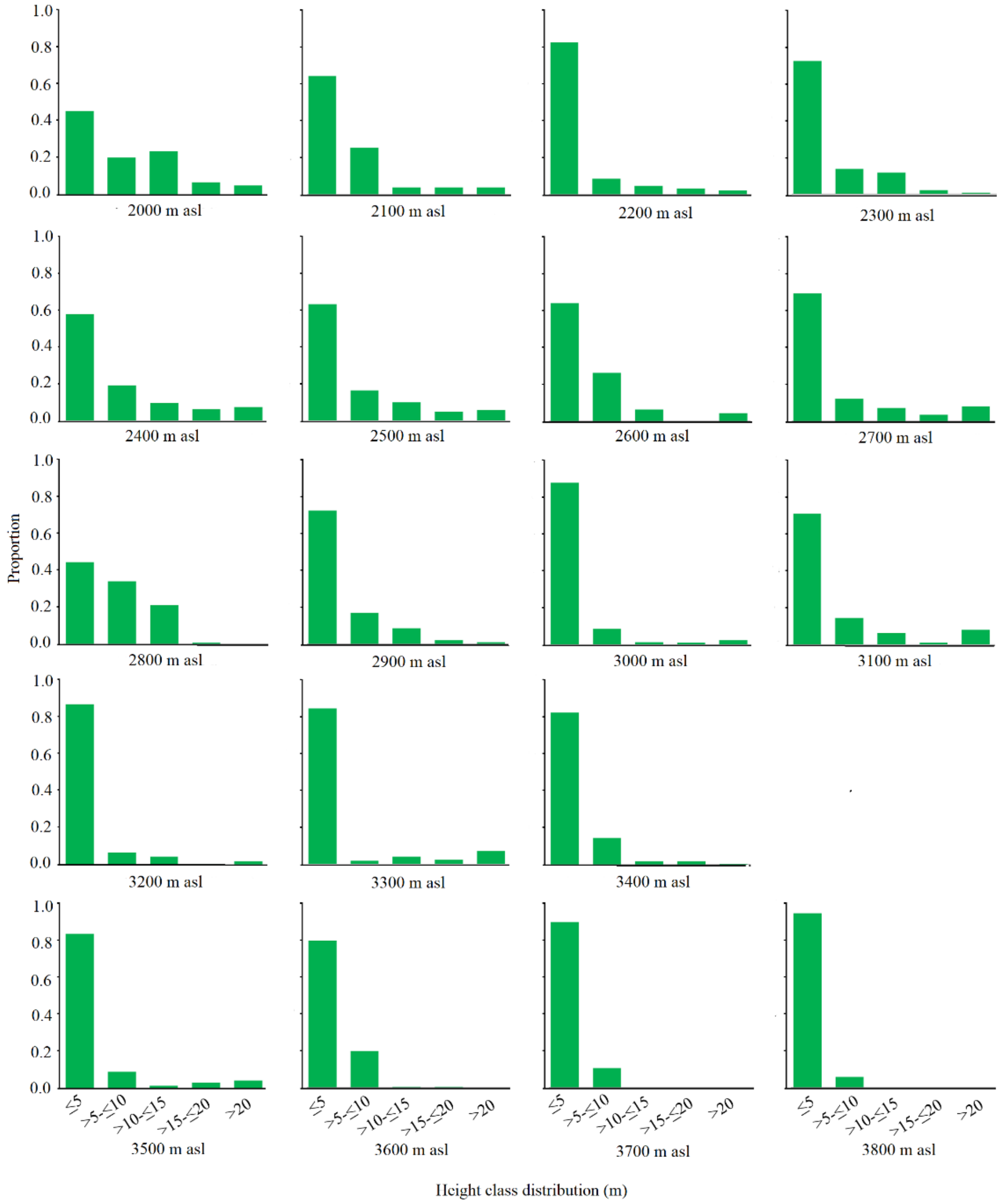

Figure 20: Height class distribution of trees along elevational gradient.

4.1.8 Forest community characteristics

The community characteristics of different forests are presented in Table 5. The density of tree species was high in broadleaved forest (328/ha) followed by blue pine forest (168.5/ha) and chir pine forest (65/ha). On the other hand, the mean DBH and height were high in pine forests than broadleaved forests. The mean canopy diameter was also high in pine forests than broadleaved forest. The top canopy of the forest was higher in broadleaved forest than in pine forest. Mid forest canopy was higher in blue pine forest followed by broadleaved forest and chir pine forest. Low canopy was higher in pine forests than in broadleaved forest.

Table 5: Community characteristics of different forests (Main enries are mean value with standard error in parentheses).

Variables		Broadleaved forest	Chir pine forest	Blue pine forest
Number of tree species		4.83(0.30)	1.60(0.31)	2.00(0.45)
Tree density (number/ha)		328(26.02)	65(3.73)	168.5(7.15)
DBH (cm)		15.21(1.38)	23.99(1.78)	31.02(4.70)
Height (m)		5.98(0.79)	12.77(0.83)	11.49(1.02)
Mean canopy diameter (m)		1.23(0.11)	1.97(0.19)	2.8(0.15)
Canopy (%)	Top	60.61(2.96)	27.03(3.36)	32.75(3.31)
	Mid	13.75(1.41)	4.25(o.60)	16.50(1.96)
	Low	10.03(0.60)	14.59(1.18)	12.00(2.61)

4.1.8.1 Relationship between different forest community characteristics

The correlation between different community characteristics and disturbances of broadleaved forest is presented in Table 6. There was positive correlation between mean height with number and mean DBH of trees. Positive correlations were also established between canopy diameters and mean DBH and mean height of trees. The top canopy diameter was positively correlated with number of trees. The disturbance factor 1 (grazing and trampling) was negatively correlated with mid canopy and positively with low canopy. The disturbance factor 2 (cutting and looping) positively correlated with number of trees and disturbance factor 1and negatively with mid canopy.

Table 6: Correlation analysis among community characteristics and disturbances in broadleaved forest.

	No. of tree	Mean DBH	Mean Height	Canopy diameter	Top canopy	Mid canopy	Low canopy	Disturbance factor 1
No of tree	1							
Mean DBH	0.086	1						
Mean Height	**.364****	**.594****	1					
Canopy diameter	0.065	**.752****	**.727****	1				
Top canopy	**.304****	-0.025	0.152	-0.034	1			
Mid canopy	-0.074	0.025	-0.067	-0.024	-0.03	1		
Low canopy	-0.041	-0.076	0.06	0.058	-0.089	0.178	1	
Disturbance factor 1	0.068	-0.082	0.142	0.106	-0.08	**-.383****	**.204***	1
Disturbance factor 2	**.287****	-0.037	0.145	-0.087	0.121	**-.274****	-0.07	**.416****

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

The correlation between different community characteristics of chir pine forest and disturbances are presented in Table 7. There was negative correlation between density of pine with mean DBH and canopy diameter. On the other hand, the density of pine positively correlated with disturbance factor 2 (fire and cut). There was positive correlation between mean DBH and canopy diameter. The mean height was negatively correlated with top canopy and positively with disturbance factor 1 (grazing and trampling). The canopy diameter was negatively correlated with disturbance factor 2 (cut and fire).

Table 7: Correlation analysis among community characteristics and disturbances in chir pine forest.

	Density of pine	Mean DBH	Mean height	Canopy diameter	Top canopy	Mid canopy	Low canopy	Disturbance factor 1
Density of pine	1							
Mean DBH	**-0.872****	1						
Mean height	-0.248	0.347	1					
Canopy diameter	**-0.770****	**0.841****	0.276	1				
Top canopy	0.469	-0.28	**-0.695***	-0.239	1			
Mid canopy	-0.032	-0.13	0.055	0.087	-0.055	1		
Low canopy	-0.524	0.439	-0.187	0.622	-0.113	0.095	1	
Disturbance factor 1	-0.13	0.31	**0.846****	0.251	-0.505	-0.071	-0.319	1
Disturbance factor 2	**0.793****	-0.613	0.066	**-0.662***	0.436	0.063	-0.61	0.17

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

The correlation among community characteristics and disturbances in blue pine forest is presented in Table 8. The canopy diameter was negatively corelated with number of tree species. Negative relationship was also found with disturbance factor 1 and top canopy and positive relationship with low canopy.

Table 8: Correlation analysis among community characteristics and disturbances in blue pine forest.

	No of tree	Density of pine	Mean DBH	Mean height	Canopy diameter	Top canopy	Mid canopy	Low canopy
Density of pine	0.78	1						
Mean DBH	-0.81	-0.948	1					
Mean height	-0.645	-0.464	0.263	1				
Canopy diameter	**-0.987***	-0.758	0.838	0.515	1			
Top canopy	0.642	0.754	-0.919	0.107	-0.731	1		
Mid canopy	0.342	0.294	-0.018	-0.933	-0.185	-0.374	1	
Low canopy	-0.686	-0.751	0.921	-0.067	0.774	**-0.997****	0.352	1
Disturbance factor 1	-0.479	-0.71	0.867	-0.253	0.575	**-0.977***	0.464	**.959***

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

4.1.8.2 DBH and Tree height relationship

There was significant linear relationship ($p<0.001$) between DBH and height in different forest types (Figure 21). However, the value of R^2 (0.048 for broadleaved forest, 0.571 for chir pine forest and 0.551 for blue pine forest) differed with different forest types. The strength (in terms of R^2 values) of relationships was not so different among pine (blue pine and chir pine) forests. But the strength was weak in broadleaved forest as compared to pine forests.

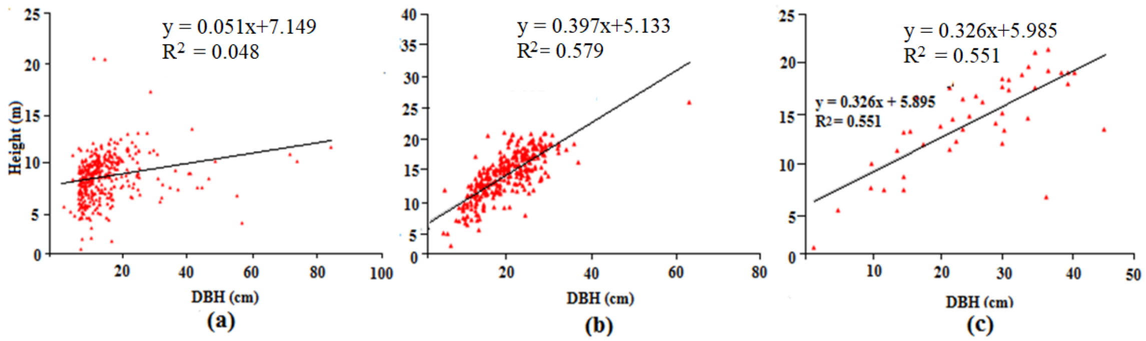

Figure 21: DBH and height relationship of different forests: (a) Broadleaved Forest, (b) Chir pine forest, and (c) Blue pine forest.

4.1.8.3 DBH and Tree crown diameter relationship

There was significant relationship between DBH and crown diameter in all forest types (Figure 21). However, the R^2 value obtained from regression between DBH and crown diameter varied with different forest types (0. 322 in broadleaved forest, 0.572 in chir pine, and 0.422 in blue pine forest.

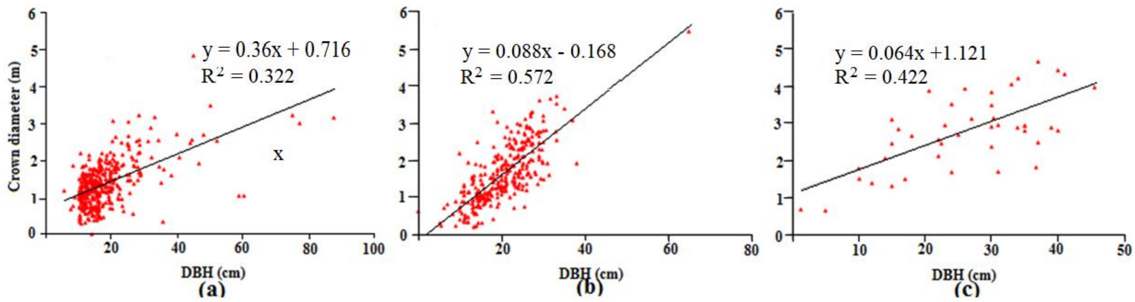

Figure 22: DBH and crown diameter relationship of different forests: (a) Broadleaved Forest, (b) Chir pine forest, and (c) Blue pine forest.

4.2 Discussion

4.2.1 Species richness

Present study demonstrated that species richness varies with different forests types in KSL Nepal. The species richness in a forest greatly varies between forest type. The species richness of vascular plants was greater in broadleaved forest as compared to both types of pine (chir pine and blue pine) forests. Wu *et al.* (2017) also reported that species richness was grater in broadleaved forest than in pine, and mixed forests in eastern China. It is also assumed that broadleaved forest provides more diversified vascular understories as compared to coniferous forest through modification of resources such as water and soil nutrients availability, sunlight, and characteristics of litter layer (Barbier *et al.*, 2008). Thus, pines are less favorable to understory vegetation thereby resulting in less species diversity. Pines are low nutrient demanding plants that enable them to outcompete high nutrient demanding broadleaved species in less fertile soil (Singh *et al.*, 2018) resulting in the monoculture development and inhibit the growth of other associated plant species in the forest. While comparing species richness, blue pine forest favors much species richness than chir pine forest. The invasive nature of chir pine encroaches other associated and understorey broadleaved plant species that lead to the development of pure stand (Bhandari, 2003; Khan *et al.*, 2014). It can also obtain more resources than other plant species of the community (Bargali, 1997). Chir pine promotes more fire. There is substantial loss of soil nitrogen after fire on the forest floor. The depletion of nitrogen in soil is one of the major causes of pure stand development of pine (Singh *et al.*, 1984). The pure stand development of pine is also revealed by phytosociological analysis (Siddiqui *et al.*, 2009). The fire on pine forest also deteriorates soil fertility and growth of other species by reducing the organic matter and soil nutrients such as potassium and phosphorus (Benerjee & Chand, 1981; Gholz & Fisher, 1982). Blue pine has tendency to share common habitat with other tree species as compared to chir pine (Bhandari, 2003) resulting in more species richness in blue pine forest in this study.

In this study, total species richness and richness of different life forms of plants (herbs, shrubs and trees) and abundance of vascular plants along elevation showed hump shaped pattern (mid elevation peak). This pattern corroborates with other studies carried out in Nepal and different parts of the world: Nepal Himalaya (Bhattarai & Vetaas, 2003; Grytnes & Vetaas, 2002), eastern Himalaya, India (Acharya *et al.*, 2011), eastern Himalaya, Bhutan (Kluge *et al.*,2017), in the Northern slopes of Qilianshan Mountains, Gansu, China (Wang *et al.*, 2002), Western Himalaya (Oommen & Shanker, 2005), Mount Kinabalu, Sabah, Borneo (Grytnes & Beaman, 2006), in the Gaoligong Mountains, south-east Tibet, China (Wang *et al.*, 2007), and Baekdudaegan Mountains, South Korea (Lee *et al.*, 2013). The mid elevation (highest richness) detail was varied with study sites (Baniya *et al.*, 2012). Different studies in Nepal showed that the species richness occurred highest between 1500 and 2500 m asl in Annapurna Conservation Area (Christensen & Heilmann-Clausen, 2009) and in Nepal Himalaya (Grytnes & Vetaas, 2002) and from 3,900-4,000 m asl in trans-Himalyan inner valley of Manang district, Central Nepal (Panthi *et al.*, 2007). However, few studies showed monotonic decrease pattern along elevation gradient in central India (Sahu *et al*., 2008), and Nepal Himalaya (Li & Feng, 2015; Rokaya *et al*., 2012). The hump shaped pattern peaked at mid elevation was the typical pattern (Rahbek, 2005). This study also indicates that the distribution pattern of vascular plant species along elevational gradient in west Nepal is partly represented by vascular plant species distribution pattern in Nepal. The mid elevation peak mainly brings due to mid domain effect that supports spatial constraint hypothesis (McCain & Grytness, 2010). The harsh climatic condition and unfavorable and rugged topography is accountable for the decrease in species richness towards high elevation (Rokaya *et al.*, 2012). The decrease in temperature and increased solar radiation (Körner, 2007), steep, rugged topography with little top soil (Miehe *et al.*, 2015), and less soil fertility (Drollinger *et al.*, 2017; Halbritter *et al.*, 2018) were responsible to bring environmental harshness in high elevation.

4.2.2 Species richness and environment

In this study, species richness in different forest types were highly influenced by pH and soil nutrients. Species richness decreased with the increase of pH value. Both very high and very low pH value has negative effect on species richness. Palmer *et al.* (2003) found that there was negative relationship between species richness and soil pH. Soil pH has negative correlation with the nutrient content of the soil (Wang *et al.*, 2010). Composition of soil microbial community is the function of soil pH (Alexander, 1991; Wang *et al.*, 2010). The activities of microbial community (decomposers) are less on soil with high pH value. Thus, soil with high pH has inhibitory effect on decomposition process and formation of soil nutrients. Negative relationship between pH and species richness in this study is most probably due to deficient of soil nutrients for the growth of ground vegetation. On the other hand, species richness increased with increased value of carbon in the soil. Carbon, nitrogen, phosphorus, and potassium are attributes of humus content of soil, and there is positive correlation between carbon with other nutrients in forests of Himalayan region (Aber & Melillo, 2001; Gairola *et al.*, 2012; Wang *et al.*, 2010). Thus, the more nutrient content in the soil resulting more species richnes in the present study. However, other soil characteristics such as moisture content, texture and cation exchange capacity could not be anaysed which was the limitation of the present study.

The species diversity increased with increasing cutting. The partial cutting of trees and shrubs in forest enables understorey vegetation to expose to sunlight resulting vigorous growth (Abella & Springer, 2015). On the other hand, the cutting at the larger scales has negative impact on diversity of plants (Santaniello *et al.*, 2016).

Decreased species abundance with increasing grazing level has also been reported from arid conditions of the world and not in moist conditions (de Bello *et al.*, 2007). The present study site falls under montane belt of the Himalaya characterized by moderate warmth and higher humidity. The study site was also en route to summer pastureland where herders let their animals graze for a few days while moving up during May and down during September. There is practice of movement of domestic animals to pastures of different elevation following seasonal calendar (high elevation during summer and low elevation during winter) in Limi Valley of Humla District (Basnet & Chaudhary, 2017) and in Manang, trans-Himalaya, Nepal (Chaudhary *et al.*, 2007). Since most of the vascular plant species were in budding stage during May, the high intensity of grazing may have serious effect on seed formation. It has also been reported that grazing limits the formation of plant buds, and long-term grazing exclusion in an area significantly increases the bud formation (Zhao *et al.*, 2019). Our study did not support the intermediate disturbance hypothesis as there is no maximum species diversity in neither undisturbed nor highly disturbed sites (Fox, 2013). This is probably due to different grazing or cutting patterns in our study site than where actual theory was tested (Bongers *et al.*, 2009). People have been practicing traditional system of grazing following seasonal calendar in our study site similar with other mountainous part of Nepal (Basnet & Chaudhary, 2017; Chaudhary *et al.*, 2007). The plant diversity and community composition are affected by soil nutrients (Gilliam & Dick, 2010; Lin *et al.*, 2013). In the present study, the increased phosphorus, potassium and nitrogen decreased the vascular plant species richness. However, the result corroborates with other studies in the case of phosphorus but not for potassium and nitrogen (Merunková & Chytrý, 2012; Wassen *et al.*, 2005). Bartels & Chen (2010) found that the herb richness was positively correlated with soil nitrogen and phosphorus. These dissimilarities might be due to variation in the physiography, sampling strategy, and climatic conditions between studied sites. However, plant diversity should significantly increase with increasing amounts of soil nutrients as high soil nutrients favour better plant growth (Denslow, 1987). Our results showing lower species richness in high nitrogen environment are quite surprising as nitrogen has positive effect on plant growth (Huston, 1980; Lawlor *et al.*, 2001). However, there was variation in loss of species richness in different British habitats (Maskell *et al.*, 2010) due to soil acidification associated with increased N deposition. The oxidation of NO_2 to NO_3^-or NH_4^+ to NO_3^- are formed acid. Having negative correlation of plant diversity and phosphorus is also due to phosphorus deposition leading to soil acidification (Maskell *et al.*, 2010).

4.2.3 Species composition

The preference of plant species differs with different forest types and soil properties. Species composition of forest is regulated by abiotic and biotic factors of the environment and their interaction (Barbier *et al.*, 2008; Gracia *et al.*, 2007; Halpern & Spices, 1995; Parker & Muller, 1979). The soil characteristics had significant role on species composition of different forest types. The soil chemical properties such as pH, carbon, nitrogen, phosphorus, and potassium influenced species composition of different forest types in our study. Carbon content of the soil strongly influence the plant species found in the broadleaved forest. This result is concurrent with the study of Zhang *et al.* (2007) in Zhejiang Province of China, and Semwal *et al.* (2009) in oak forest of central Himalaya India where they also reported that carbon content was higher in broadleaved forest as compared to pine forests. Since carbon is the main attribute of humus content of soil, the broadleaved forest has more humus as compared to pine forests so it may show strong correlation in broadleaved forest and their composition. On the other hand, species composition in chir pine forest was strongly correlated with soil pH. Chir pine forest prefers to grow on highly acidic soil (Semwal *et al.*, 2009). Thus, it showed strong correlation with pH value in our study. Species composition on blue pine forest showed strong correlation with potassium. Forest fire is common phenomenon in blue pine forests that damages understory composition and alter physical and chemical properties of soil. There was decrease in nutrient content (carbon and nitrogen) but potassium content was higher in burnt blue pine forest (Khaki *et al.*, 2015; Marafa & Chau, 1999). There was quite visible sign of forest fire in blue pine forest in this study which may lead to show strong correlation of potassium in forest composition in this study.

