ECOLOGICAL MODELLING OF VASCULAR PLANT DIVERSITY UNDER DIFFERENT CLIMATE AND LAND USE CHANGE SCENARIOS IN NEPAL HIMALAYA

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BY
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DECLARATION

Thesis entitled **“Ecological Modelling of Vascular Plant Diversity Under Different Climate and Land Use Change Scenarios in Nepal Himalaya”** which is being submitted to the Central Department of Botany, Institute of Science and Technology(IOST), 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. Krishna Kumar Shrestha, Central Department of Botany, Tribhuvan University and co-supervised by Prof. Dr. Christoph Scheidegger, Swiss Federal Institute for Forest Snow and Landscape Research, WSL, Switzerland and Dr. Michael Nobis, Swiss Federal Institute for Forest Snow and Landscape Research, WSL, Switzerland.

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.

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RECOMMENDATION

This is to recommend that **Mr. Sanjeev Kumar Rai** has carried out research entitled **"Ecological Modelling of Vascular Plant Diversity Under Different Climate And Land Use Change Scenarios in Nepal Himalaya"** for the award of Doctor of Philosophy (Ph.D.) in **Botany** under our supervision. To our knowledge, this work has not been submitted for any other degree.

He 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.

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On the recommendation of Prof. Dr. Krishna Kumar Shrestha, Prof. Dr. Christoph Scheidegger and Dr. Michael Nobis this Ph. D. thesis submitted by Sanjeev Kumar Rai, entitled **“Ecological Modelling of Vascular Plant Diversity Under Different Climate and Land Use Change Scenarios in Nepal Himalaya”** is forwarded by Central Department Research Committee (CDRC) to the Dean, IOST, T.U.

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Sanjeev Kumar Rai
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ABSTRACT

The effect of climate, topography and land-use on the plant species richness and composition are widely studied topics in ecology. Recent scenarios of climate change studies also show the effect on the species diversity and gain in new area and loss in old habitats. The species richness is considerably high in Nepal with respect to its surface area due to its topography and diversity in microclimates. Climate change and land use change are affecting such richness and composition world widely. Current study was focused on assessing the species richness of vascular plants, their composition and finding the environmental variables which affect them in different elevations and land use gradients in the Nepal Himalaya. We also assessed the effect of climate change on the future distribution of *Betula utilis* and *Larix potaninii* var. *himalaica* which are both tree-line vascular plant species in Nepal Himalaya. The elevation of study sites ranged from 2200 m to 3800 m in six river valleys of Gorkha, Solukhumbu and Taplejung districts of Nepal. Four land use types namely crop field, meadow, exploited forest and natural forest were surveyed. Species were recorded in 25m x 2.5m plots in each land use type. We measured soil temperature as well as air humidity and temperature with data loggers on all study sites. The recorded data show a clear gradient of elevation and land use types designed in current study. Two visits were done for all plots in two different seasons. Although there are some common species recorded in both visits, the species record in individual visits are also unique. The field survey revealed a total of 840 vascular plant species belonging to 492 genera of 120 families. Among them 631 were dicots, 159 monocots, 12 gymnosperms and 38 pteridophytes. There were 96 tree species, 110 shrub species, 586 herbs and 48 climber species. Asteraceae comprised the highest number of species (85 spp.). Multivariate ordination techniques such as Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were used to analyze the patterns of species composition and Generalized Linear Model (GLM) was used to find out the significant environmental variables affecting the species richness. In DCA, the first two axes were more than 4.0 standard units inferring high beta diversity. Three sets of environmental variables namely microclimate, bioclimate and topography were used for the ordination. In CCA, isothermality, minimum temperature of the coldest month, precipitation seasonality, precipitation of the coldest quarter were significant contributing bioclimatic variables. Similarly, exposition, land use types, elevation, aspect, slope, region, and valley were significant constraining variables for the species composition. Same set of predictor variables were used to develop three models using GLM. In addition, a synthetic model was developed by combining significant predictor variables from each set of the variables. Linear combination of mean soil temperature, mean humidity, minimum humidity, maximum temperature of warmest month, precipitation of the driest month, precipitation seasonality, valleys, land use types, elevation and latitude produce the best model in forward selection procedure. Maxent modelling was done to predict the future distribution of vascular plants under different climate change scenarios by 2050 and 2070. We chose two species namely *Betula utilis* and *Larix potaninii* var. *himalaica* for this purpose. Both plants occur on high Himalaya up to tree-line. *Larix* is a deciduous conifer which has limited distribution in central Nepal and adjoining region of Tibet, China. *Betula utilis* is a deciduous broad-leaved plant with wide distribution from Pakistan to China. It occurs in almost all high mountains of Nepal. The bioclimatic variables were taken from CCSM4 climate database with RCPs 2.6, 4.5, 6.0, 8.5 for 2050 and 2070. Additionally, elevation, aspect and land use types were taken as predictor variables which were taken from the land cover map of Nepal 2010. All models were validated with various statistical tests. All models showed AUC > 0.9, accuracy between 88.4875 and 95.2858, error rate between 0.1151 and 0.0471, and TSS between 0.6359 and 0.7613. The validation parameters showed the robustness of the models. The elevation and annual mean precipitation were main contributing factors for the distribution of *Betula utilis* and *Larix potaninii* var. *himalaica* respectively. The distribution area of *Betula utilis* will decrease by -18.72% under RCP 2.6 but will increase in all other scenarios by 2050 and 2070. The new gains in area will be distributed towards the western mountains at all RCPs in 2050 and 2070. The predicted area of *Larix potaninii* var. *himalaica* did not show specific trend of increment or decrease at all RCPs by 2050 and 2070. The findings of the current study will be applicable in the assessment of effect of environmental and land use variables on the species composition and richness other group of plants too. Current study will be also helpful in devising future policies of conservation of rare, vulnerable, and threatened plant species whose distributions are more likely to be affected by the climate change in the future.