Elevation contributed highly to composition of plant species like that of other studies carried out in Nepal Himalaya *viz.* Christensen & Heilmann-Clausen (2009) in

Annapurna Conservation Area in mountainous region of Nepal; Panthi *et al.* (2007) in trans-Himalayan region of Manang District; and Timsina *et al.* (2016) in Central Nepal. The negative correlation of elevation with temperature and precipitation is similar to a study in Alxa plateau in China (Li *et al.*, 2009). Contribution of temperature and precipitation in shaping composition of vascular plant species was obvious because the present study was carried out in a site with high abundances of species where there was high mean annual temperature and annual precipitation. The variation in species composition was significantly affected by grazing. The grazing suppresses recruitment, survival and growth of plant species by modifying soil nutrition and soil seed bank (Khurana & Singh, 2001). However, in the present study soil nutrients did not affect species composition and ongoing anthropogenic disturbances are more important in shaping composition of vascular plant species along elevational gradient in west Nepal in general and Chamelia Valley in specific.

4.2.4 Forest structure

The population dynamics and management of forests are indicated by the size distribution of trees (Kohira & Ninomiya, 2003; White *et al.*, 2007). The DBH and height class distribution pattern in the present study was inverse J shaped and hump shaped (unimodal). Inverse J shaped was found in broadleaved forest and forests along the elevational gradient and hump shaped distribution pattern was found in pine forests. The inverse J shaped population distribution is formed by a greater number of small sized tree in the studied area and indicated regenerating forest (Bhat *et al.*, 2011; Khan *et al.*, 2014). Such type of distribution pattern was also reported in the forests of other parts of the Himalaya such as Kumaon Himalaya, Uttarakhand, India (Hussain *et al.*, 2010), northern Pakistan (Khan *et al.*, 2014), and Hindu Kush range of Pakistan (Siddiqui *et al.*, 2009) too. According to local people, the broadleaved forest was heavily degraded before 2050 BS (1993 AD). Later local people had begun to protect and restore it for sustainable utilization of forest resources through community forestry programme. Because of restoration more population of small sized trees may have reported in the forest that gives inverse J-shaped distribution pattern. On the other hand, the unimodal distribution pattern due to fewer juveniles than adults proportions exhibited disruptive regeneration most probably due to disturbance (Condit *et al.*, 1998; Deb & Sundrial, 2008; George *et al.*, 2005). Wangda & Ohsawa (2006) also reported unimodal distributionp pattern in *P. roxburghii* forest in Bhutan Himalaya due to natural and anthropogenic disturbances. On the other hand, forest of *P. wallichiana* in trans-Himalayan dry valley of Manang, Nepal showed inverse J-shaped distribution (Ghimire *et al.*, 2010). Both pine forests under this study are used by communities for extraction of timber, resin trapping in chir pine forest, and hence the preference is obviously for large-sized trees. The felling of large-sized trees destroyed seedlings and saplings and could possibly affected their regeneration. Thus, greater number of medium sized individuals and smaller number of juveniles and seedlings were found in the forest.

4.2.5 Forest community characteristics and their relationship

Tree density, DBH, height, canopy diameter and anthropogenic disturbance were considered as community characteristics of the forest in this study. There was positive correlation between mean height, mean DBH and canopy diameter in the broadleaved forests. Iizuka *et al.* (2017) also found similar type of result in Japan. Due to the linear relationship of these variables, it is used in the management, inventory, growth, and yield estimation of forest and also to predict the status of forest (Iizuka *et al.*, 2017; Li *et al.*, 2015). There was negative correlation between mid canopy and disturbance factors (Grazing, trampling, cutting, and lopping). The forest users were not allowed to harvest tree and their products but there is no restriction to graze their livestock. Thus, pressure on mid canopy vegetation that comprising shrubs through collection of fodder and cattle grazing is quite obvious. This may probably lead to less understory canopy in the forest. On the other hand, low canopy (comprising ground vegetation) was positively correlated with disturbance factor class 1 (grazing and trampling). The grazing and trampling by mammals increased species richness of vascular plant species by favoring growth of graminoids and herbaceous species (Eskelinen & Oksanen, 2006). The understory of the broadleaved forest in this study was also dominated by small herbaceous species and graminoids.

There was negative correlation between density of chir pine with mean DBH and canopy diameter but positive correlation exists with disturbance factor class 2 (fire and cut) in chir pine forest. Since people extracted large size trees for timber purposes, the density of high DBH class individuals is less in the forest. On the other hand, there was visible sign of fire on forest floor. Fire allows regeneration of seedlings in pine forest (Pausas *et al.*, 2004), and thus the density of smaller size trees was high. Usually, the canopy of trees is high with high DBH individuals. Due to this linear relationship, it is used to develop crown width model that has been used for predicting growth, biomass production, mortality rate, etc. in the forest (Sharma *et al.*, 2017). The positive correlation between disturbance and density in this study is supported by the fact that chir pine can tolerate more stress and potentially colonize disturbed and moisture deficient areas (Ryan *et al.*, 1997; Singh & Singh, 1992). When cones are exposed to fire, seeds are liberated. The liberated seeds regenerate and helps to monospecific stand development of *Pinus halepensis* in Iberian Peninsula, eastern Spain (Moya *et al.*, 2007; Pausas *et al.*, 2004). The fire also contributed in the natural recovery of *Pinus yunnanensis* thereby contributing to the density of pine in central Yunnan, China (Tang *et al.*, 2013).

The stem size, stand density and site productivity determine the crown radius of tree. Thus, linear relationship has been established between crown radius with DBH (Attocchi & Skovsgaard, 2015; Avsar & Ayyildiz, 2005). In accordance with this, there was positive correlation between DBH and mean canopy in chir pine forest in this study. The crown morphology also revealed the competition among different species of a community (Messier, 1996; Messier *et al.*, 1999). There is less amount of solar radiation and more deposition of litter on forest floor having high canopy cover. Such condition hinders seedlings establishment (Spanos *et al.*, 2001). This may result in a smaller number of trees in the blue pine forest. Similarly, top canopy hinders the light to penetrate on the ground surface and the nature of pine litter modifies less availability of soil nutrients for ground vegetation (Barbier *et al.*, 2008; Spanos *et al.*, 2001). Thus, negative relation was found with top canopy and low canopy in the forest. Like broadleaved forest, the positive correlation between low canopy and disturbance factor class 1 (grazing and tramping) was found in blue pine forest. The grazing and trampling promote the growth of small vascular plants on forest floor (Eskelinen & Oksanen, 2006) and brings more ground vegetation representing low canopy.

A significant relationship was found between DBH-height and DBH-crown diameter relationship in broadleaved and both fine forests in this study. However, the strength of relationship is stronger in pine forest as compared to broadleaved forest. Since, the canopy of pine is conical and broadleaved is parabolic or circular. This difference in the shape of canopy might have contributed in the stronger relation in pine as compared to broadleaved forest. The forest stand, site, time and competition situation among tree specify the DBH-height relationship of trees (Pretzsch, 2009; Schmidt *et al.,* 2011;

Trincado *et al.*, 2007). The DBH of tree was significantly related with the height and age of the forest stand and has strong correlation with each other which have direct effect on sustainable tree volume production (Khan, 2016). There is variation in relationship between diameter and height of tree among the stands depending upon the stand conditions and growing environment (Calama & Montero, 2004; Sharma & Zhang, 2004). The crown diameter is usually not measured during forest inventory, but its measurement is important to determine the canopy cover (Gill *et al.*, 2000; Popescu *et al.*, 2003). DBH predicted most in the different model developed for coniferous trees, where the R^2 values range from 0.2691 to 0.6077 (Gill *et al.*, 2000). The relationship between DBH and height is less accurate in different species of pine to develop model for estimation of tree volume (Bi *et al.*, 2012; Gonzalez-Benecke *et al.*, 2014). Thus, the accuracy of prediction of model can be improved by incorporating crown area into the model (Gonzalez-Benecke *et al.*, 2014; Nakai *et al.*, 2010). Due to this linear relationship, it is used to develop crown width model that has been used for predicting growth, biomass production, mortality rate, etc. in the forest (Sharma *et al.*, 2017). Thus, the significant relationship of DBH, height and crown can also be used in the similar type of forests of Nepal.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Blue pine, chir pine and broadleaved (*Quercus* dominated) forest contributed substantial part of forests in the landscape. The species composition of different forest types in this study is comparable to similar forest types of Nepal. Soil chemical properties and human disturbance mainly grazing, trampling, fire and cut are the underlying factors for the floristic composition and their richness in different forest types. The pine forest structure has disruptive regeneration indicates that they are heavily managed mainly for timber. On the other hand, the broadleaved forest along the elevation gradient indicates the regenerating forest. The regeneration and recruitment of species in a forest is determined by the structure and extent of disturbances. Thus, are important for effective forest management.

Environmental factors such as abiotic and biotic factors, that vary along the elevational gradient play significant role on diversity patterns of plant species (species richness, abundance and composition) in KSL, Nepal. Therefore, environmental factors need to be taken into account for better understanding of spatial distribution of plant species. Among different environmental factors studied, the plant diversity is mostly influenced by human disturbances. The forest resources such as fuel-wood, non-timber forest products, timber, and cattle grazing are the livelihoods opportunity for mountain inhabitant in mountainous countries including Nepal. Grazing and cutting are the major human pressure on plant diversity. The continuation of such disturbances affects the health and resilience of forest ecosystem in a long run. The clearance of the natural vegetation by human activities not only degraded forest ecosystem but also introduced invasive species which are the potential threats to local and regional biodiversity. Knowing the pattern of species diversity and incorporation of socio-ecological dimension is important for developing and implement the future biodiversity conservation strategies.

5.2 Recommendations

The study area of this study partly covers two protected areas, namely Khaptad National Park and newly established Api Nampa Conservation Area, both of which are poorly studied in terms of vegetation and ecology. Following recommendations can be made based on this research for the proper management of forest ecosystem of the area.

1. Since the local livelihood is strongly forest-dependent, there is a need of strengthening the existing approach for the management of forest ecosystem incorporating both the local needs, and the availability and status of the forest resources. The approach should have a mechanism for sustainable management to protect the forest resources, maintain ecosystem functions, and provide livelihood support to the people. Species- and habitat-specific sustainable harvesting/management strategies, and monitoring guidelines are needed for maintaining long-term viability of key resources. More researches should be conducted to develop such strategies and guidelines focusing NTFPs, and more particularly, the rare and threatened (including endemic and protected) species. Local people should be provided with trainings for sustainable harvesting of such key resources. Awareness programme is needed about the importance and conservation of rare and protected plant species. It is also recommended that local people should be provided with trainings for skill development so that they can diversify their income. To minimize the use of forest-based fuel resources, local people need direct supports in the form of renewable and alternative energy technologies. Awareness programme should be launched targeting forest dependent household for sustainable utilization of forest resources.
2. Pine forests should be strictly protected from timber harvesting. Conservation strategies of forest need to be incorporated in the forest management plan of these forests.
3. Rampant human activities should be minimized on broadleaved forest, and forests along altitudinal gradient to keep their regeneration potentiality.
4. Alternative to forest resources dependency should be provided to the herders for the health and resilience of the forests along the route.
5. Environmental condition of the forest needs to be considered while formulating future biodiversity and forest management strategy.

CHAPTER 6

6. SUMMARY

6.1 Introduction

Human activities have direct impact on ecosystem processes and resilience, and are also responsible for eliminating genes, species and functioning of ecosystems. One third of the terrestrial biodiversity of the world is represented by mountains alone. The variation in environmental gradient in the mountain favors different biodiversity community and hot spots. Vegetation is a part of biodiversity that regulates biogeochemical cycle, provide habitat for wild animals, control soil erosion and global energy balances.

Forests and forest products play important role in livelihoods of people of Nepal by providing provisioning, regulating, cultural and supporting ecosystem services. Structure and composition are important for the integration and dynamics of forest ecosystem. Species composition and structure are important attributes for vegetation study that is determined by biotic and abiotic components of the environment. Now a days, human disturbance and biological processes are considered as the significant factors for structure and composition of forests.

The KSL Nepal falls in Himalayan biodiversity hot-spot harboring significant flora and fauna. The region is poorly studied in terms of vegetation. Few studies showed the expansion of cropland and decrease in forest coverage due to the dependency of people on forest resources to support their livelihoods. It leads to deterioration of plant and animal species of the area. On the other hand, there is meager study on vegetation structure and composition. Since study on vegetation composition and structure help for the management and development of conservation strategy, this study is helpful to develop management plan of forest resources. Structure and composition of vegetation are determined by various environmental as well as anthropogenic factors. Thus, this study aimed to explore the role of environmental factors (abiotic and biotic) for shaping structure and composition of vegetation in far-western Nepal that vary with space.

6.2 Methods

The research was carried out in the Kailash Sacred Landscape (KSL), Nepal encompassing Humla District of Karnali province and Darchula, Bajhang, and Baitadi Districts of Sudurpaschim Province. It is a part of Himalayan biodiversity hotspot comprising five ecoregions and 18 types of forests out of 35 forest type of Nepal. Actual sampling was conducted in blue pine forest in Bajhang District, chir pine forest, broadleaved forest and along altitudinal gradient in Chamelia valley, Darchula District.

Based on the availability of space, different plot sizes were established to collect data on vegetation and environment. The vegetation data was collected by establishing nested 20 m×25 m plot and 10 m × 10 m plot in different forest types and forests along altitudinal gradient in Chamelia Valley respectively. Surface soil (10 cm depth) was collected from the centre of each plot. The anthropogenic variables were visually recorded. Plants were identified with the help of standard flora and by consulting herbarium specimens housed at TUCH and KATH. The climatic data was obtained for WorldClim version 1.4. The soil characteristics were analyzed in Soil Science Division, National Agriculture Research Division, and Soil and Water Analysis Laboratory, Kathmandu University, Dhulikhel, Nepal.

Spearmen's correlation was used to establish relationship between community characteristics and environmental variables of forests. Linear regression analysis was performed to obtain relationship between different forest community characteristics. Dimension reduction process in principle component analysis is implemented to combine different disturbance variables. R statistical software was used to analyze data collected from altitudinal gradient. Vegetation data was analyzed using three terms: species richness, its abundance and composition. Spearmen's rank correlation was adopted to determine relationship among different environmental variables and generalized linear model was used to determine effect of environmental variables on species richness. Pattern of species composition along the elevational bands was analyzed by non-metric multidimensional scaling ordination method implemented through the package 'Vegan'.

6.3 Results

The species richness in 500 m^2 plot size was high in broadleaved forest (15 species) followed by blue pine forest (10 species) and chir pine forest (Five species). Species richness of plants decreased with soil pH and increased with carbon content of the soil. The species composition of particular forest was influenced by soil properties. Carbon content in soil strongly influenced the species composition in broadleaved forest, soil pH in chir pine forest and potassium in blue pine forest. The DBH and height class distribution of tree species revealed that broadleaved forest exhibited inverse 'J' shaped distribution pattern and pine forests exhibited unimodal type. The tree density (number per hactre) was highest in broadleaved forest (328) followed by blue pine (168) and chir pine forest (65). Mean height of the trees in broadleaved forest is positively correlated with mean DBH and canopy diameter and mean canopy was negatively correlated with disturbance factor classes 1 and 2, and low canopy positively correlated with disturbance factor class 1 in broadleaved forest. Density of chir pine forest negatively correlated with mean DBH and canopy diameter and positively with disturbance factor class 2, mean height negatively correlated with top canopy and positively with disturbance factor class 2 and canopy diameter negatively correlated with disturbance factor class 2 in chir pine forest. The top canopy of tree negatively correlated with low canopy and disturbance factor class 1 and low canopy positively correlated with disturbance factor 1 in blue pine forest. The DBH-height and DBH-crown diameter relationship in all three types of forest showed significant linear relationship. However, the strength in terms of R^2 is strong in pine forests (R^2 = 0.572 in chirpine forest and R^2 = 0.422 in blue pine forest) as compared to broadleaved forest (R^2 = 0.322).

The species richness and abundance of vascular plants along elevation revealed hump shaped pattern. The species richness showed significant relation with elevation, annual precipitations and mean annual temperature. On the other hand, species abundance showed significant relation with elevation, anthropogenic variables (grazing and cutting), and soil characteristics (potassium phosphorus, nitrogen) and mean annual temperature. The species richness pattern of herbs, shrubs, trees, and all plants showed unimodal pattern. The species abundance increased with the intensity of cutting and decreased with grazing intensity. NMDS revealed that elevation, annual precipitation, mean annual temperature and grazing factors were significant to determine composition of all plant species. The correlation between different environmental variables revealed that elevation is negatively correlated with cutting, annual precipitation and mean annual temperature; cutting is positively correlated with annual precipitation and mean annual temperature; whereas, potassium is negatively correlated with mean annual temperature. The DBH and height size class distribution showed inverse ‘J’ shaped structure along altitudinal gradient in Chamelia Valley.

6.4 Conclusion

The composition and structure of plant species in different forest type and along altitudinal gradients is comparable with other forest types of Nepal. However, the altitudinal range of high species richness vary with other studies. The pine forests are heavily managed, and broadleaved and forests along altitudinal gradient are in the state of regeneration. The extent of disturbance in the forest and their recruitment is important for forest management plan and strategies in the area. The continuation of dependency of local people on forest resources affect health and resilience of ecosystems. The knowledge on pattern of species diversity and incorporation of socio-ecological dimension is essential for formulating future strategies of biodiversity conservation and its implementation.

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APPENDICES

APPENDIX 1

Plot details of Community Forest

Plot no	Elevation (masl)	Latitude	Longitude	Slope (°)	Aspect
Chir pine forest					
1	1941	29° 42' 57"	80° 27' 10"	5	East
2	1889	29° 42' 53"	80° 27' 05"	9	West
3	1843	29° 43' 41"	80° 26' 44"	10	East
4	1839	29° 43' 35"	80° 26' 43"	20	Southwest
5	1893	29° 43' 34"	80° 26' 50"	12	Southwest
6	1915	29^0 43' 25"	80^0 27' 02"	22	South
7	1911	29^0 43' 12"	80^0 26' 59"	22	West
8	1950	29° 43' 08"	80° 27' 05"	16	West
9	1871	29° 43' 05"	80° 27' 01"	11	Southwest
10	1826	29° 42' 46"	80° 27' 02"	16	Southeast
Broadleaved forest					
1	2183	29° 47' 26"	80° 38' 46"	17	East
2	2159	29° 47' 32"	80° 38' 37"	23	East
3	2197	29° 47' 28"	80° 38' 43"	13	West
4	2244	29° 47' 36"	80° 38' 20"	10	Northeast
5	2308	29° 47' 52"	80° 38' 05"	16	Northeast
6	2309	29° 47' 54"	80° 38' 02"	13	Northeast
Blue pine forest					
1	2166	29° 31' 54"	81° 13' 37"	13	East
2	2165	29° 31' 50"	81° 13' 34"	14	West
3	2182	29° 31' 44"	81° 13' 38"	8	South
4	2073	29° 31' 39"	81° 13' 32"	7	West

APPENDIX 2

Plot details of Chamelia Valley

Plot no	Elevation (m asl)	Latitude	Longitude	Slope (°)	Aspect
1	2000	29° 51' 29"	80°54' 8.9"	5	Northwest
2		29° 51' 19.9"	80° 54' 6.5"	45	Northwest
3		29° 51' 19.1"	80° 54' 6.1"	35	Northwest
4		29° 51' 17.6"	80° 54' 6.0"	25	Northwest
5		29° 51' 16.9"	80° 54' 5.1"	30	Northwest
6		29° 51' 23.2"	80° 54' 1.6"	10	Northwest
7	2100	29° 51' 44.6"	80° 54' 17.5"	40	Northwest
8		29° 51' 44.1"	80°54' 18.35"	20	Northwest
9		29° 51' 43.0"	80° 54' 18.1"	20	Northwest
10		29° 51' 16.3"	80° 54' 5.3"	30	Northeast
11		29° 51' 15.6"	80° 54' 5.5"	45	North
12		29° 51' 19.5"	80° 54' 4.7"	15	Northwest
13	2200	29° 51' 51.7"	80° 54' 28.5"	20	Northwest
14		29° 51' 51.0"	80° 54' 28.2"	15	Northwest
15		29° 51' 50.0"	80° 54' 26.8"	10	Northwest
16		29° 51' 51.8"	80° 54' 27.5"	25	Northwest
17		29° 51' 52.3"	80° 54' 28.3"	45	Northwest
18		29° 51' 40.6"	80° 54' 19.1"	15	Northwest
19	2300	29° 52' 20.4"	80° 54' 49.2"	40	Northwest
20		29° 52' 14.6"	80° 54' 44.7"	15	Northwest
21		29° 52' 14.1"	80° 54' 43.8"	30	Northwest
22		29° 52' 10.3"	80° 54' 43.1"	40	Northwest
23		29° 52' 3.0"	80° 54' 40.7"	40	Northwest
24		29° 52' 3.3"	80° 54' 39.7"	40	Northwest
25	2400	29° 52' 42.8"	80° 54' 58.8"	30	Northwest
26		29° 52' 34.2"	80° 54' 53.4"	45	Northwest
27		29° 52' 30.7"	80° 54' 51.9"	20	Northwest
28		29° 52' 30"	80° 54' 52.2"	45	Northwest
29		29° 52' 30.8"	80° 54' 53.2"	40	Northwest
30		29° 52' 28.8"	80° 54' 50.9"	20	Northwest