Key words: Biodiversity, SDM, Species composition, Species distribution, Tree-line

LIST OF ACRONYMS AND ABBREVIATIONS

AIC	Akaike Information Criterion
AUC	Area Under ROC curve
CCA	Canonical Correspondence Analysis
CCSM	Community Climate System Model
CDB	Central Department of Botany, Tribhuvan University
CIMP5	Coupled Model Inter-comparison Project Phase 5
DCA	Detrended Correspondence Analysis
DoS	Department of Survey, Nepal
FRA	Forest Resource Assessment, Nepal
GAM	Generalized Additive Model
GCM	Global Climate Model
GHG	Green House Gas
GLM	Generalized Linear Model
GLMM	Generalized Linear Mixed Model
GPS	Geographical Positioning System
HBM	Humped Back Model
ICIMOD	Integrated Centre for Mountain Development
KCA	Kanchenjunga Conservation Area
LRMP	Land Resources Mapping Project
MARS	Multivariate Adaptive Regression Splines

MCA	Manaslu Conservation Area
MDE	Mid Domain Effect
MPFS	Master Plan for the Forestry Sector
MTE	Metabolic Theory of Ecology
NFI	National Forest Inventory
NRSC	National Remote Sensing Centre, Nepal
OLS	Ordinary Least Square
OWL	Other Wooded Land
RCP	Representative Concentration Pathways
ROC	Receiver Operating Characteristic Curve
RSFD	Range Size Frequency Distribution
SAR	Species Area Relationship
SDM	Species Distribution Model
TSS	True Skill Statistics
TU	Tribhuvan University, Kathmandu, Nepal
WED	Water Energy Dynamics
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research

LIST OF SYMBOLS

α	Alpha diversity of species richness
β	Beta diversity of species richness
γ	Gama diversity of species richness
pH	Symbol to denote the value of acidity or alkaline nature of matters

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CHAPTER 1

1. INTRODUCTION

1.1 Background

Analyses of species richness and their relationships with climatic and topographical factors are one of the common studies in ecology. The concept of the fundamental and the realized species niche (sensu. Hutchinson, 1957) have been revised through period of time and several theories of species diversity and related patterns have been proposed (Huston, 1979). Species have been projected along resource gradients and into multidimensional space to demonstrate their different environmental niches (Whittaker, 1972). Changes of species assemblages along latitudinal and elevational gradients have been documented since the advent of modern biogeography shaped by the works of leading naturalists von Humboldt (1807), Darwin (1839, 1859) and Wallace (1876, 1878) as cited in Colwell *et al*. (2004) and Lomolino (2001). The effect of latitudinal gradient on species richness has been known for a long time (Pianka, 1966; Stevens, 1989). Stevens (1989) has compiled the published literatures showing latitudinal gradients in species richness at regional as well as local scales. Species richness and species distribution also vary along elevational gradients (Stevens, 1992; McCain & Grytnes, 2010), for example, in mammals (McCain, 2007), birds (Zou *et al*., 2012) and vascular plants (Trigas *et al*., 2013). However, such correlations with latitude and elevation do not imply the causal biological factors, instead they are proxy for numerous more direct factors such as temperature, moisture, energy which change along the elevation (Carpenter, 2005; Körner, 2007) or topography (Hofer *et al*., 2008; Moeslund *et al*., 2013). In addition to topographic factors such as elevation, aspect and slope, also land use and land use history play important roles for species distributions in any area (Vellend, 2004).

Previous works in Nepal and adjoining Himalaya have revealed mid elevation peaks in species richness along the elevational gradient for different taxonomic groups including vascular plants (Vetaas & Grytnes, 2002; Bhattarai & Vetaas, 2003), ferns (Bhattarai *et al*., 2004), bryophytes (Grau *et al*., 2007), lichens (Baniya *et al*., 2010) and reptiles (Chettri *et al*., 2010). Those studies have often focused on elevation pattern in the species richness driven by changes in temperature, energy and water availability (Bhattarai *et al*., 2004). In contrast, topographical variables such as slope or aspect as well as regional differences were rarely analyzed in the Himalayan region (Paudel & Vetaas, 2014). The same holds true for microclimatic factors such as small scale temperature and water availability which directly affect species distributions (Geiger *et al*., 1995). In addition, different land use types also result in different species' communities with varying species richness and species combinations. The settlements in the mountains of the Himalaya chiefly rely on agro-pastoral system. The shifting and open grazing system is practiced in the mountain areas. Besides crop farming, the mountain people of Nepal keep yaks, sheep, and mountain goats for the supply of food and economic transactions. Their energy source is mainly the firewood collected from the nearby forests (Fox, 1984). All the above activities can lead to the degradation of the natural habitats which affect upon the species diversity in different ways (Honnay *et al*., 2005; Cousins, 2009). In most of the cases, the species diversity declines in the degraded area due to the fragmentation of the natural forests (Tilman *et al*., 1997; Maitima *et al*., 2009). These losses are linked with the disturbances and changes in the nutrient cycling processes such as organic carbon in the soil (Maitima *et al*., 2009) and available nitrogen (Li *et al*., 2006).

1.1.1 Effect of climate change on species distribution

Simulations derived from the concentration driven CMIP5 models have projected global surface temperature change by the end of 21st century (2081-2100) is likely to exceed 1.5 degree Celsius relative to the end of the twentieth century (1986-2005) for all Representative Concentration Pathways (RCP) (IPCC, 2013). Species distribution models (SDMs) are a widely used approach to assess the potential impact of climate change on species distributions (Elith & Leathwick, 2009; Guisan & Thuiller, 2005; Guisan & Zimmermann, 2000). Many plants will move upwards in mountain habitats under future climate change (Singh *et al*., 2012). So far, published SDM simulations in general predict shifts in species ranges, which can result in both losses and gains of suitable habitats in the future (Berry *et al*., 2002; Khanum *et al*., 2013; Maharjan *et al*., 2019; Shrestha & Bawa, 2014). New species might colonize such lost habitats in faster rate and larger extent than even by urban sprawl (Nobis *et al*., 2009; Tanaka *et al*., 2012). There are also assumptions that loss of the species richness at local level are supplemented by exotic and invasive plant species (Ellis *et al*., 2012; Maharjan *et al*., 2019).

Nepal Himalaya is a part of the Hindu-Kush Himalaya system which is very sensitive and vulnerable to climate change (Shrestha & Aryal, 2011). According to future climate change scenarios, in Nepal Himalaya tree-line is expected to shift to higher elevations, growing season to be prolonged and biomass in the wetlands to increase (Tsering *et al*., 2010).