Plot no	Elevation (m asl)	Latitude	Longitude	Slope (°)	Aspect
31	2500	29° 52' 59.9"	80° 55' 7.9"	30	Northwest
32		29° 52' 56.7"	80° 55' 4.6"	10	Northwest
33		29° 52' 52.1"	80° 55' 3.3"	40	Northwest
34		29° 52' 46.9"	80° 55' 2.0"	5	Northwest
35		29° 52' 43.4"	80° 55' 1.9"	30	Northwest
36		29° 52' 41.3"	80° 55' 1.01"	15	Northwest
37	2600	29° 48' 11.4"	80° 53' 2.7"	20	North
38		29° 48' 10.8"	80° 53' 1.5"	45	North
39		29° 48' 8' 6"	80° 53' 0.9"	30	North
40		29° 48' 8.9"	80° 53' 1.9"	20	North
41		29° 48' 9.4"	80° 53' 2.6"	45	North
42		29° 48' 10"	80° 53' 3.7"	40	North
43	2700	29° 53' 26.9"	80° 55' 22.3"	10	Northwest
44		29° 53' 26.8"	80° 55' 39.5"	10	Northwest
45		29° 53' 25.1"	80° 55' 37.5"	20	Northwest
46		29° 53' 25"	80° 55' 35.9"	20	Northwest
47		29° 53' 22.9"	80° 55' 33.6"	15	Northwest
48		29° 53' 21.3"	80° 55' 32.4"	15	Northwest
49	2800	29° 53' 40.8"	80° 56' 4.1"	15	Northwest
50		29° 53' 41"	80° 56' 3.8"	5	Northwest
51		29° 53' 43.2"	80° 56' 7.6"	15	North
52		29° 53' 43.5"	80° 56' 7.4"	10	North
53		29° 53' 44"	80° 56' 7.1"	10	North
54		29° 53' 44.5"	80° 56' 7.4"	15	North
55	2900	29° 54' 5.8"	80° 56' 34.9"	30	Northwest
56		29° 54' 5.6"	80° 56' 34.1"	45	Northwest
57		29° 54' 13.6"	80° 56' 86.6"	30	Northwest
58		29° 54' 12.8"	80° 56' 50.1"	15	Northwest
59		29° 54' 11.0"	80° 56' 47.9"	20	Northwest
60		29° 54' 11.0"	80° 56' 47.3"	10	Northwest
61	3000	29^0 54' 18.7"	80^0 56' 52.6"	35	Northwest
62		29° 54' 18.5"	80° 56' 52.1"	40	Northwest
63		29° 54' 17.0"	80° 56' 50"	30	Northwest
64		29° 54' 16.5"	80° 56' 49.1"	30	Northwest
65		29° 54' 16.1"	80° 57' 0.5"	30	Northwest
66		29° 54' 16.3"	80° 56' 57.7"	5	Northwest

Plot no		Latitude	Longitude	Slope (°)	Aspect
67	3100	29° 54' 22.6"	80° 6' 56.9"	45	Northwest
68		29° 54' 19.2"	80° 57' 7.1"	20	Northwest
69		29° 54' 18.8"	80° 57' 11.2"	20	Northwest
70		29° 54' 18.4"	80° 57' 13.3"	5	Northwest
71		29° 54' 18.2"	80° 57' 14.8"	30	Northwest
72		29° 54' 19.2"	80° 57' 17.4"	10	Northwest
73	3200	29° 54' 28.1"	80° 56' 59.2"	60	West
74		29° 54' 28.7"	80° 56' 59.4"	25	West
75		29° 54' 28.5"	80° 56' 59.3"	30	West
76		29° 54' 28.0"	80° 56' 00.3"	40	West
77		29° 54' 24.9"	80° 56' 00.4"	10	West
78		29° 54' 24.9"	80° 56' 00.4"	20	West
79	3300	29° 55' 30.4"	80° 56' 36.5"	5	Northwest
80		29° 55' 28.2"	80° 56' 38.0"	10	Northeast
81		29° 55' 26.7"	80° 56' 39.3"	10	Northeast
82		29° 55' 27.3"	80° 56' 44.0"	10	Northwest
83		29° 55' 29"	80° 56' 46.0"	5	Northwest
84		29° 55' 29.5"	80° 56' 47.2"	5	Northwest
85	3400	29° 55' 39"	80° 56' 22.5"	35	North
86		29° 55' 38.9"	80° 56' 22"	15	North
87		29° 55' 38.4"	80° 56' 21.4"	30	Northeast
88		29° 55' 38.6"	80° 56' 20.2"	20	Northeast
89		29° 55' 38.1"	80° 56' 24.1"	20	Northeast
90		29° 55' 29.8"	80° 56' 22"	20	Northeast
91	3500	29° 55' 29.3"	80° 56' 16.8"	30	Northwest
92		29° 55' 28.9"	80° 56' 15.8"	20	Northwest
93		29° 55' 28.6"	80° 56' 15"	30	Northwest
94		29° 55' 28.3"	80° 56'14.3"	20	Northwest
95		29° 55' 26.7"	80° 56'16.6"	30	Northwest
96		29° 55' 27.5"	80° 56'17.5"	20	Northwest
97	3600	29° 55' 28.1"	80° 56' 6.1"	20	Northeast
98		29° 55' 27.7"	80° 56' 7.0"	40	Northeast
99		29° 55' 28.5"	80° 56' 7.5"	30	Northeast
100		29° 55' 30.5"	80° 56' 7.3"	40	Northeast
101		29° 55' 32.4"	80° 56' 7.7"	30	Northeast
102		29° 55' 31.2"	80° 56' 8.6"	45	Northeast

Plot no	Elevation (m asl)	Latitude	Longitude	Slope (°)	Aspect
103	3700	29° 55' 38.2"	80° 56' 3.2"	30	Northwest
104		29° 55' 38.4"	80° 56' 2.6"	30	North
105		29° 55' 38.4"	80° 56' 4.9"	40	Northeast
106		29° 55' 52.2"	80° 55' 55.6"	30	Northeast
107		29° 55' 53.2"	80° 55' 55.1"	30	Northeast
108		29° 55' 53.4"	80° 55' 54.3"	35	Northeast
109	3800	29° 55' 54.3"	80° 55' 48.6"	50	North
110		29° 55' 56.3"	80° 55' 47.1"	10	North
111		29° 55' 57.3"	80° 55' 47.5"	35	North
112		29° 55' 40.2"	80° 55' 56.1"	30	Northeast
113		29° 55' 38.5"	80° 55' 57.1"	60	Northeast
114		29° 53' 37.9"	80° 55' 57.3"	20	North

APPENDIX 3

Plant list of broadleaved forest

Latin name	Abbreviation	Family	Life form
*Ageratina adenophora (*Spreng.*)* R.M.King *&* H.Rob.	Age ade	Asteraceae	Herb
Ainsliaea latifolia (D.Don) Sch.Bip.	Ain lat	Asteraceae	Herb
Anaphalis busua (Buch.-Ham. ex D. Don) Dc.	Ana bus	Asteraceae	Herb
Aster sp.	Ast Sp.	Asteraceae	Herb
Berberis aristata Dc.	Ber ari	Berberidaceae	Shrub
Berberis asiatica Roxb. ex Dc.	Ber asi	Berberidaceae	Shrub
Calanthe mannii Hook. f.	Cal man	Orchidaceae	Herb
Carex filicina Nees	Car fil	Cyperaceae	Herb
Carpinus viminea Lindl.	Car vim	Corylaceae	Tree
Cephalanthera erecta (Thunb.) Blume var. *oblanceolata* N. Pearce & P.J. Cribb Lindl.	Cep ere	Orchidaceae	Herb
Cheilanthes sp.	Che Sp.	Pteridaceae	Herb
Clematis montana Buch.-Ham. ex Dc.	Cle mon	Ranunculaceae	Shrub
Cotoneaster frigidus Wall. ex Lindl.	Cot fri	Rosaceae	Shrub
Daphne papyracea Wall. ex Steud.	Dap pap	Thymelaeaceae	Shrub
Deutzia compacta Craib	Deu com	Hydrangeaceae	Shrub
Elaegnus infundibularis Momiyama	Ela inf	Eleagnaceae	Tree
Erigeron karvinskianus Dc.	Eri kar	Asteraceae	Herb
Eurya acuminata Dc.	Eur acu	Theaceae	Tree
Ficus neriifolia Sm.	Fic ner	Moraceae	Tree
Fragaria nubicola (Hook. f.) Lindl. ex Lacaita	Fra nub	Rosaceae	Herb
Galium asperifolium Wall	Gal asp	Rubiaceae	Herb
Gonostegia hirta (Blume) Miq.	Gon hir	Urticaceae	Herb
Goodyera biflora (Lindl.) Hook. f.	Goo bif	Orchidaceae	Herb
Hedera nepalensis K. Koch	Hed nep	Araliaceae	Herb
Hemiphragma heterophyllum Wall.	Hem het	Scrophulariaceae	Herb
Hypericum uralum Buch.-Ham. ex D. Don	Hyp ura	Clusiaceae	Shrub
Ilex dipyrena Wall.	Ile dip	Aquifoliaceae	Tree
Indigofera atropurpurea Hornem.	Ind atr	Fabaceae	Shrub
Jasminum humile L.	Jas hum	Oleaceae	Shrub
Leptodermis lanceolata Wall.	Lep lan	Rubiaceae	Shrub
Lindera pulcherrima (Nees) Benth. ex Hook. f.	Lin pul	Lauraceae	Tree
Lyonia ovalifolia (Wall.) Drude	Lyo ova	Ericaceae	Tree
Lysimachia congestiflora Hemsl.	Lys con	Primulaceae	Herb
Micromeria biflora (Buch.-Ham. ex D. Don) Benth.	Mic bif	Lamiaceae	Herb
Myrsine africana L.	Myr afr	Myrsinaceae	Shrub
Neolitsea pallens (D. Don) Momiy. & H. Hara ex H. Hara	Neo pal	Lauraceae	Tree
Ophiopogon intermedius D. Don	Oph int	Convallariaceae	Herb
Oplismenus compositus (L.) P. Beauv.	Opl com	Poaceae	Herb
Origanum vulgare L.	Ori vul	Lamiaceae	Herb
Oxalis corniculata L.	Oxa cor	Oxalidaceae	Herb
Parthenocissus semicordata (Wall.) Planch.	Par sem	Vitaceae	Herb
Potentilla fulgens Wall. ex Hook.	Pot ful	Rosaceae	Herb
Potentilla nepalensis Hook.	Pot nep	Rosaceae	Herb
Prinsepia utilis Royle	Pri uti	Rosaceae	Shrub

Latin name	Abbreviation	Family	Life form
Pyrus pashia Buch.-Ham. ex D. Don	Pyr pas	Rosaceae	Tree
Quercus lanata Sm.	Que lan	Fagaceae	Tree
Rhododendron arboreum Sm.	Rho arb	Ericaceae	Tree
Rosa macrophylla Lindl.	Ros mac	Rosaceae	Shrub
Rubia manjith Roxb. ex Fleming	Rub man	Rubiaceae	Herb
Rubus ellipticus Sm.	Rub ell	Rosaceae	Shrub
Sarcococca saligna (D. Don) Mull. Arg.	Sar sal	Buxaceae	Shrub
Scutellaria repens Buch.-Ham. ex D. Don	Scu rep	Lamiaceae	Herb
Smilax aspera L.	Smi asp	Smilacaceae	Shrub
Stellaria semivestita Edgew. ex Edgew. & Hook. f.	Ste sem	Caryophyllaceae	Herb
Strobilanthes capitata (Nees) T. Anderson	Str cap	Acanthaceae	Herb
Symplocos pyrifolia Wall. ex G. Don	Sym pyr	Symplocaceae	Tree
Taraxacum parvulum Candolle	Tar par	Asteraceae	Herb
Thalictrum reniforme Wall.	Tha ren	Ranunculaceae	Herb
Tsuga dumosa (D. Don) Eichler	Tsu dum	Pinaceae	Tree
Valeriana hardwickii Wall.	Val har	Valerianaceae	Herb
Viburnum cotinifolium D. Don	Vib cot	Sambucaceae	Tree
Viburnum erubescens Wall. ex Dc.	Vib eru	Sambucaceae	Shrub
Viburnum mullaha Buch.-Ham. ex D. Don	Vib mul	Sambucaceae	Shrub
Viola pilosa Blume	Vio pil	Violaceae	Herb

APPENDIX 4

Plant list of chir pine forest

Latin name	Abbreviation	Family	Life form
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	Age ade	Asteraceae	Herb
Alnus nepalensis D. Don	Aln nep	Betulaceae	Tree
Anaphalis busua (Buch.-Ham. ex D. Don) DC.	Ana bus	Asteraceae	Herb
Anaphalis triplinervis (Sims) C. B. Clarke	Ana tri	Asteraceae	Herb
Berberis asiatica Roxb. ex Dc.	Ber asi	Berberidaceae	Shrub
Carex filicina Nees	Car fil	Cyperaceae	Herb
Cirsium wallichii Dc.	Cir wal	Asteraceae	Herb
Commelina benghalensis L.	Com ben	Commmelinaceae	Herb
Drosera peltata Sm.	Dro pel	Droseraceae	Herb
Erigeron karvinskianus Dc.	Eri kar	Asteraceae	Herb
Fimbristylis dichotoma (L.) Vahl	Fim dic	Cyperaceae	Herb
Flemingia strobilifera (L.) W. T. Aiton	Fle str	Fabaceae	Herb
Fragaria indica Andrews	Fra ind	Rosaceae	Herb
Galium elegans Wall. ex Roxb.	Gal ele	Rubiaceae	Herb
Gonostegia hirta (Blume) Miq.	Gon hir	Urticaceae	Herb
Hedysarum kumaonense Benth. ex Baker	Hed kum	Fabaceae	Shrub
Hypericum japonicum Thunb. ex Murray	Hyp jap	Clusiaceae	Herb
Imperata cylindrica (L.) P. Beauv.	Imp cyl	Poaceae	Herb
Lyonia ovalifolia (Wall.) Drude	Lyo ova	Ericaceae	Tree
Micromeria biflora (Buch.-Ham. ex D. Don) Benth.	Mic bif	Lamiaceae	Herb
Ophioglossum Sp.	Oph Sp.	Ophioglossaceae	Herb
Oplismenus compositus (L.) P. Beauv.	Opl com	Poaceae	Herb
Oxalis corniculata L.	Oxa cor	Oxalidaceae	Herb
Pinus roxburghii Sarg.	Pin rox	Pinaceae	Tree
Quercus lanata Sm.	Que lan	Fagaceae	Tree
Reinwardtia indica Dumort.	Rei ind	Linaceae	Herb
Rhododendron arboreum Sm.	Rho arb	Ericaceae	Tree
Rubus ellipticus Sm.	Rub ell	Rosaceae	Shrub
Rubus paniculatus Sm.	Rub pan	Rosaceae	Shrub
Taraxacum parvulum Dc.	Tar par	Asteraceae	Herb
Viola serpens Wall. ex Ging.	Vio ser	Violaceae	Herb

APPENDIX 5

Plant list of blue pine forest

Latin name	Abbreviation	Family	Life form
Ageratina adenophora *(*Spreng.) R.M.King & H.Rob.	Age ade	Asteraceae	Herb
Anaphalis triplinervis (Sims) C. B. Clarke	Ana tri	Asteraceae	Herb
Berberis asiatica Roxb. ex DC.	Ber asi	Berberidaceae	Shrub
Bidens pilosa	Bid pil	Asteraceae	Herb
Carex filicina Nees	Car fil	Cyperaceae	Herb
Centella asiatica (L.) Urb.	Cen asi	Apiaceae	Herb
Cotoneaster microphyllus Wall. ex Lindl.	Cot mic	Rosaceae	Shrub
Daphne papyracea Wall. ex Steud.	Dap pap	Thymelaeaceae	Shrub
Erigeron karvinskianus DC.	Eri kar	Asteraceae	Herb
Flemingia strobilifera (L.) W. T. Aiton	Fle str	Fabaceae	Shrub
Fragaria indica Andrews	Fra ind	Rosaceae	Herb
Galium elegans Wall. ex Roxb.	Gal ele	Rubiaceae	Herb
Gaultheria nummularioides D. Don	Gau num	Ericaceae	Shrub
Gnaphalium affine D. Don	Gna aff	Asteraceae	Herb
Gonostegia hirta (Blume) Miq.	Gon hir	Urticaceae	Herb
Hypoxis aurea Lour.	Hyp aur	Hypoxidaceae	Herb
Imperata cylindrica (L.) P. Beauv.	Imp cyl	Poaceae	Herb
Indigofera heterantha Wall. ex Brandis	Ind het	Fabaceae	Shrub
Inula cappa (Buch.-Ham. ex D. Don) DC.	Inu cap	Asteraceae	Shrub
Lyonia ovalifolia (Wall.) Drude	Lyo ova	Ericaceae	Tree
Micromeria biflora (Buch.-Ham. ex D. Don) Benth.	Mic bif	Lamiaceae	Herb
Myrsine africana L.	Myr afr	Myrsinaceae	Herb
Oplismenus compositus (L.) P. Beauv.	Opl com	Poaceae	Herb
Origanum vulgare L.	Ori vul	Lamiaceae	Herb
Oxalis corniculata L.	Oxa cor	Oxalidaceae	Herb
Pinus wallichiana A.B. Jacks.	Pin wal	Pinaceae	Tree
Potentilla sundaica (Blume) Kuntze	Pot sun	Rosaceae	Herb
Prinsepia utilis Royle	Pri uti	Rosaceae	Shrub
Pyracantha crenulata (D. Don) M. Roem.	Pyr cre	Rosaceae	Shrub
Rhododendron arboreum Sm.	Rho arb	Ericaceae	Tree
Rubus ellipticus Sm.	Rub ell	Rosaceae	Shrub
Smilax aspera L.	Smi asp	Smilacaceae	Shrub
Spiraea bella Sims	Spi bel	Rosaceae	Shrub
Symplocos pyrifolia Wall. ex G. Don	Sym pyr	Symplocaceae	Tree
Taraxacum parvulum DC.	Tar par	Asteraceae	Herb
Viburnum cotinifolium D. Don	Vib cot	Sambucaceae	Shrub
Viburnum erubescens Wall. ex DC.	Vib eru	Sambucaceae	Tree
Viola serpens Wall. ex Ging.	Vio ser	Violaceae	Herb

APPENDIX 6

Plant List of Chamelia valley

Latin name	Abbreviation	Family	Life forms
Abies spectabilis (D. Don) Mirb.	Abi spe	Pinaceae	Tree
Acer cappadocicum var. *indicum* (Pax) Rehder	Ace cap	Aceraceae	Tree
Acer pectinatum Wall. ex G. Nicholson	Ace pec	Aceraceae	Tree
Acer sterculiaceum var. *tomentosum* E. Murray	Ace ste	Aceraceae	Tree
Achyranthes bidentata Blume	Ach bid	Amaranthaceae	Herb
Aconitum *spicatum* (Bruhl) Stapf	Aco spi	Ranunculaceae	Herb
Aco*nogonum molle* var. *frondosum* (D. Don) H. Hara	Aco mol	Polygonaceae	Herb
Aconogonum rumicifolium (Royle ex Bab.) H. Hara	Aco rum	Polygonaceae	Herb
Actaeaspicata var. *acuminata* (Wall. ex Royle) H. Hara	Act spi	Ranunculaceae	Herb
Adiantum capillus-veneris L.	Adi cap	Pteridaceae	Herb
*Aesculus ind*ica (Colebr. ex Cambess.) Hook.	Aes ind	Hippocastanaceae	Tree
Ageratum conyzoides L.	Age con	Asteraceae	Herb
Ainsliaea latifolia (D. Don) Sch. Bip.	Ain lat	Asteraceae	Herb
Alnus nepalensis D. Don	Aln nep	Betulaceae	Tree
Amaranthus lividus L.	Ama liv	Amaranthaceae	Herb
Anaphalis triplinervis var. *intermedia* (DC.) Airy Shaw	Ana tri	Asteraceae	Herb
Anemone demissa Hook. f. &Thoms	Ane dem	Ranunculaceae	Herb
Anemone vitifolia Buch.-Ham. ex DC.	Ane vit	Ranunculaceae	Herb
Anemone tetrasepala Royle	Ane tet	Ranunculaceae	Herb
Angelica glauca Edgeworth	Ang gla	Apiaceae	Herb
Anisomeles indica (L.) Kuntze	Ani ind	Lamiaceae	Herb
Arabidopsis himalaica (Edgew.) O. E. Schulz	Ara him	Brassicaceae	Herb
Arisaema consanguineum Schott	Ari con	Araceae	Herb
Arisaema flavum (Forssk.) Schott	Ari fla	Araceae	Herb
Arisaema tortuosum (Wall.) Schott	Ari tor	Araceae	Herb
Artemisia dubia Wall. ex Besser	Art dub	Araceae	Herb
Artemisia gmelinii Weber ex Stechm.	Art gme	Asteraceae	Herb
Asparagus racemosus Willd.	Asp rac	Asparagaceae	Herb
Aster diplostephioides (DC.) C. B. Clarke	Ast dip	Asteraceae	Herb
Aster falconeri subsp. *nepalensis* Grierson	Ast fal	Asteraceae	Herb
Astilbe rivularis Buch.-Ham. ex D. Don	Ast riv	Saxifragaceae	Herb
Astragalus donianus DC.	Ast don	Fabaceae	Herb
Berberis aristata var. *floribunda* (G. Don) Hook. f. & Thomson	Ber ari	Berberidaceae	Shrub
Berberis asiatica Roxb. ex DC.	Ber asi	Berberidaceae	Shrub
*Betula alnoides*Buch.-Ham. ex D. Don	Bet aln	Betulaceae	Tree
Betula utilis D. Don	Bet uti	Betulaceae	Tree
Bidens pilosa var. *minor* (Blume) Sherff	Bid pil	Asteraceae	Herb
Bistorta affinis (D. Don) Greene	Bis aff	Polygonaceae	Herb
Bistorta amplexicaulis var. *amplexicaulis* (D. Don) Greene	Bis amp	Polygonaceae	Herb
*Boehmeria terni*folia D. Don	Boe ter	Urticaceae	Herb
Bupleurum falcatum subsp. *marginatum* (Wall. ex DC.) H. Wolff	Bup fal	Polygonaceae	Herb
Buxus wallichiana Baill.	Bux wal	Buxaceae	Tree
Calanthe tricarinata Lindl.	Cal tri	Orchidaceae	Herb
Caltha palustris var. *himalensis* (D. Don) Mukerjee	Cal pal	Ranunculaceae	Herb