1.1.2 Effect of land use change on biodiversity

Land use changes are also the drivers of the change in species diversity (Paz-Kagan *et al*., 2017). When the natural forest is exploited and fragmented, there is a threat to the biodiversity (Cousins, 2009; Honnay *et al*., 2005). The fragmentation are generated by three interdependent processes namely habitat loss, reduced patch size and isolation (Andren, 1994). Isolation and the reduced size of habitat patches can reduce reproductive success of small populations when compared with large population (Jacquemyn *et al*., 2002). The past history of the landscape change also affects the species distribution, while metapopulation dynamics may not answer all the dynamics (Dupré & Ehrlén, 2002). The populations of forest species occurring for example on the edge of disturbed sites are more likely to decline while populations far from the edge are more likely to be stable (Jules, 1998).

Basic research on ecological responses of high-elevation species to climatic and land use changes is notably lacking in the Himalaya. While doing investigation on the species diversity of Himalayan landscapes, land use variables were found to be equally important as topographic variables (Paudel & Vetaas, 2014). The different land use types exhibit difference in the species diversity; for example lichen diversity changed along the elevational gradients and in different land use types (Chongbang *et al*., 2018). The landscape change due to habitat fragmentation and intensive use of degraded land opens the avenue for invasive species too. Biological invasions seem to be accelerated by climate change, although they are often initiated by land use change (Maharjan *et al*., 2019). Such invasion not only affect the local biodiversity but also ecosystem services (Pathak *et al*., 2021). Forest restoration, however, can restore many ecosystem functions and recover many components of the original biodiversity (Chazdon, 2008).

1.2 Relevance of the Research

Mountains are characterized by high degree of species turnover and high endemism (Kessler, 2002; Trigas *et al*., 2013). Managing mountain biodiversity has increasingly been recognized as a global responsibility in recent decades. Climate change and land use change may further increase the pressure on the resource use in mountains. The necessity of innovative concepts and approaches are highlighted by many recent studies and surveys to reconcile biodiversity conservation with development (Pandey, 2008). Most of the ecological studies in Nepal Himalaya are carried out only in limited areas of the mountains. A comprehensive study for the present-day species composition has not been studied in Nepal. The effect of environmental variables on the species composition are well recorded. However, a combined effect of the environmental variables, topographical variables and land use types have not been studied yet. The current study will document and identify all the vascular plants detected in the study area. This kind of research work will find out the present status of the biodiversity in the Nepal Himalaya and will project the future species distributions of vascular plants under climate change scenarios and land use change scenarios. The findings and recommendation will support climate change and mountain biodiversity strategies and policies in Nepal.

1.3 Major research questions

The principal research questions that this study tries to answer are the following:

a. What are the general patterns in species composition for vascular plants along the elevational gradient of study area in the Nepalese Himalaya?

b. Which environmental factors influence the species richness and composition of vascular plants in this regard?

c. How will habitats of species probably change over time and space with respect to future climate change?

1.4 Objectives

The general aim of the study is to investigate the effect of environmental factors on biodiversity of vascular plants in the Nepalese Himalaya and to analyze present and potential future species distributions under different climate change scenarios.

The specific objectives are as follows:

1. To document the vascular plant diversity in a three-dimensional environmental space of (1) climate (2) topography and (3) land use.
2. To find out present-day vascular plant composition based on climate and topography in the mountain area of Nepal.
3. To identify the main determinants of the present-day diversity of vascular plants at different spatial scales (local: at a given altitude of a valley; regional: whole valleys or study regions; overall: including all study regions)
4. To develop species distribution models (SDMs) to assess the current distribution and to project future distributions of two vascular plant species of high Himalaya with high and less habitat distribution under different climate change scenarios.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Species response to environmental factors

The effect of environmental and climatic factors on species distributions has often been documented. Species richness in general increases towards lower latitudes (Pianka, 1966). This pattern has been confirmed for many different taxa. Along with decreasing species richness towards higher latitudes, Rappoport's rule states a positive correlation of the geographical range size of species with increasing latitude (Stevens, 1989). Stevens compiled published works of regional surveys and point surveys exhibiting latitudinal gradient in species richness. However, the underlying cause of the gradients he found needed explantion. Rohde (1992) tried to look for the primary causes of latitudinal gradients in species diversity by reviewing many hypotheses such as competition (Pianka, 1966), mutualism (Brown & Gibson, 1983), predation (Paine, 1966; Pianka, 1966), host diversity (Rohde, 1989), or niche width (Brown & Gibson, 1983). While reviewing all the works he concludes that 'an ecological equilibrium explantion of latitudinal gradients cannot be given'. He argued that solar radiation effects the evolutionary speed to make it the primary cause although there are many factor responsible for local differences in diversity and secondary effects on the latitudinal gradients. Stevens (1992) drew an analogy between latitudinal effect and elevational effects on the species richness. In both cases, the species richness decreased with increasing latitude and elevation. He proposed to extend the Rapoport rule of latitude for the elevation too. The postulation was criticized by Colwell & Hurtt (1994), instead they argued that the Rapoport effect is due to sampling bias, as the null models also produced similar results which assumed no environmental gradients. There may be other effects too such as area effect on the species richness, since the area differs along the elevational gradient (Rahbek, 1995). He warned that the elevational pattern between taxa may be misleading when we do not consider the effect of area and sampling design. The monotonic decline of species richness along the elevational gradient as in the latitudinal gradient is because of the resemblances of climatic factors such as temperature (Rahbek, 1995). Rohde (1996) proposed to restrict the term Rapoport's rule proposed by Stevens (1989) with a view that the Rapoport rule is strictly a local phenomenon shown above 40-50 degree North which fails its application in the tropics. He argued that the emphasis to evolutionary approach rather than ecological approaches should be implemented to explain the gradients in species diversity.

Colwell & Lees (2000) again argued that although many believe that the species patterns are influenced by many factors however the shared role of physiography and physiology have been much neglected. They did not say that the geographical variates do not affect, but want to know the extent of its effect. As the effect of elevation on the species diversity was known since the advent of biogeography, Lomolino (2001) emphasized that instead of testing the effect of one independent force, we should consider "a combination of ecological and evolutionary processes." Instead of drawing conclusion from a single factor for the species richness, the results could be better reproduced by incorporating three models simultaneously namely data model, ecological model and statistical model (Austin, 2002). In his observations, skewed species response curve had predominated on the contrary to the statistical models which assumed symmetric unimodal. On the other hand, if the species ranges are studied without considering the environmental gradients within a geographical space, still it shows a mid-domain-effect (MDE) irrespective of environmental gradients (Colwell *et al*., 2004). The authors showed that the results of 21 empirical studies which considered evolutionary, ecological, and historical processes also matched with the MDE. However, there is still not a common consensus about the drivers of MDE. The studies about the effect of environmental factors on the species richness and composition extended further. Sherman *et al*. (2007) conducted a quantitative but rapid regional level assessment of alpine flora across Yunnan mountains. Their results showed that elevation and geographic locations were principal environmental factors for the species composition. They found that the climate, geology, soil and topography influence the species composition with superimposed effects of land use systems in the Yunnan mountains. Stage & Salas (2007) used a linear model to analyze the combined effects of elevation, aspect, and slope in predicting the forest species composition and productivity. They argued that the combined effects are important.

Although, the biogeographic gradients in biodiversity are well known for terrestrial ecosystems such gradients have not been established in fresh water ecology (Bhatt *et al*., 2012). They found that the non-endemic and total fish species richness decreased with the increased elevation, however, the endemics richness still peaked around 700-1000 m. Since there are many studies about the effect of environmental gradients on the species diversity, lately the elevational gradient being taken as the proxy of temperature, Sanders & Rahbek (2012) reviewed 97 papers about the effect if elevational gradient on species diversity. Most of the studies showed the hump shaped models with the diversity highest in the mid-elevations. No single cause for the elevational gradient could be traced out since there are many evidences of multiple causes cited therein include climate and productivity (Rahbek, 1995), source sink dynamics (Kessler *et al*., 2011), area (Rahbek, 1995), disturbance (Escobar *et al*., 2007), geometric constraints (Sanders, 2002) and evolutionary history (Machac *et al*., 2011).