Latin name	Abbreviation	Family	Life forms
Campanula aristata Wall.	Cam ari	Campanulaceae	Herb
Capsella bursa-pastoris (L.) Medik.	Cap bur	Brassicaceae	Herb
Cardamine violacea (D. Don) Wall.	Car vio	Brassicaceae	Herb
Cardiocrinum giganteum (Wall.) Makino	Car gig	Liliaceae	Herb
Carex sp.	Car sp.	Cyperaceae	Herb
Cautleya spicata (Sm.) Baker	Cau spi	Zingiberaceae	Herb
Celtis australis L.	Cel aus	Ulmaceae	Tree
Cephalanthera longifolia (L.) Fritsch	Cep lon	Orchidaceae	Herb
Chaerophyllum villosum Wall. ex DC.	Cha vil	Apiaceae	Herb
Cheilanthes rufa D. Don	Che ruf	Pteridaceae	Herb
Cirsium wallichii var. *glabratum* (Hook. f.) Wendelbo	Cir wal	Asteraceae	Herb
Clematis connata DC.	Cle con	Ranunculaceae	Herb
Clematis montana Buch.-Ham. ex DC.	Cle mon	Ranunculaceae	Herb
Coleus barbatus (Andrews) Benth.	Col bar	Lamiaceae	Herb
Colocasia fallax Schott	Col fal	Araceae	Herb
Commelina paludosa Blume	Com pal	Commelinaceae	Herb
Corydalis cashmeriana Royle	Cor cas	Papaveraceae	Herb
Corydalis juncea Wall.	Cor jun	Papaveraceae	Herb
*Corylus jacquemontii*Decne.	Cor jac	Corylaceae	Tree
Cotoneaster frigidus Wall. ex Lindl.	Cot fri	Rosaceae	Tree
Crotalaria cytisoides Roxb. ex DC.	Cro cyt	Fabaceae	Herb
Cuscuta europaea var. *indica* Englem.	Cus eur	Convolvulaceae	Herb
Cyananthus lobatus Wall. ex Benth.	Cya lob	Campanulaceae	Herb
Cyathula tomentosa (Roth) Moq.	Cya tom	Amaranthaceae	Shrub
Cynoglossum amabile Stapf&Drumm.	Cyn ama	Boraginaceae	Herb
Cyperus sp.	Cyp sp.	Cyperaceae	Herb
Cypripedium sp.	Cyp sp.	Orchidaceae	Herb
Daphne papyracea Wall. ex Steud.	Dap pap	Thymelaeaceae	Shrub
Delphinium himalayai Munz	Del him	Ranunculaceae	Herb
Desmodium elegans DC.	Des ele	Fagaceae	Shrub
Deutzia compacta Craib	Deu com	Hydrangeaceae	Shrub
Dioscoreadeltoidea Wall. ex Griseb.	Dio del	Dioscoreaceae	Herb
Dipsacusinermis var. *mitis* Wall.	Dip ine	Dipsacaceae	Herb
Drepanostachyum falcatum (Nees) Keng f.	Dre fal	Poaceae	Shrub
Dubyaea hispida DC.	Dub his	Asteraceae	Herb
Elaeagnus parvifolia Wall. ex Royle	Ela par	Elaeagnaceae	Tree
Elatostema sessile J. R. & G. Forst.	Ela ses	Urticaceae	Herb
Elsholtzia fruticosa (D. Don) Rehder	Els fru	Lamiaceae	Shrub
Euonymus fimbriatus Wall.	Euo fim	Celastraceae	Tree
*Euonymus porphyreus*Loes.	Euo por	Celastraceae	Tree
Fagopyrum dibotrys (D. Don) H. Hara	Fag dib	Polygonaceae	Herb
Ficus sarmentosa Buch.-Ham. ex Sm.	Fic sar	Moraceae	Shrub
Fragaria nubicola Lindl. ex Lacaita	Fra nub	Rosaceae	Herb
Fritillaria cirrhosa D. Don	Fri cir	Liliaceae	Herb
Galium asperuloides subsp. *hoffmeisteri* (Klotzsch) H. Hara	Gal asp	Rubiaceae	Herb
Galium paradoxum Maxim.	Gal par	Rubiaceae	Herb
Geranium nepalense Sweet	Ger nep	Geraniaceae	Herb
Geranium pratense L.	Ger pra	Geraniaceae	Herb
Girardinia diversifolia (Link) Friis	Gir div	Urticaceae	Herb
Habenaria pectinata D. Don	Hab pec	Orchidaceae	Herb
Halenia elliptica D. Don	Hal ell	Gentianaceae	Herb
Hedera nepalensis K. Koch	Hed nep	Araliaceae	Herb
Hedychium sp.	Hed sp.	Zingiberaceae	Herb

Latin name	Abbreviation	Family	Life forms
Hemiphragma heterophyllum Wall.	Hem het	Scrophulariaceae	Herb
Heracleum lallii C. Norman	Her lal	Apiaceae	Herb
Heracleum sp.	Her sp.	Apiaceae	Herb
Herminium duthiei Hook. f.	Her dut	Orchidaceae	Herb
Hippophae salicifolia D. Don	Hip sal	Elaeagnaceae	Tree
Holboellia latifolia Wall.	Hol lat	Lardizabalaceae	Shrub
Hydrangea anomala D. Don	Hyd ano	Hydrangeaceae	Shrub
Hydrangea heteromalla D. Don	Hyd het	Hydrangeaceae	Tree
Ilex dipyrena Wall.	Ile dip	Aquifoliaceae	Tree
Impatiens bicornuta var. *bicornuta* Wall.	Imp bic	Balsaminaceae	Herb
Impatiens sulcata Wall.	Imp sul	Balsaminaceae	Herb
Impatiens urticifolia Wall.	Imp urt	Balsaminaceae	Herb
Imperata sp.	Imp sp	Poaceae	Herb
Indigofera bracteata Graham ex Baker	Ind bra	Fagaceae	Shrub
Jasminum dispermum Wall.	Jas dis	Oleaceae	Shrub
Jasminum humile L.	Jas hum	Oleaceae	Shrub
Juglans regia L.	Jug reg	Juglandaceae	Tree
Juncus sp.	Jun sp.	Juncaceae	Herb
Lamium album L.	Lam alb	Lamiaceae	Herb
Lathyrus laevigatus subsp. *emodi* (Waldst. & Kit.) Gren.	Lat lae	Fabaceae	Herb
Lecanthus peduncularis (Royle) Wedd.	Lec ped	Urticaceae	Herb
Lepisorus sp.	Lep sp.	Polypodiaceae	Herb
Leucas lanata Benth.	Leu lan	Lamiaceae	Herb
Leucosceptrum canum Sm.	Leu can	Lamiaceae	Shrub
Leycesteria formosa Wall.	Ley for	Caprifoliaceae	Shrub
Ligularia amplexicaulis DC.	Lig amp	Asteraceae	Herb
Lilium nanum Klotzsch	Lil nan	Liliaceae	Herb
Lilium nepalense D. Don	Lil nep	Liliaceae	Herb
*Lonicera quinquelocularis*Hardw.	Lon qui	Caprifoliaceae	Tree
Lonicera webbiana Wall. ex DC.	Lon web	Caprifoliaceae	Shrub
Lygodium japonicum (Thunberg) Swartz	Lyg jap	Lygodiaceae	Herb
Lysimachia ferruginea Edgew.	Lys fer	Primulaceae	Herb
Lysionotus serratus D. Don	Lys ser	Gesneriaceae	Herb
Maianthemum purpureum (Wall.) LaFrankie	Mai pur	Convallariaceae	Herb
Meconopsis sp.	Mec sp.	Papaveraceae	Herb
Microsorum sp.	Mic sp.	Polypodiaceae	Herb
Morina longifolia Wall. ex DC.	Mor lon	Dipsacaceae	Herb
Myriactis nepalensis Less.	Myr nep	Asteraceae	Herb
Neolitsea pallens (D. Don) Momiy. & H. Hara ex H. Hara	Neo pal	Lauraceae	Tree
Neottia listeroides Lindl.	Neo lis	Orchidaceae	Herb
Nepeta erecta (Boyle ex Benth.) Berth.	Nep ere	Lamiaceae	Herb
Nepeta lamiopsis Benth. ex Hook. f.	Nep lam	Lamiaceae	Herb
Nephrolepis sp.	Nep	Nephrolepidaceae	Herb
Oxalis corniculata L.	Oxa cor	Oxalidaceae	Herb
Paeonia emodi Wall. ex Royle	Pae emo	Paeoniaceae	Herb
Parasenecio chenopodifolius (DC.) Grierson	Par che	Asteraceae	Herb
Paris polyphylla subsp. *wallichii* Sm.	Par pol	Trilliaceae	Herb
Parnassia nubicola Wall. ex Royle	Par nub	Parnassiaceae	Herb
Parochetus communis Buch.-Ham. ex D. Don	Par com	Fabaceae	Herb
Pedicularis gracilis Wall. ex Benth.	Ped gra	Scrophulariaceae	Herb
Pedicularis klotzschii Hurus.	Ped klo	Scrophulariaceae	Herb
Persicaria capitata (Buch.-Ham. ex D. Don) H. Gross	Per cap	Polygonaceae	Herb

Latin name	Abbreviation	Family	Life forms
Philadelphus tomentosus forma *nepalensis* Wall. ex G. Don	Phi tom	Hydrangeaceae	Shrub
Phlomis bracteosa Royle ex Benth.	Phl bra	Lamiaceae	Herb
Pilea racemosa (Royle) Tuyama	Pil rac	Urticaceae	Herb
Pilea umbrosa Blume	Pil umb	Urticaceae	Herb
Piptanthus nepalensis (Hook.) D. Don	Pip nep	Fabaceae	Shrub
Pleurospermum angelicoides (DC.) C. B. Clarke	Ple ang	Apiaceae	Herb
Podophyllum hexandrum Royle	Pod hex	Berberidaceae	Herb
Polygonatum cirrhifolium (Wall.) Royle	Pol cir	Convallariaceae	Herb
Polygonatum verticillatum (L.) All.	Pol ver	Convallariaceae	Herb
Polystichum prescottianum (Wallich ex Mettenius) T. Moore	Pol pre	Dryopteridaceae	Herb
Potentilla argyrophylla var. *atrosanguinea* Wall. ex Lehm.	Pot arg	Rosaceae	Herb
Potentilla cuneata Wall. ex Lehm.	Pot cun	Rosaceae	Herb
Prenanthesbrunoniana Wall. ex DC.	Pre bru	Asteraceae	Herb
Primula involucrata Wall. ex Duby	Pri inv	Primulaceae	Herb
Prinsepia utilis Royle	Pri uti	Rosaceae	Shrub
Prunus cornuta (Wall. ex Royle) Steud.	Pru cor	Rosaceae	Tree
Prunus napaulensis (Ser.) Steud.	Pru nap	Rosaceae	Tree
Pyracantha crenulata (D. Don) M. Roem.	Pyr cre	Rosaceae	Shrub
Quercus semecarpifolia Sm.	Que sem	Fagaceae	Tree
Ranunculus diffusus DC.	Ran dif	Ranunculaceae	Herb
Rheum australe D. Don	Rhe aus	Polygonaceae	Herb
Rhodiola chrysanthemifolia (H. Léveillé) S. H. Fu	Rho chr	Crassulaceae	Herb
Rhododendron arboreum Sm.	Rho arb	Ericaceae	Tree
Rhododendron barbatum Wall. ex G. Don	Rho bar	Ericaceae	Tree
Rhododendron campanulatum D. Don	Rho cam	Ericaceae	Shrub
Rhus wallichii Hook. f.	Rhu wal	Anacardiaceae	Tree
Ribes glaciale Wall.	Rib gla	Grossulariaceae	Shrub
Ribes luridum Hook. f. & Thomson	Rib lur	Grossulariaceae	Shrub
Rosa macrophylla Lindl.	Ros mac	Rosaceae	Shrub
Rosa sericea Lindl.	Ros ser	Rosaceae	Shrub
Rubia manjith Roxb. ex Fleming	Rub man	Rubiaceae	Herb
Rubia wallichiana Decne.	Rub wal	Rubiaceae	Herb
Rubus biflorus Buch.-Ham. ex Sm.	Rub bif	Rosaceae	Shrub
Rubus calycinus Wall. ex D. Don	Rub cal	Rosaceae	Herb
Rumex acetosa L.	Rum ace	Polygonaceae	Herb
Salix hylematica C. K. Schneid.	Sal hyl	Salicaceae	Shrub
Salix tetrasperma var. *pyrina* Roxb.	Sal tet	Salicaceae	Tree
Sarcococca saligna (D. Don) Mull. Arg.	Sar sal	Buxaceae	Shrub
Saurauia napaulensis DC.	Sau nap	Saurauiaceae	Tree
Saussurea fastuosa (Decne.) Sch. Bip.	Sau fas	Asteraceae	Herb
Saxifraga parnassifolia D. Don	Sax par	Saxifragaceae	Herb
Saxifraga sp.	Sax sp.	Saxifragaceae	Herb
S*currula elata* (Edgew.) Danser	Scu ela	Loranthaceae	Shrub
Scutellaria prostrata Jacq. ex Benth.	Scu pro	Lamiaceae	Herb
Sedum multicaule Wallich ex Lindley	Sed mul	Crassulaceae	Herb
Selaginella sp.	Sel sp.	Selaginellaceae	Herb
Selinum wallichianum (DC.) Raizada& Saxena	Sel wal	Apiaceae	Herb
Senecio chrysanthemoides DC.	Sen chr	Asteraceae	Herb
Silene stracheyi Edgew.	Sil str	Caryophyllaceae	Herb
smilax aspera L.	smi asp	Smilacaceae	Shrub
Solena heterophylla Lour.	Sol het	Cucurbitaceae	Herb
Sorbus lanata (D. Don) Schauer	Sor lan	Rosaceae	Tree

Latin name	Abbreviation	Family	Life forms
Sorbus microphylla Wenz.	Sor mic	Rosaceae	Tree
Spiraea bella Sims	Spi bel	Rosaceae	Shrub
Stachys melissaefolia Benth.	Sta mel	Lamiaceae	Herb
Stellaria media Vill.	Ste med	Caryophyllaceae	Herb
Stellaria monosperma forma *paniculata* (Edgew.) Majumdar	Ste mon	Caryophyllaceae	Herb
Stephania glabra (Roxb.) Miers	Ste gla	Menispermaceae	Herb
Strobilanthes attenuata subsp. *nepalensis* J. R. I. Wood	Str att	Acanthaceae	Shrub
Strobilanthes tomentosa (Nees) J. R. I. Wood	Str tom	Acanthaceae	Herb
Swertia chirayita (Roxb. ex Fleming) Karsten	Swe chi	Gentianaceae	Herb
Swertia ciliata (D. Don ex G. Don) B. L. Burtt	Swe cil	Gentianaceae	Herb
Swertia petiolata D. Don	Swe pet	Gentianaceae	Herb
Syringa emodi Wall. ex Royle	Syr emo	Oleaceae	Shrub
Taxus contorta Griff.	Tax con	Taxaceae	Tree
Tetrastigma serrulatum (Roxb.) Planch.	Tet ser	Vitaceae	Herb
Thalictrum cultratum Wall.	Tha cul	Ranunculaceae	Herb
Thalictrum foliolosum DC.	Tha fol	Ranunculaceae	Herb
Thelypteris erubescens (Wall. ex Hook.) Ching	The eru	Thelypteridaceae	Herb
Toona serrata (Royle) M. Roem	Too ser	Meliaceae	Tree
Trifoliumrepens L.	Tri rep	Fabaceae	Herb
Trigonella emodii Benth.	Tri emo	Fabaceae	Herb
Tsuga dumosa (D. Don) Eichler	Tsu dum	Pinaceae	Tree
Ulmus wallichiana Planch.	Ulm wal	Ulmaceae	Tree
Urtica ardens Link	Urt ard	Urticaceae	Herb
Valeriana hardwickii Wall.	Val har	Velerianaceae	Herb
Veronica cana Wall. ex Benth.	Ver can	Scrophulariaceae	Herb
Viburnum cotinifolium D. Don	Vib cot	Sambucaceae	Shrub
Viburnum erubescens Wall. ex DC.	Vib eru	Sambucaceae	Tree
Viburnum mullaha Buch.-Ham. ex D. Don	Vib mul	Sambucaceae	Shrub
Viola biflora L.	Vio bif	Violaceae	Herb
Vitis parvifolia Roxb.	Vit par	Vitaceae	Shrub

APPENDIX 7

List of Publications

I. Research articles

1. **Subedi C.K**., Rokaya M.B., Münzbergová Z., Timsina B., Gurung J., Chettri N., Baniya C.B., Ghimire S.K. & Chaudhary R.P. (2020). Vascular Plant Diversity along an Elevational Gradient in the Central Himalayas, Western Nepal. *Folia Geobotanica*, **55**: 127–140. https://doi.org/10.1007/s12224-020-09370-8
2. **Subedi, C.K.**, Gurung, J., Ghimire, S.K., Chettri, N., Pasakhala, B., Bhandari, P., & Chaudhary, R.P. (2018). Variation in Structure and Composition of Two Pine Forests in Kailash Sacred Landscape, Nepal. *Banko Janakari*, **28**(1): 26-36. https://doi.org/10.3126/banko.v28i1.21453
3. **Subedi, C.K.**, Bhandari, P., Thapa, S., Pandey, M., Gurung, J., Shakya, L.R., & Chaudhary, R.P. (2018). *Cephalanthera erecta* var. oblanceolata (Orchidaceae)—A New Record for the Flora of Nepal. *Japanese Journal of Botany*, **93**(4): 287-290.

II. Book

1. Ghimire, S.K., **Subedi, C.K.**, Budha-Magar, S., Adhikari, M., Pandey, T.R., Awasthi, B., Thapa-Magar, S., Paudeyal, M.R., Ghimire, K.M., Shrestha, B.B., Bhatt, G.D., Joshi, L.R., Poudel, A., Chapagain, D.J., & Gurung, J. (2021). *Flora of Kailash Sacred Landscape Nepal: An Annotated Checklist. Volume 1(Gymnosperms and Angiosperms: Ephedraceae – Buxaceae).* Research Centre for Applied Science and Technology (RECAST), Tribhuvan University, Kathmandu.

III. Contributions ((Technical team member)

DNPWC (2019). *Biodiversity Profile of the Api Nampa Conservation Area, Nepal*. Department of National Parks and Wildlife Conservation, Kathmandu.

Folia Geobot
https://doi.org/10.1007/s12224-020-09370-8

Vascular plant diversity along an elevational gradient in the Central Himalayas, western Nepal

Chandra K. Subedi · Maan B. Rokaya · Zuzana Münzbergová · Binu Timsina · Janita Gurung · Nakul Chettri · Chitra B. Baniya · Suresh K. Ghimire · Ram P. Chaudhary

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Abstract Elevational gradients are linked with different abiotic and biotic factors, which in turn influence the distribution of plant diversity. In the present study we explored the relative importance of different environmental factors in shaping species diversity and composition of vascular plant species along an elevational gradient in the Chamelia Valley, Api-Nampa Conservation Area in western Nepal. Data were collected from 2,000 to 3,800 m above sea level and analysed using a generalized linear mixed model (GLM) and non-metric multidimensional scaling (NMDS). We recorded 231 vascular plant species consisting of 158 herb species belonging to 55 families, 37 shrub species belonging to 22 families and 36 tree species belonging to 23 families. Species richness and species abundance significantly decreased with increasing elevation. However, species richness increased with the intensity of vegetation cutting. Species richness and abundance also increased with increased annual precipitation and mean annual temperature whereas species abundance decreased with grazing, soil phosphorus and nitrogen. NMDS ordination revealed that mean annual temperature and annual precipitation affect the composition of vascular plant species in opposite ways to elevation. Among the many anthropogenic disturbances, only grazing affected species composition. In conclusion, more than one environmental factor contribute to the shaping of patterns of vascular plant species distribution in western Nepal. Knowledge on species diversity, distribution and underlying factors needs to be taken into consideration when formulating and implementing conservation strategies.

Keywords disturbance · soil nutrients · species abundance · species composition · species richness

C. K. Subedi (✉) · R. P. Chaudhary
Research Centre for Applied Science and Technology, Tribhuvan University, Kirtipur 44600, Nepal
e-mail: chandraks2000@yahoo.com

M. B. Rokaya · Z. Münzbergová
Institute of Botany, Czech Academy of Sciences, Zámek 1, 252 43 Průhonice, Czechia

M. B. Rokaya · B. Timsina
Department of Biodiversity Research, Global Change Research Centre, Czech Academy of Sciences, Bělidla 4a, 603 00 Brno, Czechia

Z. Münzbergová · B. Timsina
Department of Botany/Institute of Environmental Studies, Faculty of Science, Charles University, Benátská 2, 128 01 Prague, Czechia

J. Gurung · N. Chettri
International Centre for Integrated Mountain Development, Khumaltar, Lalitpur, Nepal

C. B. Baniya · S. K. Ghimire
Central Department of Botany, Tribhuvan University, Kirtipur 44600, Nepal

Introduction

Mountain regions have a unique biodiversity due to environmental heterogeneity and variation in the landscape (Körner 2003). Elevational gradients are the major

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ecological factor shaping spatial distribution of different species, including plants (Kluge et al. 2017). The effect of elevation is often linked to the variation in numerous abiotic and biotic factors, which in turn affect the distribution of different plant species (Kluge et al. 2017). It is therefore important to know how biotic factors (such as canopy cover, competition, herbivore damage, disturbance and grazing – Bhatta et al. 2015; Adhikari et al. 2017) and abiotic factors (such as temperature, precipitation and soil properties – Díaz et al. 1999; Laughlin and Abella 2007) affect distributional patterns of plant species along elevational gradients (Körner 2007). Generally, abiotic factors explain a higher proportion of variation in species composition in colder climate zones whereas in warmer climates biotic factors explain more variation (Laughlin and Abella 2007; Klanderud et al. 2015).

Among biotic factors, anthropogenic disturbances are the major ones affecting plant diversity and community composition (Harrelson and Matlack 2006) by favouring stress-tolerant species (Laughlin et al. 2005). According to the intermediate disturbance hypothesis (Fox 1979), species diversity is maximum when ecological disturbance (either natural or anthropogenic) is neither too rare nor too frequent (Molino and Sabatier 2001; Huston 2014; Yuan et al. 2016). The importance of disturbances, however, varies between localities (Bongers et al. 2009). Likewise, different abiotic factors, such as temperature, precipitation, soil nutrients and soil pH, affect productivity, which ultimately determine the carrying capacity of a particular area. This results in specific patterns of plant species diversity (Amjad et al. 2014; Peters et al. 2016) at local or regional scales (Zellweger et al. 2016).

There are some empirical studies on patterns of plant species distribution along elevational gradients in Nepal, studying ferns (Bhattarai et al. 2004), trees (Bhattarai and Vetaas 2006) and vascular plants (Panthi et al. 2007). Some studies have also covered sub-alpine forest border ecotone species (Shrestha and Vetaas 2009), woody plant species under different types of land use and on different slopes in trans-Himalayan valleys in central Nepal (Paudel and Vetaas 2014), plant species richness of different life-forms along a subtropical elevational gradient in eastern Nepal (Bhattarai and Vetaas 2003), and variation in forest biodiversity in central Nepal (Christensen and Heilmann-Clausen 2009). There is, however, limited research from western Nepal (Bhattarai et al. 2014). We therefore explored the effects of biotic and abiotic factors on species richness, abundance and composition of vascular plant species along an elevational gradient in western Nepal. The purpose was to provide further insights into distribution patterns of plant species along an elevational gradient (in a temperate region) in a less explored area in western Nepal. Specifically, we asked the following questions: (1) Do species richness, abundance and composition of different vascular plant species vary along the elevational gradient? (2) What are the different environmental factors responsible for shaping the patterns of richness, abundance and composition of vascular plant species after accounting for elevation? To answer these questions, we collected data on vascular plant species from 2,000 to 3,800 m a.s.l. in western Nepal and tested for the effects of abiotic and biotic factors on richness, abundance and composition of these plant species.

Material and methods

Study area

The study was conducted in the Chamelia Valley (Fig. 1) located in the Api-Nampa Conservation Area (ANCA; 29°30′ – 30°15′ N and 80–81°09′ E) in the Darchula district in western Nepal. The ANCA covers an area of 1,903 km^2 with an elevation range from 518 to 7,132 m a.s.l. Climate conditions vary from subtropical to alpine. The average maximum annual temperature of the area is 18.6°C, the minimum annual temperature is 7.7°C, and average annual precipitation is 2,129 mm (DoHM 2017). Vegetation in the ANCA is characterized by lower-temperate mixed broad-leaved forest (2,000–2,300 m a.s.l.), temperate mixed broad-leaved forest (2,400–2,600 m a.s.l.), upper temperate mixed broad-leaved forest (2,700–3,200 m a.s.l.) and birch-rhododendron forest (3,300–3,800 m a.s.l.). Data for our study were collected in the Chamelia Valley at an interval of 100 m elevation from Khayakot (2,000 m a.s.l.) to Shiyela (3,800 m a.s.l.).

Vegetation sampling

Our study only covered the elevation range from 2,000 to 3,800 m a.s.l. because below 2,000 m a.s.l. there was an agricultural field and above 3,800 m a.s.l. there

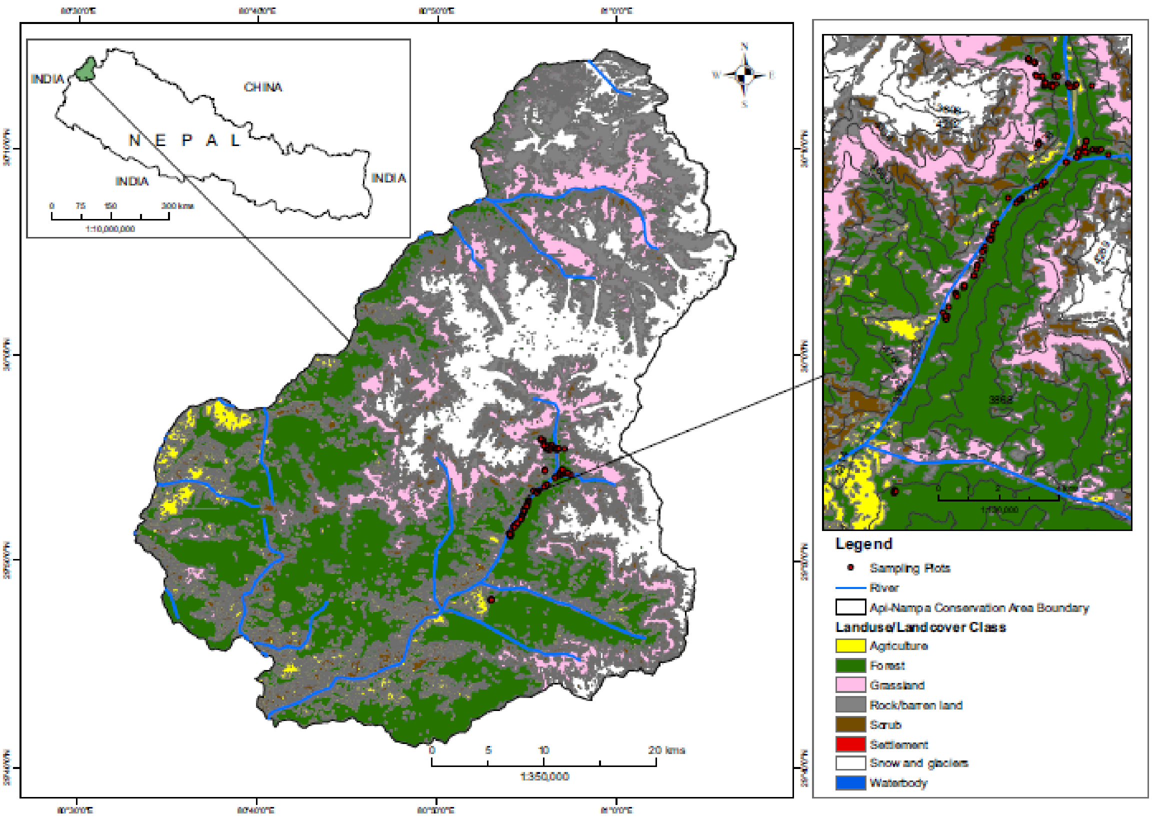

Fig. 1 Study area in the Chamelia Valley, western Nepal

was no forest. We carried out the field work during June and August 2014. We laid transects of 160 m at each study elevation comprising six quadrats (plots) of size 10 m × 10 m. The quadrats were 20 m apart from one another (Appendix Fig. 1). In total we used 19 transects with 114 quadrats along the elevational gradient. The presence or absence of different vascular plant species were recorded in each quadrat. All plant species were collected, kept between newspaper sheets, pressed by herbarium press and dried in sunlight (Forman and Bridson 1989). The collected species were later identified with the help of available literature (Sharma and Kachroo 1983; Polunin and Stainton 1984; Stainton 1988; Watson et al. 2011). We followed Press et al. (2000) for the species nomenclature.

In addition to recording vascular plant species in each quadrat, we noted the elevation by using an altimeter (Sunto), longitude and latitude by using a portable global positioning system (GPS) receiver (eTrex Vista, Garmin), and slope and aspect by using a compass (Sunto). Annual precipitation and mean annual temperature were obtained from WorldClim version 1.4 (www.worldclim.org – Hijmans et al. 2005).

Anthropogenic variables

As our study area was easily accessible from nearby villages, we predicted that human disturbance could play a vital role in maintaining patterns of species diversity. Therefore, disturbances such as grazing and cutting were visually estimated in each quadrat under study. They were recorded on a scale ranging from 0 (no disturbance) to 3 (highest level of disturbance).

Soil sampling and laboratory analysis

Top soil (0–10 cm) was collected from the centre of each 10 m × 10 m quadrat (i.e. 114 quadrats in total). Soil samples were stored separately in zip-lock plastic bags (Carter and Gregorich 2008) and transported to Kathmandu for analysis. In Kathmandu, soil was air-dried and then analysed at the Soil Science Division, National Agriculture Research Centre (NARC), Khumaltar, Lalitpur, Nepal.

Soil pH was determined in a 1:2 soil: water suspension and measured with a pH meter using a calomel electrode assembly (John et al. 2007). Soil organic carbon (SOC) was determined using the Walkley–Black method (Walkley and Black 1934), total nitrogen (N) using the Kjeldhal method (Jacobs 1951), and available phosphorus (P) and potassium (K) using the modified Olsen's bicarbonate method and a flame photometer, respectively (Walkley and Black 1934).

Statistical analysis

Data were analysed using three terms: species richness, abundance and composition. Plant species richness refers to the number of species in each sampling plot. Abundance of each species in each plot refers to the occurrence of the species in four subplots on the scale of 0 (if absent from all subplots) to 4 (if present in all four subplots). Species composition refers to the type of species encountered in each plot (Timsina et al. 2016).

We used Spearman's rank correlation in R (R Development Core Team 2019) to determine the relationships among different environmental variables.

To determine the effect of environmental variables (elevation, grazing, cutting, pH, SOC, total N, P, K, annual precipitation and mean annual temperature) on species richness, we used a generalized linear model (GLM) in R (R Development Core Team 2019). In the model, we first determined the effect of elevation and, if found significant, it was used as a covariate in subsequent analyses.

Patterns in plant species composition in different elevational bands were analysed by the non-metric multidimensional scaling (NMDS) ordination method. NMDS is an indirect gradient analysis that performs a certain number of random iterations until a convergent value of stress is obtained. It was applied to the whole samples-by-species data matrix of Bray-Curtis dissimilarity distances.

NMDS ordination was performed using the package 'vegan' with the function 'metaMDS' (Oksanen et al. 2019). Significant environmental variables were overfitted to the model. Final NMDS result with sample plots of varied abundance sample scores were fitted with significant environmental variables using the package 'ggplot2' (Wickham 2016).

Results

Elevation had significant negative correlations with cutting, annual precipitation and mean annual temperature. Cutting was positively correlated with grazing intensity. Carbon was positively correlated with total nitrogen. Available potassium was positively correlated with available phosphorus. Annual precipitation and mean annual temperature were also highly correlated with each other (Table 1).

In total, we recorded 231 plant species consisting of 158 herb species belonging to 55 families, 37 shrub species belonging to 22 families and 36 tree species belonging to 23 families (Appendix Table 1). Vascular

Table 1 Correlations of environmental variables. Values marked in bold are significant at $P < 0.05$, $N = 456$.

	Grazing	Cutting	pH	Potassium	Phosphorus	Nitrogen	Carbon	Annual precipitation	Mean annual temperature
Elevation	0.02	**−0.26**	−0.10	0.18	−0.12	−0.01	0.04	**−0.95**	**−0.96**
Grazing	1.00	**0.27**	−0.02	0.17	0.10	0.10	0.05	0.10	0.05
Cutting		1.00	0.00	0.01	−0.01	0.13	0.17	**0.20**	**0.24**
pH			1.00	−0.04	−0.10	0.01	−0.02	0.05	0.03
Potassium				1.00	**0.19**	−0.01	0.02	−0.16	**−0.19**
Phosphorus					1.00	−0.04	−0.08	0.12	0.09
Nitrogen						1.00	**0.88**	0.01	0.02
Carbon							1.00	−0.04	−0.03
Annual precipitation								1.00	**0.98**

plant species richness and abundance significantly decreased with increasing elevation (Fig. 2, Table 2). However, the greatest species richness and species abundance was actually observed at 2,500 m a.s.l. and at 2,300 m a.s.l, respectively (Fig. 2, Table 2).

Species richness increased significantly with increasing intensity of vegetation cutting (Fig. 3) and also with an increase in annual precipitation and mean annual temperature (Table 2). Plant abundance decreased with increasing grazing intensity (Fig. 4), soil phosphorus and total nitrogen (Table 2). Species abundance increased with increasing soil potassium, annual precipitation and mean annual temperature (Table 2).

Convergence of NMDS ordination was confirmed by obtaining stress value of 0.2 on the whole sample by species dataset. Vector fitting of environmental variables on samples by species dataset revealed that elevation, grazing, mean annual temperature and annual precipitation were significant (Table 3, Fig. 5). Elevation governed the significantly high NMDS1 score value of 0.967 ($P < 0.001$, $R^2 = 0.93$, Table 3). Mean annual temperature and annual precipitation were significantly negative with NMDS1 ($P = 0.001$, $R^2 = 0.906$ and $P = 0.001$, $R^2 = 0.868$ for both variables, respectively). The highest compositional abundances of species was found towards the high amount of mean annual temperature and annual precipitation gradients which were at lower elevations (negative end of NMDS1). Similarly, fewer number of species had high compositional abundances towards high elevation (positive end of NMDS1). Relatively, a small number of species had high compositional abundance at negative end of NMDS2 which was a grazing gradient ($P = 0.039$, $R^2 = 0.060$). Conversely, the compositional abundance was high in plots where there was no grazing and cutting, that is, the positive end of NMDS2 (Table 3, Fig. 5).

Discussion

Our present study indicates that there is a significant positive correlation between carbon and nitrogen because both soil carbon and nitrogen availability are mainly determined by the quantity of organic matter in the form of dead plants and animal debris in the ground (Aber and Melillo 2001). Similar findings have also been reported from moist temperate forests of Garhwal Himalaya, India (Gairola et al. 2012).

There was a monotonic decrease in species richness and abundance of vascular plant species along our elevational gradient in western Nepal. This decreasing pattern of species along the elevational gradient corroborates many previous studies from different parts of the world (Rahbek 2005; Sahu et al. 2008), including Nepal (Rokaya et al. 2012; Li and Feng 2015). However, there were differences in the details of the decline because of the variation in study sites (Baniya et al. 2012). In our study, the maximum number of vascular plant species

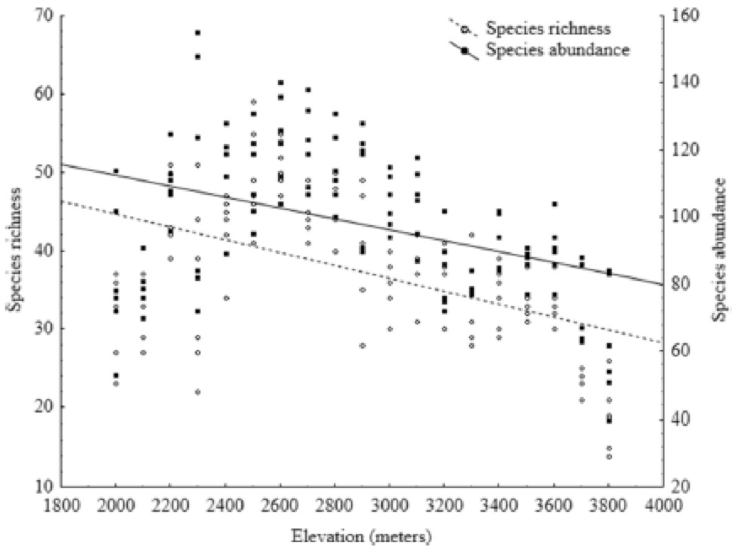

Fig. 2 Relationship between plant species richness, species abundance and elevation of vascular plant species

Table 2 The species richness part presents the results of generalized linear model (GLM) tests showing the associations between species richness and species abundance for all vascular plant species and different environmental variables (elevation, grazing, trampling, cutting, lopping, pH, potassium, phosphorus, nitrogen and carbon). Significant *P*-values are marked in bold.

	D.f.	Species richness		Species abundance	
		P	R^2	*P*	R^2
Elevation	1	< **0.001**	0.224	< **0.001**	0.161
Grazing	3	0.543	–	< **0.001**	0.048
Cutting	3	0.029	0.033	< **0.001**	0.036
pH	1	0.572	–	0.402	–
Potassium	1	0.057	–	**0.016**	0.010
Phosphorus	1	0.092	–	**0.010**	0.012
Nitrogen	1	0.164	–	**0.043**	0.007
Carbon	1	0.259	–	0.851	–
Annual precipitations	1	**0.031**	0.017	0.004	0.015
Mean annual temperature	1	**0.001**	0.043	< **0.001**	0.033

was precisely at 2,500 m a.s.l. whereas in other studies (Grytnes and Vetaas 2002; Christensen and Heilmann-Clausen 2009) this occurred between 1,500 and 2,500 m a.s.l. This shows that the distribution pattern of vascular plant species in western Nepal is partly represented by all vascular plant species in Nepal. As expected, there was great vascular plant species richness at lower elevations compared to higher elevations because of variation in precipitation and temperature. The decrease in species richness with increasing elevation is related to the harsh climate and unfavorable physiography towards the higher elevations (Rokaya et al. 2012). Environmental harshness at high elevations is a result of lower temperatures and increased solar radiation (Körner 2007), decreased soil fertility (Drollinger et al. 2017; Halbritter et al. 2018), and also the presence of steep, rugged topography with little top soil (Miehe et al. 2015).

The pattern of increased species diversity with increasing vegetation cutting occurs when cutting trees and shrubs exposes understorey vegetation to sunlight, which makes it grow more vigorously (Abella and Springer 2015). Although partial cutting is beneficial for the growth of plant species, cutting of vegetation on

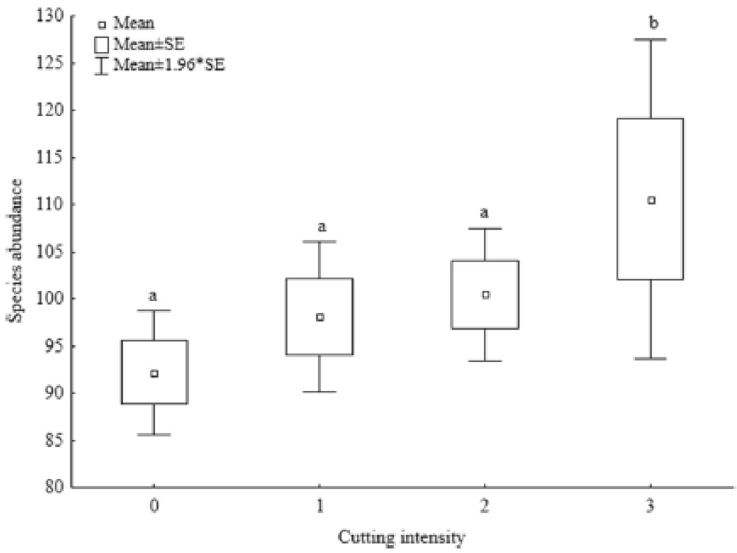

Fig. 3 Relationship between species abundance of vascular plant species and cutting intensity

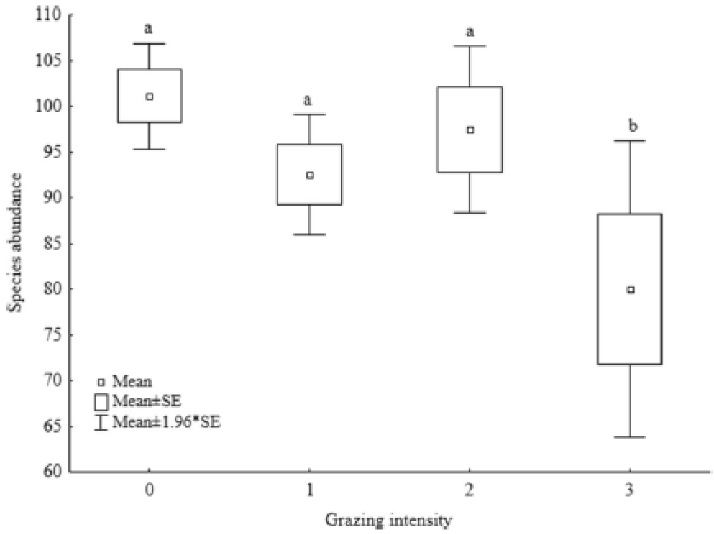

Fig. 4 Relationship between species abundance and grazing intensity

larger scales has a negative impact on plant diversity (Santaniello et al. 2016).