Beside environmental factors, there are also other factors which effect the diversity and distribution of species. Hettenbergerova *et al*. (2013) wanted to know the effect of moisture and nutrients on the changes in species richness and composition of vascular plants and bryophytes at sites of Czech and Slovak Republics. They found the unimodal pattern with the optimum skewed towards lower moisture values. Species richness of vascular plants correlated negatively with N:P (Nitrogen: Phosphorus) biomass ratio. The species richness of bryophytes did not show correlations with nutrients but decreased linearly along the decreasing moisture gradient. The soil moisture and local hydrology are affected by the topography which is essential for the growth of plants and makeup of the diversity and pattern (Moeslund *et al*., 2013). Local hydrology also forms a gradient for the diversity of the species. The change in hydrology is expected to produce various types of vegetation pattern. Although the biodiversity may be due to evolutionary process, some of its patterns are attributed to the conservation of their ecological traits over time, now referred to as niche conservatism (Wiens *et al*., 2010). Pereira & Palmeirim (2013) studied the mechanism behind the latitudinal gradients in species richness and evolutionary age of New World bats and tested niche conservatism hypothesis. Generalized additive models were used to relate latitude with species richness and mean root distance. Yet, their result did not go in line with the niche conservatism hypothesis.

Still the effect of environmental and topographical factors on the species richness and pattern are subjects to research. Trigas *et al*. (2013) investigated the elevational pattern of vascular plant diversity and endemism on Crete Island. The plants species richness deceased monotonically with increasing elevation and endemic plants showed mid elevation peak. They concluded that post isolation uplift of Cretan mountains made the mountain lacking of high-elevation specialist plant group. Moura *et al*. (2016) studied the role of climate, topography and land use types in the species richness and pattern. They argued that, the species richness are affected synergetically by various variables instead of one single set of variable. They selected amphibians, non-volant mammals and bats and birds as response variable. The synergy of climate and topography was evident however climate itself was also a good factor to explain species richness pattern. They also found that topographic and biotic factors also explained variation in species richness.

2.2 Species response to topographical and land use changes

The separate effects of heterogeneity in land cover, vegetation, climate, soil, geographical and environmental factors are significantly positively correlated with vegetation and topographic heterogeneity showing strong association with species richness and diversity (Aranda *et al*., 2014; Stein *et al*., 2014). The correlation of human disturbances on the plant species composition and vegetation coverage also needs attention (Zhao *et al*., 2015). Their study revealed that the wetland species composition was significantly affected by human disturbances. Similarly, Kouba *et al*. (2015) wanted to assess the Mediterranean basin landscape which was once intensely managed forest and cultivated land and recovering into new vegetation after land abandonment. They studied land use history and succession of plant species. Their study revealed that the composition patterns differed significantly according to successional stage. Historical land management was attributed for increased compositional divergence and loss of late successional forest species.

There are many dimensions of ecological explanations for the diversity and patterns of species in general. However, the environmental gradients of species diversity might correlate with the fundamental aspects of ecology such as net primary productivity, age structure, metabolic activity (Fraser *et al*., 2015; Laanisto & Hutchings, 2015; Nobis & Schweingruber, 2013; Xu *et al*., 2015).

2.3 Studies about species environment relationships in Nepal

The studies about the plant species and environment relationship in Nepal began during the first decades of twenty first century. Vetaas & Grytnes (2002) used the published data to analyze the diversity pattern according to elevation starting from 1000 to 5000 m.a.s.l. They found that the maximum species richness range was between 1500-2500 m; however, the hump was higher at c. 4000 m for the endemic species. They express the possibility of hard boundary theory for the rapid decrease of species after 4000 m. They reject the idea of deduction of the Rapoport's effect put forth by Stevens (1989). Furthermore, Bhattarai and Vetaas (2003) explored the variation of species richness of ferns along the elevation band from 100 to 1500 m. Potential evapotranspiration (PET), mean annual rainfall (MAR) and moisture index (MI) as explanatory variable to analyze the pattern. They found that, the shrubs, trees and total species richness of vascular plants showed unimodal responses, whereas the fern species richness generally decreased and woody climbers increased. The herbaceous species didn't show any pattern for the climatic variables. They tested water-energy dynamics model which explained 63% of variation in shrubs, 67% for trees and 70% for the woody climbers. Their quest extended further to an elevation range of 100-4800 m in the Central Himalaya to see the pattern of fern species richness (Bhattarai *et al*., 2004). They used generalized linear models using potential evapotranspiration and moisture index as predictors and fern species richness as a response. They found a unimodal relationship with maximum species richness at 2000 m. They claimed that fern species richness has unimodal response for the energy gradients and linear response for moisture gradients. The unimodal trend was also observed by (Carpenter, 2005). He assessed the factors driving environmental factors of species density in Nepal Himalaya with elevation starting from 250 m and reached up to 4250 m. The species assessed showed a unimodal trend with more species accumulated towards the low elevations. He concluded that neither of mid-domain effect nor boundary effects explained the plant species density observations.