Decreased species abundance with increasing grazing level has also been reported from other parts of the world, but only in arid conditions and not in moist conditions (de Bello et al. 2007). Our study site was neither in a moist nor in a dry area; it falls under the montane belt of the Himalayas, characterized by moderate warmth and higher humidity. The study site was also situated along the way to a summer pastureland where herders let their animals graze for a few days while moving up during May and down during September. Different plant species are mostly in their budding stages during May and their destruction by grazing may have serious effects on seed formation. Zhao et al. (2019) also reported that grazing limited plant buds and long-term grazing exclusion significantly increased plant buds. Our study does not support the intermediate disturbance hypothesis, because there is no maximum species diversity in neither undisturbed nor in highly disturbed sites (Fox 1979). This is probably caused by different grazing or cutting patterns in our study site than where the theory was tested (Bongers et al. 2009). People have been practising a traditional system of grazing system at our study site. Globally, soil nutrients affect plant diversity and community composition (Gilliam and Dick 2010; Lin et al. 2013). In our study, vascular plant species richness decreased with increased phosphorus, potassium and nitrogen. Similar findings have been made by other studies in the case of phosphorus but not for potassium and nitrogen (Wassen et al. 2005; Merunková and Chytrý 2012). In a different study, there was a positive correlation between herb species richness and nutrients such as nitrogen and phosphorus (Bartels and Chen 2010). Such dissimilarities could be caused by variation in sampling strategy, physiography and climatic conditions between our study and other studies. However, plant diversity should significantly increase with increasing amounts of soil nutrients, as high soil nutrients improve plant growth (Denslow 1987). Our results showing lower species

Table 3 Results of NMDS ordination of the samples-by-species dataset. Presented are scores on the NMDS1 and NMDS2 axes, significance values and coefficients of determination for the environmental variables examined. Significant *P*-values are marked in bold.

Variable	NMDS1	NMDS2	*P*	R^2
Elevation	0.967	−0.256	0.001	0.935
Grazing	0.011	−1.000	**0.039**	0.060
Cutting	−0.962	0.274	0.053	–
pH	−0.299	0.954	0.782	–
Potassium	0.905	−0.425	0.063	–
Phosphorus	−0.311	0.950	0.243	–
Nitrogen	−0.140	−0.990	0.677	–
Carbon	0.995	0.096	0.939	–
Annual precipitations	−1.000	0.026	**0.001**	0.868
Mean annual temperature	−0.999	0.054	**0.001**	0.906

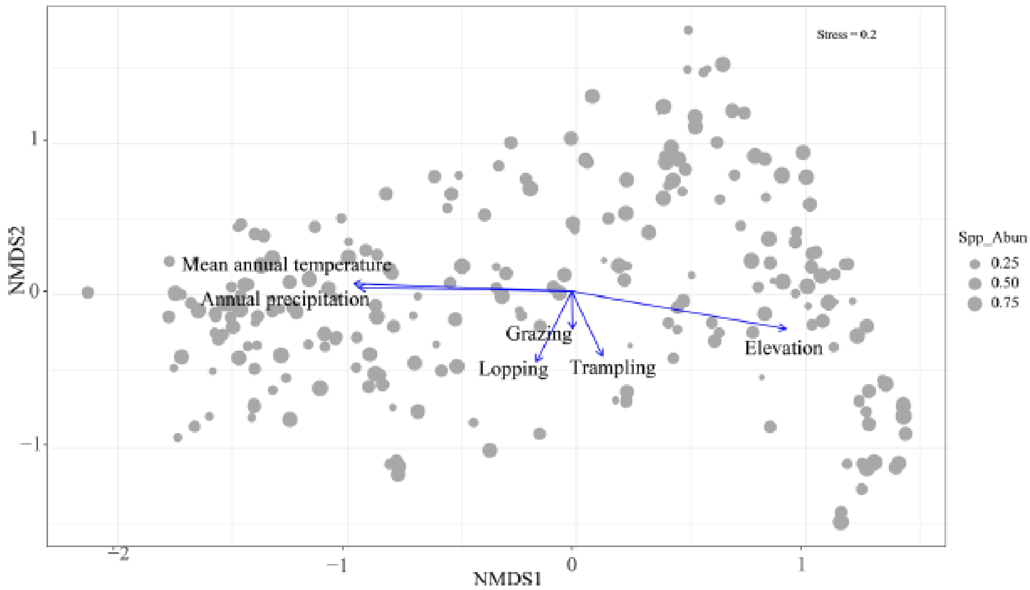

Fig. 5 Effect of different environmental variables on the composition of all plant species, analysed by NMDS. Only significant variables are shown

richness in nitrogen-rich environments are quite surprising because nitrogen has been repeatedly demonstrated to increase plant growth (Huston 1980; Lawlor et al. 2001). However, there was variation in loss of species richness in different habitats in Britain (Maskell et al. 2010). It has been explained that there is a reduction in species richness because of soil acidification associated with increased N deposition. Acids are formed due to oxidation of NO_2 to NO_3^- or NH_4^+ to NO_3^-. Having a negative correlation between plant diversity and phosphorus is also a result of phosphorus deposition leading to soil acidification.

Elevation contributed greatly to the composition of plant species like in other studies (Panthi et al. 2007; Christensen and Heilmann-Clausen 2009; Timsina et al. 2016). Among disturbance variables, grazing also significantly contributed to the variation in species composition. The negative correlation of elevation with temperature and precipitation is similar to one study conducted in China (Li et al. 2009). The contribution of temperature and precipitation to the shaping of the composition of vascular plant species was obvious because the present study was carried out at a site with high abundances of species where there was high mean annual temperature and annual precipitation (Panthi et al. 2007).

Anthropogenic disturbances often suppress recruitment, survival and growth of plant species by modifying the soil seed bank and soil nutrition (Khurana and Singh 2001). However, in our study soil nutrients did not affect species composition, meaning that ongoing anthropogenic disturbances are more important in shaping the species composition of vascular plant species in western Nepal.

Implication for biodiversity conservation

Different environmental factors play important roles in the distribution of plant species in the Chamelia Valley, western Nepal. Among different biotic factors, anthropogenic disturbance is the most important factor that influences plant diversity. Since the livelihoods of mountain people rely on forest resources, mainly for timber, fuel-wood, non-timber forest products and cattle grazing, the human dimension must be taken into account when declaring certain areas as protected areas for conservation and development activities. Cutting and grazing are the major anthropogenic disturbances in forest areas resulting in immense pressure on plant diversity in the ANCA. In the long term, such disturbances will affect ecosystem health and resilience. The present study area, which is located along the way to summer pasture-lands is impacted by residents of nearby villages, medicinal plant collectors and cattle grazers. Clearance of natural vegetation by human activities not only leads to the destruction of natural forests, but also to the introduction of invasive species. Invasive species are potential threats to local and regional biodiversity. Therefore, further studies should be carried out to ascertain the impacts of human disturbances on different plant species along with biodiversity in general. It is also necessary to provide alternative resources in order to reduce the dependence of local communities on forestry, as socio-ecological dimensions are important for developing future conservation strategies.

Conclusion

We studied vascular plant species diversity and composition along an elevational gradient in the Chamelia Valley in western Nepal. Species diversity patterns (species richness, abundance and composition) were affected by different abiotic and biotic factors. Accounting for environmental factors is therefore necessary for better understanding the spatial distribution of plant species. Knowing patterns of species diversity is important when formulating future strategies for plant and biodiversity conservation.

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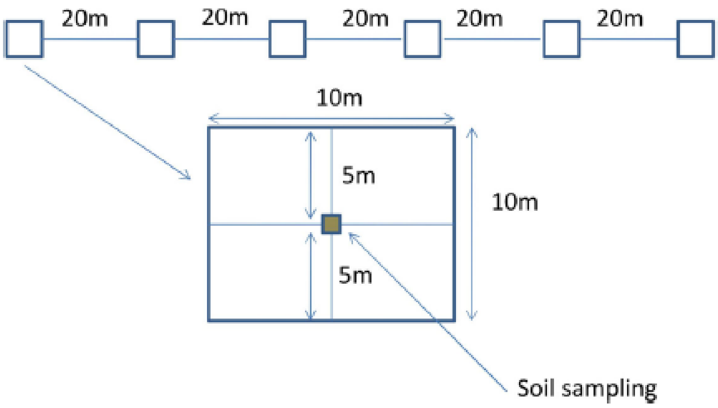
Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix



Appendix Fig. 1. Sampling design for the vegetation survey in the Chamelia Valley, western Nepal.

Appendix

Appendix Table 1 List of plant species recorded in the sampling plots.

Plant species	Life form
Abies spectabilis (D. Don) Mirb.	Tree
Acer cappadocicum var. *indicum* (Pax) Rehder	Tree
Acer pectinatum Wall. ex G.Nicholson	Tree
Acer sterculiaceum var. *tomentosum* E. Murray	Tree
Achyranthes bidentata Blume	Herb
Aconitum spicatum (Bruhl) Stapf	Herb
Aconogonum molle var. *frondosum* (D. Don) *H. Hara*	Herb
Aconogonum rumicifolium (Royle ex Bab.) H. Hara	Herb
Actaeaspicata var. *acuminata* (Wall. ex Royle) H. Hara	Herb
Adiantum capillus-veneris L.	Herb
Aesculus indica (Colebr. ex Cambess.) Hook.	Tree
Ageratum conyzoides L.	Herb
Ainsliaea latifolia (D. Don) Sch. Bip.	Herb
Alnus nepalensis D. Don	Tree
Amaranthus lividus L.	Herb
Anaphalis triplinervis var. *intermedia* (DC.) Airy Shaw	Herb
Anemone demissa Hook. f. &Thoms	Herb
Anemone vitifolia Buch.-Ham. ex DC.	Herb
Anemone tetrasepala Royle	Herb
Angelica glauca Edgeworth	Herb
Anisomeles indica (L.) Kuntze	Herb
Arabidopsis himalaica (Edgew.) O. E. Schulz	Herb
Arisaema consanguineum Schott	Herb
Arisaema flavum (Forssk.) Schott	Herb
Arisaema tortuosum (Wall.) Schott	Herb
Artemisia dubia Wall. ex Besser	Herb
Artemisia gmelinii Weber ex Stechm.	Herb
Asparagus racemosus Willd.	Herb
Aster diplostephioides (DC.) C. B. Clarke	Herb
Aster falconeri subsp. *nepalensis* Grierson	Herb
Astilbe rivularis Buch.-Ham. ex D. Don	Herb
Astragalus donianus DC.	Herb
Berberis aristata var. *floribunda* (G. Don) Hook. f. & Thomson	Shrub
Berberis asiatica Roxb. ex DC.	Shrub
Betula alnoides Buch.-Ham. ex D. Don	Tree
Betula utilis D. Don	Tree
Bidens pilosa var. minor (Blume) Sherff	Herb
Bistorta affinis (D. Don) Greene	Herb
Bistortaamplexicaulis var. *amplexicaulis* (D. Don) Greene	Herb
Boehmeria ternifolia D. Don	Herb
Bupleurum falcatum subsp. *marginatum* (Wall. ex DC.) H. Wolff	Herb
Buxus wallichiana Baill.	Tree
Calanthe tricarinata Lindl.	Herb
Caltha palustris var. *himalensis* (D. Don) Mukerjee	Herb
Campanula aristata Wall.	Herb
Capsella bursa-pastoris (L.) Medik.	Herb
Cardamine violacea (D. Don) Wall.	Herb
Cardiocrinum giganteum (Wall.) Makino	Herb
Carex sp.	Herb
Cautleya spicata (Sm.) Baker	Herb
Celtis australis L.	Tree
Cephalanthera longifolia (L.) Fritsch	Herb
Chaerophyllum villosum Wall. ex DC.	Herb
Cheilanthes rufa D. Don	Herb
Cirsium wallichii var. *glabratum* (Hook. f.) Wendelbo	Herb
Clematis connata DC.	Herb
Clematis montana Buch.-Ham. ex DC.	Herb
Coleus barbatus (Andrews) Benth.	Herb
Colocasia fallax Schott	Herb
Commelina paludosa Blume	Herb
Corydalis cashmeriana Royle	Herb
Corydalis juncea Wall.	Herb
Corylus jacquemontii Decne.	Tree
Cotoneaster frigidus Wall. ex Lindl.	Tree
Crotalaria cytisoides Roxb. ex DC.	Herb
Cuscutaeuropaea var. *indica* Englem.	Herb
Cyananthus lobatus Wall. ex Benth.	Herb
Cyathula tomentosa (Roth) Moq.	Shrub
Cynoglossum amabile Stapf&Drumm.	Herb
Cyperus sp.	Herb
Cypripedium sp.	Herb
Daphne papyracea Wall. ex Steud.	Shrub
Delphinium himalayai Munz	Herb
Desmodium elegans DC.	Shrub
Deutzia compacta Craib	Shrub
Dioscorea deltoidea Wall. ex Griseb.	Herb
Dipsacus inermis var. *mitis* Wall.	Herb
Drepanostachyum falcatum (Nees) Keng f.	Shrub
Dubyaea hispida DC.	Herb
Elaeagnus parvifolia Wall. ex Royle	Tree
Elatostema sessile J. R. & G. Forst.	Herb
Elsholtzia fruticosa (D. Don) Rehder	Shrub

Appendix Table 1 (continued)

Plant species	Life form
Euonymus fimbriatus Wall.	Tree
*Euonymus porphyreus*Loes.	Tree
Fagopyrum dibotrys (D. Don) H. Hara	Herb
Ficus sarmentosa Buch.-Ham. ex Sm.	Shrub
Fragaria nubicola Lindl. ex Lacaita	Herb
Fritillaria cirrhosa D. Don	Herb
Galium asperuloides subsp. *hoffmeisteri* (Klotzsch) H. Hara	Herb
Galium paradoxum Maxim.	Herb
Geranium nepalense Sweet	Herb
Geranium pratense L.	Herb
Girardinia diversifolia (Link) Friis	Herb
Habenaria pectinata D. Don	Herb
Halenia elliptica D. Don	Herb
Hedera nepalensis K. Koch	Herb
Hedychium sp.	Herb
Hemiphragma heterophyllum Wall.	Herb
Heracleum lallii C. Norman	Herb
Heracleum sp.	Herb
Herminium duthiei Hook. f.	Herb
Hippophae salicifolia D. Don	Tree
Holboellia latifolia Wall.	Shrub
Hydrangea anomala D. Don	Shrub
Hydrangea heteromalla D. Don	Tree
Ilex dipyrena Wall.	Tree
Impatiens bicornuta var. *bicornuta* Wall.	Herb
Impatiens sulcata Wall.	Herb
Impatiens urticifolia Wall.	Herb
Imperata sp.	Herb
Indigofera bracteata Graham ex Baker	Shrub
Jasminum dispermum Wall.	Shrub
Jasminum humile L.	Shrub
Juglans regia L.	Tree
Juncus sp.	Herb
Lamium album L.	Herb
Lathyrus laevigatus subsp. *emodi* (Waldst. & Kit.) Gren.	Herb
Lecanthus peduncularis (Royle) Wedd.	Herb
Lepisorus sp.	Herb
Leucas lanata Benth.	Herb
Leucosceptrum canum Sm.	Shrub
Leycesteria formosa Wall.	Shrub
Ligularia amplexicaulis DC.	Herb
Lilium nanum Klotzsch	Herb
Lilium nepalense D. Don	Herb

Appendix Table 1 (continued)

Plant species	Life form
Lonicera quinquelocularis Hardw.	Tree
Lonicera webbiana Wall. ex DC.	Shrub
Lygodium japonicum (Thunberg) Swartz	Herb
Lysimachia ferruginea Edgew.	Herb
Lysionotus serratus D. Don	Herb
Maianthemum purpureum (Wall.) LaFrankie	Herb
Meconopsis sp.	Herb
Microsorum sp.	Herb
Morina longifolia Wall. ex DC.	Herb
Myriactis nepalensis Less.	Herb
Neolitsea pallens (D. Don) Momiy. & H. Hara ex H. Hara	Tree
Neottia listeroides Lindl.	Herb
Nepeta erecta (Boyle ex Benth.) Berth.	Herb
Nepeta lamiopsis Benth. ex Hook. f.	Herb
Nephrolepis sp.	Herb
Oxalis corniculata L.	Herb
Paeonia emodi Wall. ex Royle	Herb
Parasenecio chenopodifolius (DC.) Grierson	Herb
Paris polyphylla subsp. *wallichii* Sm.	Herb
Parnassia nubicola Wall. ex Royle	Herb
Parochetus communis Buch.-Ham. ex D. Don	Herb
Pedicularisgracilis Wall. ex Benth.	Herb
Pedicularis klotzschii Hurus.	Herb
Persicaria capitata (Buch.-Ham. ex D. Don) H. Gross	Herb
Philadelphus tomentosus f. *nepalensis* Wall. ex G. Don	Shrub
Phlomis bracteosa Royle ex Benth.	Herb
Pilea racemosa (Royle) Tuyama	Herb
Pilea umbrosa Blume	Herb
Piptanthus nepalensis (Hook.) D. Don	Shrub
Pleurospermum angelicoides (DC.) C. B. Clarke	Herb
Podophyllum hexandrum Royle	Herb
Polygonatum cirrhifolium (Wall.) Royle	Herb
Polygonatum verticillatum (L.) All.	Herb
Polystichum prescottianum (Wallich ex Mettenius) T. Moore	Herb
Potentilla argyrophylla var. *atrosanguinea* Wall. ex Lehm.	Herb
Potentilla cuneata Wall. ex Lehm.	Herb
Prenanthes brunoniana Wall. ex DC.	Herb
Primula involucrata Wall. ex Duby	Herb
Prinsepia utilis Royle	Shrub
Prunus cornuta (Wall. ex Royle) Steud.	Tree
Prunus napaulensis (Ser.) Steud.	Tree
Pyracantha crenulata (D. Don) M. Roem.	Shrub

Appendix Table 1 (continued)

Plant species	Life form
Quercus semecarpifolia Sm.	Tree
Ranunculus diffusus DC.	Herb
Rheum australe D. Don	Herb
Rhodiola chrysanthemifolia (H. Léveillé) S. H. Fu	Herb
Rhododendron arboreum Sm.	Tree
Rhododendron barbatum Wall. ex G. Don	Tree
Rhododendron campanulatum D. Don	Shrub
Rhus wallichii Hook. f.	Tree
Ribes glaciale Wall.	Shrub
Ribes luridum Hook. f. & Thomson	Shrub
Rosa macrophylla Lindl.	Shrub
Rosa sericea Lindl.	Shrub
Rubia manjith Roxb. ex Fleming	Herb
Rubia wallichiana Decne.	Herb
Rubus biflorus Buch.-Ham. ex Sm.	Shrub
Rubus calycinus Wall. ex D. Don	Herb
Rumex acetosa L.	Herb
Salix hylematica C. K. Schneid.	Shrub
Salix tetrasperma var. *pyrina* Roxb.	Tree
Sarcococca saligna (D. Don) Mull. Arg.	Shrub
Saurauia napaulensis DC.	Tree
Saussurea fastuosa (Decne.) Sch. Bip.	Herb
Saxifraga parnassifolia D. Don	Herb
Saxifraga sp.	Herb
Scurrula elata (Edgew.) Danser	Shrub
Scutellaria prostrata Jacq. ex Benth.	Herb
Sedum multicaule Wallich ex Lindley	Herb
Selaginella sp.	Herb
Selinum wallichianum (DC.) Raizada & Saxena	Herb
Senecio chrysanthemoides DC.	Herb
Silene stracheyi Edgew.	Herb
Smilax aspera L.	Shrub
Solena heterophylla Lour.	Herb
Sorbus lanata (D. Don) Schauer	Tree
Sorbus microphylla Wenz.	Tree
Spiraea bella Sims	Shrub
Stachys melissaefolia Benth.	Herb
Stellaria media Vill.	Herb
Stellaria monosperma f. *paniculata* (Edgew.) Majumdar	Herb
Stephania glabra (Roxb.) Miers	Herb
Strobilanthes attenuata subsp. *nepalensis* J. R. I. Wood	Shrub
Strobilanthes tomentosa (Nees) J. R. I. Wood	Herb
Swertia chirayita (Roxb. ex Fleming) Karsten	Herb

Appendix Table 1 (continued)

Plant species	Life form
Swertia ciliata (D. Don ex G. Don) B. L. Burtt	Herb
Swertia petiolata D. Don	Herb
Syringa emodi Wall. ex Royle	Shrub
Taxus contorta Griff.	Tree
Tetrastigma serrulatum (Roxb.) Planch.	Herb
Thalictrum cultratum Wall.	Herb
Thalictrum foliolosum DC.	Herb
Thelypteris erubescens (Wall. ex Hook.) Ching	Herb
Toona serrata (Royle) M. Roem	Tree
Trifolium repens L.	Herb
Trigonella emodii Benth.	Herb
Tsuga dumosa (D. Don) Eichler	Tree
Ulmus wallichiana Planch.	Tree
Urtica ardens Link	Herb
Valeriana hardwickii Wall.	Herb
Veronica cana Wall. ex Benth.	Herb
Viburnum cotinifolium D. Don	Shrub
Viburnum erubescens Wall. ex DC.	Tree
Viburnum mullaha Buch.-Ham. ex D. Don	Shrub
Viola biflora L.	Herb
Vitis parvifolia Roxb.	Shrub

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Variation in structure and composition of two pine forests in Kailash Sacred Landscape, Nepal

C. K. Subedi[1]*, J. Gurung[2], S. K. Ghimire[3], N. Chettri[2], B. Pasakhala[2], P. Bhandari[1] and R. P. Chaudhary[1]

Chir pine (*Pinus roxburghii* Sarg.) and blue pine (*Pinus wallichiana* A.B. Jacks.) are two common species found in mid-hill forests of Nepal where households largely depend on forest resources for their livelihoods and subsistence. The management of such forests is supported by our understanding of the dynamics in forest structure and species composition and the relationship between different forest community characteristics. This study was designed to determine the variation in species composition and the relationship between various forest community characteristics in two pine forests of Kailash Sacred Landscape, Nepal.Quadrat sampling was applied to collect information on forest species, forest community structure, and disturbance factors.Data was statistically analyzed using IBM SPSS. There were a total of31 plant species under 28 genera and 20 families in the *P. roxburghii* forest, and 38 plant species under 37 genera and 19 families in the *P. wallichiana* forest. Mean DBH, height and canopy diameter of *P. roxburghii* was 23.98 cm, 12.77 m and 1.97 m, respectively, and that of *P. wallichiana* was 31.5 cm, 11.48 m and 2.79 m, respectively. The relationship between DBH and both height and crown diameter showed strong relationships in the two forest types.In both forests, DBH and height class distribution showed a hump-shaped (unimodal type) distribution with a greater proportion of medium-sized individuals that indicated disruptive forest regeneration. Fire and tree-cut were significant disturbance factors in *P. roxburghii* forest, while grazing and trampling were significant in *P. wallichiana* forest. The extent of these disturbance factors as determinants of regeneration and species recruitment is important to assess for effective forest management.

Key words: Community characteristics, disturbance, forest structure, *Pinus roxburghii, Pinus wallichiana*

The structure of a forest is determined by biotic and abiotic components (Behera *et al*., 2012; Mishra *et al*., 2013), along with human disturbance (Sanderson *et al*., 2002; Kareiva *et al*., 2007). Disturbance and biological processesare significant factors determining forest stand development (Franklin *et al*., 2002). Both forest structure and composition respond to environmental fluctuations and anthropogenic activities (Gairola *et al*., 2008). Moreover, stand structure, tree size and composition are key characteristics for maintaining ecological integrity and dynamics of forest ecosystems and their functions (Elourad *et al*., 1997;Kuuluvainen, 2002;Larsen *et al*., 2005; Merlin *et al*., 2014). These are also the basis for developing forest management and conservation strategies (Gutierrez and Huth, 2012). In mountain areas, forest structure and composition is regulated by slope orientation and elevation which both affect incoming solar radiation in an area (Gallardo-Cruz *et al*., 2009). Topographic variables, such as radiation, in turn affect species composition between slopes due to their influence on small-scale abiotic environmental variables (Ferrer-Castan and Vetaas, 2003; Paudel and Vetaas, 2014).

1. Research Centre for Applied Science and Technology (RECAST), Tribhuvan University, Kirtipur, Kathmandu, Nepal
* E-mail: chandraks2000@yahoo.com
2. International Centre for Integrated Mountain Development (ICIMOD), Khumaltar, Lalitpur, Nepal
3. Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu, Nepal

Chir pine (*Pinus roxburghii* Sarg.) and blue pine (*Pinus wallichiana* A.B. Jacks.) are two pine species distributed mainly in the western Himalaya while also flourishing in Bhutan (Ohsawa *et al*., 1986). They are commercially important plant species in the Himalaya used for timber, turpentine and several medicinal and cultural purposes (Tiwari, 1994; Siddique *et al*., 2009). Several research studies have been conducted on these pine species from different parts of the Himalaya. A review of *P. roxburghii* was made by Kaushik *et al*. (2013) on ethnobotany and phytopharmacology. Dendrochronological study was carried out to determine the impact of climate change on growth of *P. wallichiana* (Bajwa *et al*., 2015). Similar work was conducted on *P. roxburghii* to understand stand age, structure, soil erosion, disturbance history and tree health (Speer *et al*., 2016). Composition, population structure and diversity of *P. wallichiana* in Garhwal Himalaya with special reference to altitude and aspect was studied by Bhandari (2003). Study on phytosociology of *P. roxburghii* was conducted by Siddique *et al*. (2009) in the lesser Himalaya and Hindukush range of Pakistan. Ghimire *et al*. (2010) carried out research on regeneration of *P. wallichiana* in the trans-Himalayan dry valley of north-central Nepal. Most research conducted in Nepal on these pine species are focused on allometric relationships for biomass prediction (Sharma and Pukkala, 1990), basal area growth model (Gyawali *et al*., 2015), dendrochronology (Schwab *et al*., 2015) and carbon sequestration (Aryal, 2016).

In Nepal, chir pine and blue pine constitute 8.45% and 3.37%, respectively, of total forest area (DFRS, 2015). The two species are also the major constituents of forests in the midhills of Nepal (DFRS, 2015) where households largely depend on forest resources for their livelihoods and subsistence (Springate-Baginski *et al*., 2003). Long-term studies on forest socio-ecological systems are lacking in Nepal. This study was conducted in two pine-dominated community managed forests of Kailash Sacred Landscape (KSL) in Nepal to collect baseline information as part of a long-term socio-ecological study of forest ecosystems in the landscape. Knowledge on forest structure and composition is important for their management, but such studies are lacking in the landscape. Thus, the findings of this study will contribute to forest management while also providingbaseline data for long-term forest monitoring.The study addresses the following questions: 1) what are the variations in forest structure and species composition in chir pine and blue pine forests? and 2) what is the relationship between different community characteristics in the two pine forests ?

Materials and method

Study area

The study was carried out in KSL-Nepal (MFSC, 2016) (Fig. 1). The landscape, whichextendsbetween 29° 22' N to 30° 45'N latitude and 80° 15' E to 82° 10' E longitude, covers an area of 13,289 sq. km and comprises the districts of Baitadi, Bajhang, Darchula and Humla.Altitudesin KSL-Nepal range from 390 m to 7,132 m above sea level (masl). The climatic condition of the area is characterized by high rainfall and humidity, with average rainfall of 2,129 mm. Average maximum and minimum temperature is 18.6°C and 7.7°C, respectively. Forests occupy almost 30% of the total area of KSL-Nepal of which subtropical broadleaved forests (with *Shorea robusta*, *Terminalia alata*, and *Pinus roxburghii*) constitute 10% and uppermontane conifer forests (with *Cedrus deodara*, *Cupressus torulosa*, *Tsuga dumosa*, and *Pinus wallichiana*) constitute 3%.

Fig. 1: Map of the study area.

The forest survey was conducted in two community managed forests in the landscape: Kirmadhe Sinnadi in Hunainath Village Development Committee (VDC) of Darchula district and Kailash Kachaharikot Mahila in Kailash VDC of Bajhang district. Kirmadhe

Sinnadi community forest (CF) covers an area of 50.76 hectares (ha). Altitudes in this CF range from 1808 to 1958 m asl and slopes between 5° to 21°with the forest oriented towards east and west. *P. roxburghii* is the dominant tree species while other tree species include *Quercus lanata*, *Rhododendron arboreum* and *Myrica esculenta*. Kailash Kachaharikot Mahila CF covers an area of 20 hectares. Altitudes range from 1800 to 2100 masl and slope between 20° to 35°with the forest oriented towards south and west. *P. wallichiana* is the dominant tree species in this CF.

Field methods

Field work was conducted between May and June 2016 to establish permanent forest monitoring plots in the two pine forests. The boundaries of both forests were delineated using a Global Positioning System (GPS) device - Garmin Oregon 650. The forest boundary was then transferred to Google Earth map where a 20m*25m grid was overlaid. Sample forest plots were then randomly selected and verified in the field. Based on the total size of the CFs, ten permanent plots were established in *P. roxburghii* forest and four in *P. wallichiana* forest. Each plot was further divided into 20 5m*5m subplots to collect data on plant life forms (Fig. 2). The location of each plot was recorded using a GPS device, and topographic variables including altitude, slope and aspect were recorded with an altimeter (Suunto). In each plot, grazing, trampling, cutting, lopping and fire were visually estimated as disturbance variables. They were recorded on a scale ranging from 0 (no visible sign of disturbance) to 3 (high disturbance). Ocular estimate of top canopy (tree crown), mid canopy (canopy of shrubs and saplings) and low canopy (canopy of herbs, forbs and seedlings) was made from the center of each subplot.

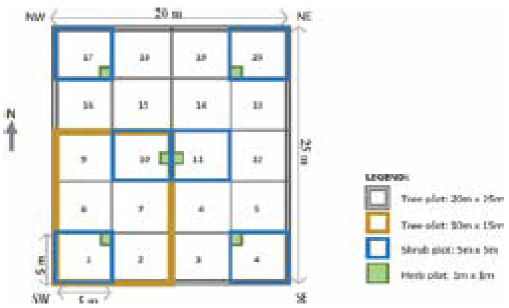

Fig: 2 Vegetation sampling design

Vegetation sampling

Based on diameter at breast height (DBH) and height (H) of the individual, plant species were classified in to three categories, *viz.* tree (>10 DBH), saplings (< 10 cm DBH and H >1.3 m) and seedlings (H<1.3 m) (Newton, 2007). Individual trees were recorded in the entire 20m*25m plot (hereby referred here as 'tree plot'). DBH of each individual tree was measured at 1.3 m height from the ground usingMillion diameter tape(YAMAYO) and its height with a Vertex IV (Haglof Sweden). Canopy of each individual tree was measured in eight directions from the center. Tree saplings were measured in a nested 10m*15 msubplot (sapling plot) within the tree plot. The number and percentage cover of shrubs were recorded in six 5m*5m subplots(shrub plot), four of which were fixed at the corners of the tree plot and two at the center. Similarly six 1m*1m subplots(herb plot) nested within the subplot were used to record herbaceous vegetation. The number of herb species and an ocular estimate of their percent cover was recorded. Most of the plant species were identified in the field withstandard flora (Stainton, 1997; Polunin and Stainton, 2000). Unidentified plant species were collected and later identified usingavailable literature (Sharma and Kachroo, 1983; Stainton, 1997; Polunin and Stainton, 2000) and by consulting herbarium specimens housed at Tribhuvan University Central Herbarium (TUCH) and National Herbarium and Plant Laboratory (KATH). Plant species nomenclature follows Press *et al.* (2000).

Statistical analysis

Spearmen's correlation was used to determine relationships between different characteristics of forest community and environmental variables. Linear regression analysis was performed to determine relationships between different forest community characteristics. The regression coefficients and equationswere obtained through a fitted line on the scattered plot, and F and p valueswere obtained through ANOVA. Before regression analysis,all disturbance variables (grazing, trampling, cut, harvesting and fire) were combined through dimension reduction process in Principle Component Analysis (PCA) to obtain a combined measure of disturbance. IBM SPSS was used for data analysis.

Table 1: Floristic composition in pine forests

Life form	Occurring in only		Common to both forests
	P. roxburghii forest	*P. wallichiana* forest	
Trees	*Alnus nepalensis, Quercus lanata*	*Symplocos paniculata, Viburnum erubescens*	*Lyonia ovalifolia, Rhododendron arboreum*
Shrubs	*Hedysarum kumaonense, Rubus paniculatus*	*Cotoneaster frigidus, Cotoneaster microphyllus, Daphne papyracea, Indigofera heterantha, Inulacappa, Myrsine africana, Prinsepia utilis, Pyracantha crenulata, Smilax aspera, Spiraea bella* and *Viburnum cotinifolium*	*Berberis asiatica, Rubus ellipticus*
Herbs	*Anaphalis busua, Cirsium wallichii, Commelina benghalensis, Curculigo orchioides, Drosera peltata, Fimbristylis dichotoma, Hypericum japonicum, Reinwardtia indica*	*Bidens pilosa, Centella asiatica, Gaultheria nummularioides, Gnaphalium affine, Origanum vulgare, Potentilla sundaica*	*Anaphalis triplinervis, Carex filicina, Erigeron karvinskianus, Flemingia strobilifera, Fragaria indica, Galiu melegans, Gonostegia hirta, Imperata cylindrica,, Micromeria biflora, Oplismenus compositus, Oxalis corniculata, Taraxacum parvulum, Viola serpens, Ageratina adenophora*

Results and discussion

Floristic composition

There were 31 plant species belonging to 28 genera and 20 families in *P. roxburghii* forest, and 38 plant species belonging to 37 genera and 19 families in *P. wallichiana* forest. Based on life forms, 22 herbs, 4 shrubs and 5 trees were recorded in the *P. roxburghii* forest, and 19 herbs, 13 shrubs and 4 tree species were found in *P. wallichiana* forest. 14 herbs, 2 shrubs, and 2 trees were common to both forests while 8 herbs, 2 shrubs and 3 trees were found exclusively in *P. roxburghii* forest and 6 herbs, 11 shrubs and 3 trees exclusively in *P. wallichiana* forest (Table 1).

P. roxburghii is invasive in nature and can easily replace broadleaved species, ultimately leading to monoculture forest development (Bhandari, 2003). It has competitive superiority than other species in obtaining resources (Bargali, 1997). It is a light demanding and fire promoting species. Surface fire causes substantial loss of nitrogen, and this depletion on nitrogen is the major cause of monoculture development of pineforests (Singh *et al*., 1984). Phytosociological analysis showed that *P. roxburghii* was generally distributed in pure form (Siddiqui *et al.* 2009). Pine forests are affected by fires especially in the summer season resulting in deterioration of soil fertility and development of new species. Fire reduces total organic matter, phosphorus and potassium (Benerjee and Chand, 1981; Ghotz and Fischer, 1982). In comparison to *P. roxburghii*, *P. wallichiana* tends to share its habitat with other tree species (Bhandari, 2003) resulting in higher species richness in this study.

Forest structure

The DBH and height class distribution of *P. roxburghii* population is presented in Fig.3 and of *P. wallichiana*in Fig. 4. In both forests,DBH and height class distribution showed hump-shaped (unimodal type) distribution with greater proportion of medium-sized individuals. There was a gradual increase in the proportion of individuals of DBH class up to >20-<30 cm for *P. roxburghii* and >30-<40 for *P. wallichiana*, and height class upto>10-<15 mfor *P. roxburghii* and >15-<20 m for *P. wallichiana* after which height class gradually decreased.

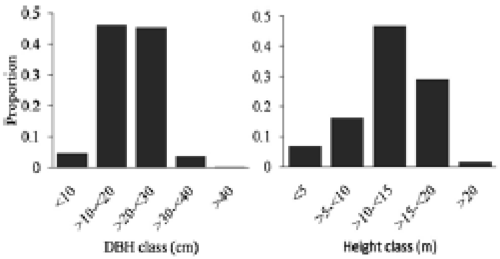

Fig. 3 DBH and height class distribution of *P. roxburghii*

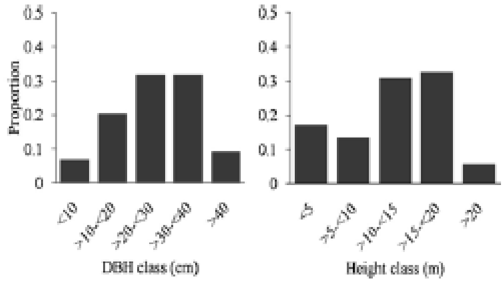

Fig. 4 DBH and height class distribution of *P. wallichiana*

The size distribution of trees is an important indicator for population dynamics and for forest management (Kohira and Ninomiya, 2003; White *et al*., 2007). This study showed that there were fewer juveniles as compared to adults in the two forests indicating disruptive regeneration probably due to disturbance (Condit *et al*., 1998; George *et al*., 2005; Deb and Sundriyal, 2008). A study on *P. roxburghii* in Bhutan showed unimodal distribution resulting from anthropogenic and natural disturbances (Wangda and Ohsawa, 2006). Both forests in KSL-Nepal are used by local communities, especially for extraction of timber, and hence the preference for large-sized trees. While felling such trees, the resulting disturbance on seedlings and saplings could possibly affect their regeneration.

Relationship between forest community characteristics

The forest community characteristics of *P. roxburghii* and *P. wallichiana* are presented in Table 2. Density of pine was high in both forests. Mean DBH, height and canopy diameter of *P. roxburghii* was 23.98 cm, 12.77 m and 1.97 m, respectively, and that of *P. wallichiana* was 31.5 cm, 11.48 m and 2.79 m, respectively. The mean top and mid canopy cover was higher in *P. wallichiana* forest than in *P. roxburghii* forest, but low canopy cover was highest in the latter forest.

Table 2: Community characteristics of *P. roxburghii* and *P. wallichiana* forest

Variables Mean (SE)		*P. roxburghii* Mean (SE)	*P. wallichiana*
Number of tree species		1.60(0.31)	2.00 (0.45)
Density of Pine (number/ha)		168.5 (7.15)	65.00 (3.73)
Mean DBH (cm)		23.99 (1.78)	31.02 (4.70)
Mean height (m)		12.77 (0.83)	11.49 (1.02)
Mean canopy diameter (m)		1.97 (0.19)	2.80 (0.15)
Canopy (%)	Top	27.03 (3.36)	32.75 (3.31)
	Mid	4.25 (0.60)	16.50 (1.96)
	Low	14.59 (1.18)	12.00 (2.61)

The dimension reduction process in PCA resulted in two PCA factors explaining 56.5% of variance: PCA factor 1 (31.32% variance) explained grazing (0.841) and trampling (0.858) as main associated variables; and PCA factor 2 (25.23% variance) explained tree cut (0.807) and fire (0.734) as main associated variables in *P. roxburghii* forest. In *P. wallichiana* forest, two PCA factors were obtained explaining 55.2% of variance: PCA factor 1 (35.25% variance) explained grazing (0.801) and trampling (0.851) as main associated variables, and PCA factor 2 (19.95% variance) explained tree cut (0.782), harvesting (0.517) and fire (0.539) as main associated variables.

The density of *P. roxburghii* was negatively correlated with mean DBH (r = -0.872, p = 0.01) and canopy diameter (r = -0.770, p = 0.01) and positively with disturbance factor 2, *i.e* fire and cut (r =0.792, p = 0.01). Since the local villagers had extracted large sized trees for timber and fire allows regeneration of pine seedlings (Paucas *et al*., 2004), large sized tree with larger DBH were absent in the forest. *P. roxburghii* can tolerate more stress and potentially colonize disturbed and moisture-deficient areas (Singh and Singh, 1992; Ryan and Yoder, 1997). Fire helped liberate seeds from cones allowing their regeneration and monospecific stand development in *Pinus halepensis* (Pausas *et al.,* 2004; Moya *et al.*, 2007). Tang *et al.* (2013) reported that the natural recovery of *Pinus yunnanensis* was more efficient after fire contributing to the density of pine in central Yunan, China. The mean DBH was positively correlated with mean canopy diameter ($r = 0.841$, $p = 0.01$). The mean crown radius was the function of stem size, stand density and site productivity and the canopy radius increased linearly with DBH (Avsar and Ayyildiz, 2005; Attocchi and Skovsgaard, 2015).

Strong negative correlation was found with canopy diameter and number of tree species ($r=0.987$, $p = 0.05$) in *P. wallichiana* forest. Crown morphology has important implications to compete with other species in a community (Messier, 1996; Messier *et al*., 1999). High tree canopy cover reduces the amount of solar radiation to the ground while facilitating more litter deposition which is not a favorable condition for seedling establishment (Spanos *et al*., 2001).

DBH-height relationship

A significant linear relationship ($p<0.001$) was found between DBH and height ($R^2 = 0.571$ for *P. roxburghii* and 0.551 for *P. wallichiana*) (Fig. 5 (a) and (b)). The strength in relationship between DBH and height of the two pine forests was not significantly different. The height–diameter relationship of trees are stand specific, site specific, and time specific and also differ within a site due to competition among trees (Trincado *et al*., 2007; Pretzsch, 2009; Schmidt *et al*., 2011). Tree diameter has a significant correlation with the height and age of the forest stand and thereby directly affects sustainable volume production (Khan *et al*., 2016). This correlation depends on the growing environment and stand conditions (Calama and Montero, 2004; Sharma and Zhang, 2004).

DBH-crown diameter relationship

Measurement of crown diameter is usually not carried out in forest inventory but is important to measure some competitive measures and to determine canopy cover (Biging *et al*., 1995; Gill *et al*., 2000; Popescu *et al*., 2003). The R^2 value obtained from regression between DBH and crown diameter in this study was 0.572 in *P. roxburghii* forest and 0.422 in *P. wallichiana* forest (Fig. 5 and 6). Gill *et al.* (2000) developed models for different coniferous trees of California and obtained R^2 values between 0.2691 and 0.6077 where DBH predicted most of the model. Incorporation of crown area into models improved accuracy of the predictions (Nakai *et al*., 2010; Gonzalez-Benecke *et al*., 2014).

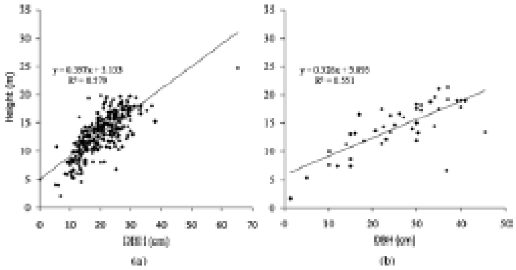

Fig 5 Regression between DBH and height of (a) *P. roxburghii* (b)*P. wallichiana*

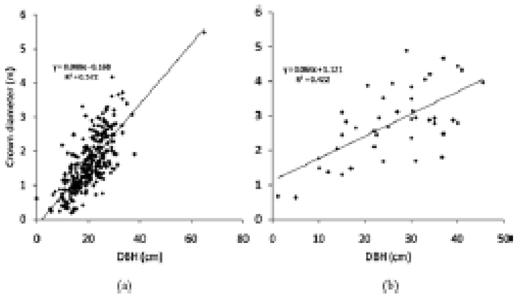

Fig 6 Regression between height and crown diameter of (a) *P. roxburghii and (b) P. wallichiana*

Conclusion

Pinus roxburghii and *Pinus wallichiana* are important needleleaved species occurring in subtropical broadleaved and upper montane conifer forests in KSL-Nepal. This study presents the forest structure and species composition of two pine forests selected for conducting long term socio-ecological research in the landscape. Both forests were dominated by the respective tree species, with mean number of tree species being 1.60 (± 0.31) in *P. roxburghii* forests and 2.00 (± 0.45) in *P. wallichiana* forests. Tree density averaged 168.5 (± 7.15) and 65.0 (± 3.73) stems per ha. in *P. roxburghii* and *P. wallichiana* forests, respectively. Size distribution of trees displayed a unimodal type with greater proportion of medium-sized individuals. The structure of both forests indicates that they are heavily disturbed. Fire and tree cut were significant disturbance factors in *P. roxburghii* forest, while grazing and trampling were significant in *P. wallichiana* forest. The extent of these disturbance factors as determinants of regeneration and species recruitment is important to assess for effective forest management.

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Chandra Kanta SUBEDI[a], Prabin BHANDARI[a,*], Santosh THAPA[a], Mohan PANDEY[a] Janita GURUNG[b], Lokesh Ratna SHAKYA[c] and Ram Prasad CHAUDHARY[a]

Cephalanthera erecta var. *oblanceolata* (*Orchidaceae*)—A New Record for the Flora of Nepal

[a]Research Centre for Applied Science and Technology, Tribhuvan University, Kirtipur, Kathmandu, NEPAL;
[b]International Centre for Integrated Mountain Development, Khumaltar, Lalitpur, NEPAL;
[c]Department of Botany, Amrit Campus, Tribhuvan University, Thamel, Kathmandu, NEPAL
*Corresponding author: prabinkb02@gmail.com

Summary: *Cephalanthera erecta* (Thunb.) Blume var. *oblanceolata* N. Pearce & P. J. Cribb (*Orchidaceae*) is reported from west and central Nepal. This is a new record for the flora of Nepal, and the western most distribution for the species. A brief note with habitat and distribution is provided.

Cephalanthera L. C. Richard (*Orchidaceae*; subfamily *Epidendroideae*; tribe *Neotiieae*) comprises about 15 species distributed in temperate zone of the northern hemisphere (Pridgeon et al. 2005, Chen et al. 2009). To date *Cephalanthera* is represented by a single species *C. longifolia* (L.) Fritsch, in Nepal (Press et al 2000, Rajbhandari 2015).

During establishment of a permanent plo for monitoring forest vegetation of Paripata Women Community Forest, Darchula District

Fig. 1. *Cephalanthera erecta* (Thunb.) Blume var. *oblanceolata* N. Pearce & P. J. Cribb. Habitat. Paripatal Women Community Forest, Darchula District, Western Nepal. 2 June 2016.

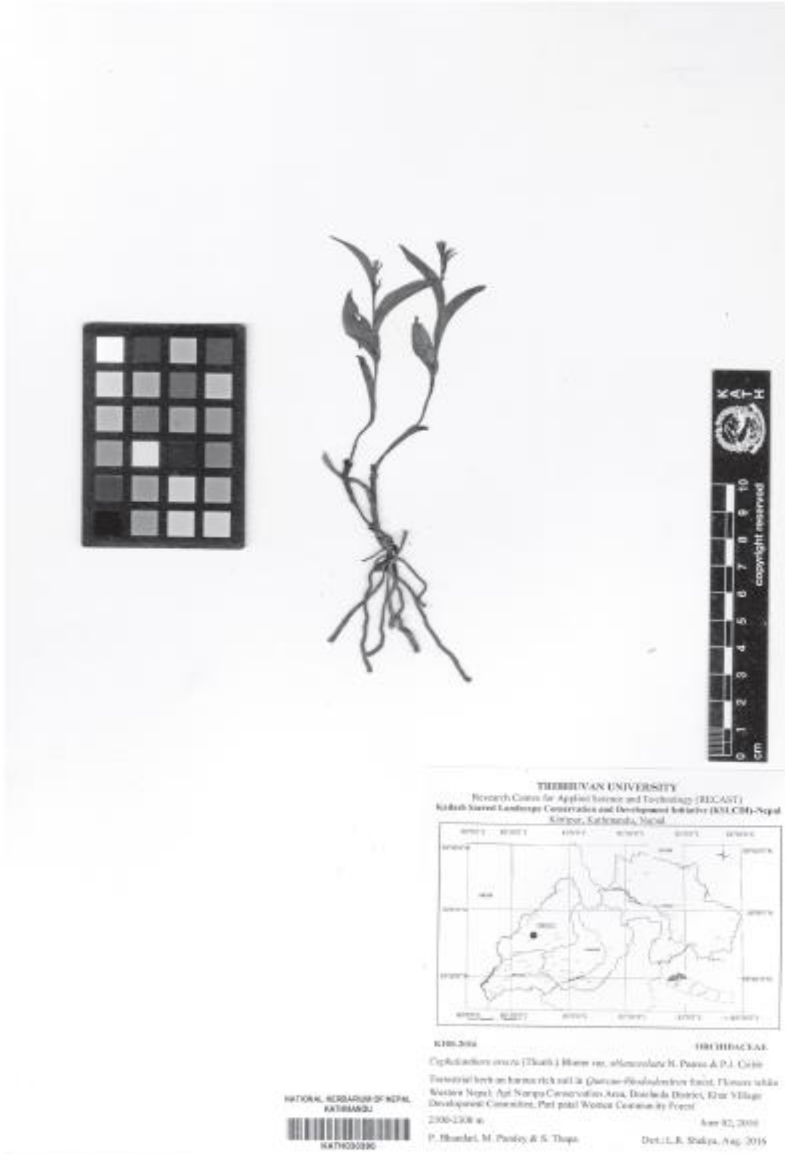

Fig. 2. *Cephalanthera erecta* (Thunb.) Blume var. *oblanceolata* N. Pearce & P. J. Cribb (P. Bhandari, M. Pandey & S. Thapa K100-2016, KATH030390).

Western Nepal, a species of *Cephalanthera* was collected in 2016. The plant was unusual in floral morphology; there was no distinction between sepals, petals and labellum. On checking relevant literature (Pearce et al. 2001, Pearce and Cribb 2002), this was found to be *Cephalanthera erecta* (Thunb.) Blume var. *oblanceolata* N. Pearce & P. J. Cribb. We also collected the same taxon in Phulchowki forest, Central Nepal in 2017.

Cephalanthera erecta var. *oblanceolata* is typically characterized by a simple lip, without spur, and is thought to be a peloric form of *C. erecta*, and is distributed in Bhutan, Korea and

Table 1. Comparison between *Cephalanthera erecta* and *C. longifolia* in morphological characters

Characters	*C. erecta*	*C. longifolia*
Plant height	up to 30 cm	up to 60 cm
Leaves	elliptic to ovate-lanceolate, ca. 2–8 cm long	lanceolate to linear-lanceolate, ca. 8–18 cm long
Inflorescence	racemose, ± laxly 3–10-flowered	racemose, ± densely 8–20-flowered
Sepals	oblong-elliptic, 8–10 × 2.5–3.5 mm	ovate-lanceolate, 12–18 × 4–6 mm
Lips	hypochile spurred, epichile with 3 brownish lamellae	hypochile saccate, epichile with 3–5 orange lamellae

Japan (Pearce and Cribb 2002, Lee et al. 2009, Takashima and Kurihara 2016). Although, the occurrence of *C. erecta* var. *erecta* has not been reported from Nepal (Hara et al. 1978, Press et al. 2000, Rokaya et al. 2013, Rajbhandari 2015), our finding is treated as a new record for the flora of Nepal, and is the western most distributional record for this species.

Cephalanthera erecta (Thunb.) Blume var. ***oblanceolata*** N. Pearce & P. J. Cribb in Edinburgh J. Bot. **58**(1): 110 (2001). [Figs. 1, 2]

Type: Bhutan. Mishichen to Khosa, 10 May 1967, H. Kanai, G. Murata, H. Ohashi, O. Tanaka & T. Yamazaki 13575 (TI–holo.).

Flowering: May–June.

Habitat: Terrestrial on humus rich soil in broad-leaved forest composed of *Quercus* species, *Lyonia ovalifolia*, *Rhododendron arboreum* and laurels.

Distribution: Nepal, Bhutan, Korea, Japan.

Specimens examined: **WESTERN NEPAL**–Mahakali Zone, Darchula District, Api Nampa Conservation Area, Khar Village Development Committee, Paripatal Women Community Forest, 2100–2300 m (P. Bhandari, M. Pandey & S. Thapa K100-2016, 2 June 2016, KATH030390). **CENTRAL NEPAL**–Bagmati Zone, Lalitpur District, Phulchowki Forest, 2000–2100 m, (P. Bhandari & M. Pandey P01-2017, 29 April 2017, KATH030391).

Cephalanthera in Nepal had been represented by a single species, *C. longifolia*, to date (Press et al. 2000, Rajbhandari 2015) and the specimens deposited at the National Herbarium and Plant Laboratories, Nepal (KATH) are also reported to be *C. longifolia* (Rajbhandari and Baral 2010). The leaf and other vegetative characters of our collections agree with those of *C. erecta* and not *C. longifolia*. While, *Cephalanthera longifolia* is characterized by having a saccate lip, enclosed within the base of lateral sepals, *C. erecta* possesses a spurred lip, protruded between bases of lateral sepals (Chen et al. 2009). Table 1 shows the difference between *C. longifolia* and *C. erecta* in morphological as well as floral characters. However, *C. erecta* var. *oblanceolata* differs from var. *erecta* in having a simple lip without spur, and is regarded as the peloric form of *C. erecta* (Pearce et al. 2001, Pearce and Cribb 2002).

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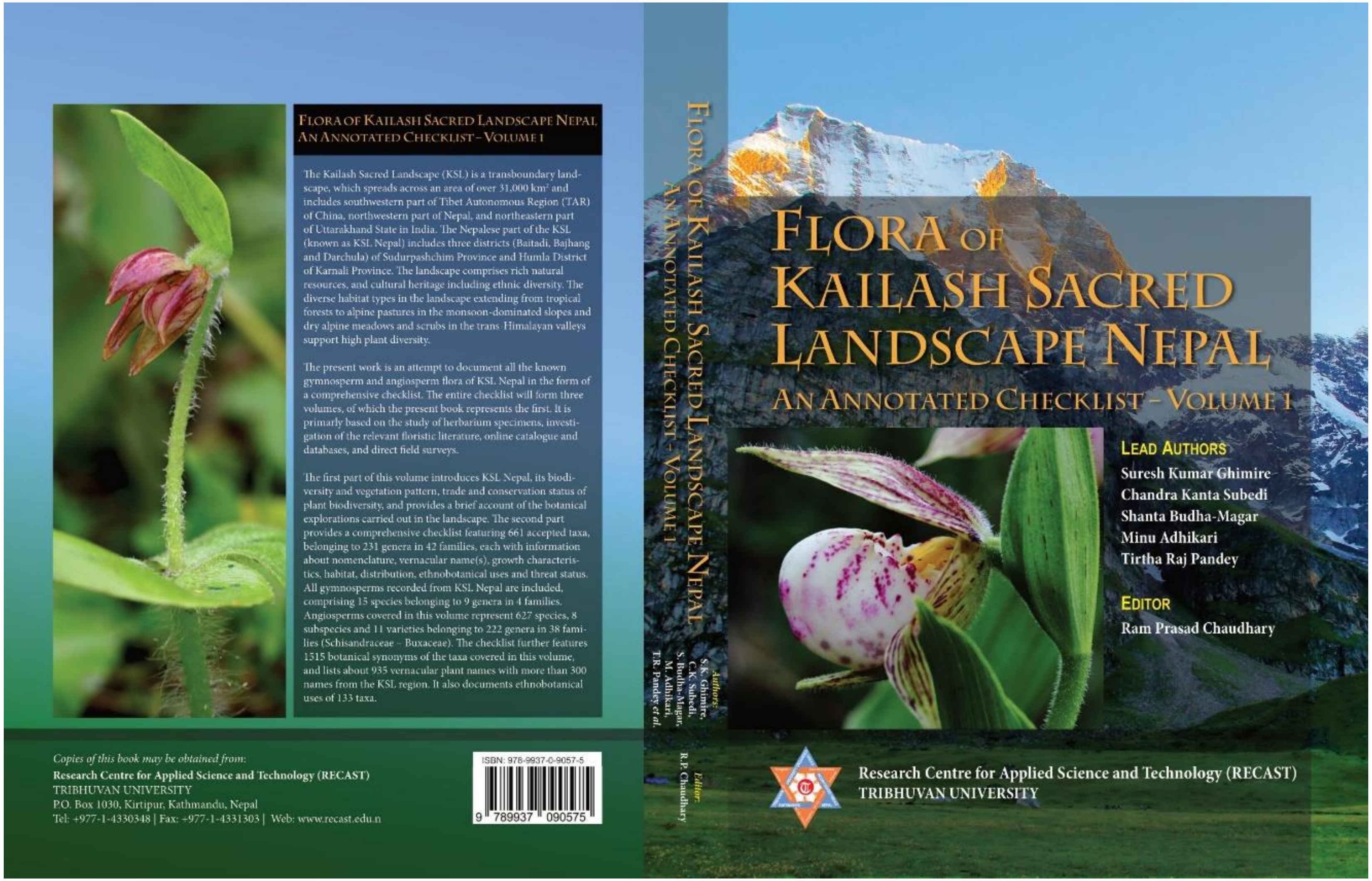
C. K. Subedi[a], P. Bhandari[a], S. Thapa[a], M. Pandey[a], J. Gurung[b], L. R. Shakya[c], R. P. Chaudhary[a]：**ネパール新産のヤビツギンラン（ラン科）**

ネパール西部と中部からヤビツギンラン *Cephalanthera erecta* (Thunb.) Blume var. *oblanceolata* N. Pearce & P. J. Cribb（ラン科）を報告した．これはネパール新産で，かつ本種としても西限となる．ここでは本種の生育地と分布について言及した．

([a]ネパール・Tribhuvan University Research Centre for Applied Science and Technology,
[b]ネパール・International Centre for Integrated Mountain Development,
[c]ネパール・Tribhuvan University Amrit Campus Department of Botany)


FLORA OF KAILASH SACRED LANDSCAPE NEPAL
AN ANNOTATED CHECKLIST – VOLUME I
The Kailash Sacred Landscape (KSL) is a transboundary landscape, which spreads across an area of over 31,000 km² and includes southwestern part of Tibet Autonomous Region (TAR) of China, northwestern part of Nepal, and northeastern part of Uttarakhand State in India. The Nepalese part of the KSL (known as KSL Nepal) includes three districts (Baitadi, Bajhang and Darchula) of Sudurpashchim Province and Humla District of Karnali Province. The landscape comprises rich natural resources, and cultural heritage including ethnic diversity. The diverse habitat types in the landscape extending from tropical forests to alpine pastures in the monsoon-dominated slopes and dry alpine meadows and scrubs in the trans-Himalayan valleys support high plant diversity.
The present work is an attempt to document all the known gymnosperm and angiosperm flora of KSL Nepal in the form of a comprehensive checklist. The entire checklist will form three volumes, of which the present book represents the first. It is primarly based on the study of herbarium specimens, investigation of the relevant floristic literature, online catalogue and databases, and direct field surveys.
The first part of this volume introduces KSL Nepal, its biodiversity and vegetation pattern, trade and conservation status of plant biodiversity, and provides a brief account of the botanical explorations carried out in the landscape. The second part provides a comprehensive checklist featuring 661 accepted taxa, belonging to 231 genera in 42 families, each with information about nomenclature, vernacular name(s), growth characteristics, habitat, distribution, ethnobotanical uses and threat status. All gymnosperms recorded from KSL Nepal are included, comprising 15 species belonging to 9 genera in 4 families. Angiosperms covered in this volume represent 627 species, 8 subspecies and 11 varieties belonging to 222 genera in 38 families (Schisandraceae – Buxaceae). The checklist further features 1515 botanical synonyms of the taxa covered in this volume, and lists about 935 vernacular plant names with more than 300 names from the KSL region. It also documents ethnobotanical uses of 133 taxa.
Copies of this book may be obtained from:
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Authors:
S.K. Ghimire,
C.K. Subedi,
S. Budha-Magar,
M. Adhikari,
T.R. Pandey et al.
Editor:
R.P. Chaudhary
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LEAD AUTHORS
Suresh Kumar Ghimire
Chandra Kanta Subedi
Shanta Budha-Magar
Minu Adhikari
Tirtha Raj Pandey
EDITOR
Ram Prasad Chaudhary
Research Centre for Applied Science and Technology (RECAST)
TRIBHUVAN UNIVERSITY

BIODIVERSITY PROFILE OF THE

API NAMPA CONSERVATION AREA

Government of Nepal
Ministry of Forests and Environment
Department of National Parks and Wildlife Conservation
Babarmahal, Kathmandu, Nepal

Technical Team
Mr. Bishnu P. Shrestha, Under-Secretary (Tech.), DNPWC
Dr. Janita Gurung, Programme Coordinator-KSLCDI, ICIMOD
Dr. Binaya Pasakhala, Resource Governance Analyst, ICIMOD
Dr. Suresh K. Ghimire, Associate Professor, Central Department of Botany, Tribhuvan University
Dr. Srijana Joshi, Ecosystem Specialist, ICIMOD
Ms. Sunayana Basnet, Research Associate, ICIMOD
Mr. Sunil Thapa, Remote Sensing and Geoinformation Analyst, ICIMOD
Mr. Prabin Bhandari, PhD Candidate, State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany-CAS
Mr. Bhumiraj Upadhyaya, Under-Secretary (Tech.), DNPWC
Mr. Ashok K. Ram, Assistant Conservation Officer, DNPWC
Ms. Corinna Wallrapp, PhD Candidate, University of Gottingen
Mr. Chandra K. Subedi, Assistant Professor, RECAST, Tribhuvan University
Dr. Kamala Gurung, Gender and Natural Resource Management Specialist, ICIMOD
Mr. Gauri Dangol, Research Associate Digital Cartography, ICIMOD
Mr. Ashish Chaudhary, Manager, Adventure West Holidays
Dr. Ram P. Chaudhary, Professor Emeritus, Tribhuvan University

Review Team
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Dr. Ram Chandra Kandel, Deputy Director General, DNPWC
Mr. Shyam Bajimaya, Former Director General, DNPWC
Dr. Mukesh K. Chalise, Professor, Central Department of Zoology, Tribhuvan University

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List of presentations in conferences/seminar/workshop during Ph.D.

1. **Subedi, C.K,** Ghimire, S. K., Chettri, N., & Chaudhary, R.P. (2020). Spatial Distribution of Vegetation Composition and Structure in Kailash sacred landscape, Nepal. (*Winter school/Conference on Modelling challenges for mountain ecosystems, February 23 – 28, 2020, Hamburg, Germany*)
2. **Subedi, C.K.,** Gurung, J., Chaudhary, R.P., & Chettri, N. (2016). Long- term Monitoring of a Temperate Mixed-oak Forest in the Kailash Sacred Landscape. *(World Wood Day Celebration, 21 March, 2016, Kathmandu, Nepal)*
3. **Subedi, C.K.,** Chaudhary, R.P., Ghimire, S. K., Chettri, N., & Gurung, J. (2016). Tree Species Richness along Altitudinal Gradient in Chamelia Valley, Api Nampa Conservation Area, Nepal. *(The 7th National Conference on Science and Technology, 29-31 March, 2016, Kathmandu, Nepal)*

We are pleased to present this

Certificate of Participation

to

Chandra Kanta Subedi

who attended successfully the winter school on

Modelling challenges for mountain ecosystems (MCME 2020)

held at the

Center for Earth System Research and Sustainability (CEN), Universität Hamburg

from February 23 – 28, 2020

including the topics

- statistical modelling of climate parameters
- modelling the ecological niche of a treeline species.

Course workload: 6 ECTS (6 credit points)

During the conference session Mr. Subedi additionally presented successfully on his research work

Spatial distribution of vegetation composition and structure in Kailash sacred landscape, Nepal

Hamburg, February 28, 2020

Dr. Bobrowski

Maria Bobrowski (Organizer)

Johannes Weidinger

Johannes Weidinger (Organizer)

Institut für Geographie – CEN - Universität Hamburg - Bundesstraße 55 - 20146 Hamburg, Germany
maria.bobrowski@uni-hamburg.de – johannes.weidinger@uni-hamburg.de


INTERNATIONAL WOOD CULTURE SOCIETY
IWCS
WOOD IS GOOD · WOOD DAY · March 21st WORLD
World Wood Day Foundation
2016 World Wood Day | Nature and Culture
Certificate of Participation
Awarded to
Chandra Kanta Subedi
In recognition of participating in 2016
World Wood Day Celebration in Kathmandu, Nepal.
Dated March 21st, 2016
Uday Chandra Thakur
Secretary
Ministry of Forests and Soil Conservation
Government of Nepal
Chung- Yun Hse
President
International Wood Culture Society

Nepal Academy of Science and Technology

CERTIFICATE

Awarded to

CHANDRA KANTA SUBEDI

for active participation/paper presentation/poster presentation

in

THE 7th NATIONAL CONFERENCE ON SCIENCE AND TECHNOLOGY

SCIENCE, TECHNOLOGY AND INNOVATION FOR NEPAL'S GRADUATION TO DEVELOPING COUNTRY STATUS

March 29-31, 2016

Kathmandu, Nepal

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