The Rapoport's rule was tested by Bhattarai & Vetaas (2006) by employing tree species richness along the elevation gradient of Himalaya. They analyzed the effect of elevation on 614 tree species richness from 100 m to 4300 m elevation of Himalaya. They found the unimodal response of species richness with widest elevation ranges between 900 and 1000 m unlike the Rapoport's effect, which expects the higher species on the lowlands and not in the mid-elevations. Rapoport's rule was also negated by the study of Grau *et al*. (2007). They tested the species richness pattern of 840 bryophytes along the Himalayan elevation gradient in Nepal from 100 m to

5500 m. They also compared the pattern with the pattern derived for the ferns and flowering plants, and evaluated also Rapoport rule. The results showed a unimodal hump at 2800 m for the liverworts and at 2500 m for the mosses. The mid elevation peak is 1900 m for the ferns and that is between1500-2000 m for the flowering plants in Nepal. The endemic species richness mid elevation peak of the endemic species was at 3300 m. Null model simulation for the bryophytes with elevation did not confirm the Rapoport's rule. The unimodal response was also observed in case of lichens of Nepal (Baniya *et al*., 2010). For lichens species richness showed a peak at 3100-3400 m elevation whereas endemic lichen showed highest species richness between 4000-4100 m. All growth forms showed unimodal relationship with the elevation except saxicolous and terricolous lichens which showed slight bimodal response. They attribute the mid elevation peak as the effect of spatial heterogeneity in rainfall, temperature, cloud formation, phorophyte abundance, bark roughness, moisture retention capacity and pH. The unimodal distribution of species were also observed by other studies in Nepal Himalaya (Bhattarai *et al*., 2014; Rokaya *et al*., 2012). Beside the elevation gradient on the distribution of species in Nepal, other ecological assumptions and factors were tested by other studies too. Baniya *et al*. (2009) tested the intermediate disturbance hypothesis in the abandoned field in the arid Trans-Himalayan region. Their aim was to see the succession and pattern of species richness with temporal land use changes. They found the beta diversity increased with the age of abandonment of the land. Their result was in line with the intermediate disturbance hypothesis as the species richness showed the hump shape along the temporal gradient.

Land use might also effect on the diversity and the distribution of the species. Paudel & Vetaas (2014) have studied the effect of topography and land use on the woody plant species composition in Manang. They have selected two pairs of northeast and southwest facing slopes where the first pair had similar land use and different exposure and other pair were different in the both aspects. They performed correspondence analysis and found that the woody species composition varied significantly according to the slope and aspects of the sites. They infer that the species composition between slopes are likely due to small scale abiotic environmental variables, yet they felt a possibility of the effect of biotic environment such as livestock grazing. They conclude that the land use and topographic variable slope are important for the woody species composition. Sharma *et al*. (2014) assessed the forest-grassland ecotone in the mountains of Nepal. They recorded the vegetation data of species richness and composition and regeneration of *Rhododendron arboreum* and *Abies spectabilis*. They found the species increased from forest interior to grassland center and the forest boundary is advancing towards the grasslands. They argued that land use change may explain the ecotone shift. Sharma & Vetaas (2015) compared tree species diversity between forest and farmland from 1000 to 1800 m.a.s.l. in the mid-hills of central Nepal. They found tree species richness was consistently higher in the farmlands than in the forest. They found shared species in both farmland and forest but the composition was different which they attributed to the differences in the relative abundance of shared species and presence of unique species in each land use types.

2.4 Species distribution models and climate change

The pace of climate change is accelarating at unprecedented rate (IPCC, 2013). Our concern on the future distribution of the species under climate change can be explored by species distribution models (SDMs) (Wiens *et al*., 2009). Vegetation on high elevations are shifting upwards due to increasing temperatures in high mountains (Pauli *et al*., 1996). Such transformations of vegetation are largely seen as a result of climate change we are witnessing (Elmendorf *et al*., 2012). Guisan & Zimmermann (2000) have reviewed a wide range of species distribution models trying to explain various theories on biogeography, conservation biology and climate change. They point out that, although they are statistically accurate they may not explain the ecological patterns well (Elith & Leathwick, 2009). They have elaborated model formulation, sampling design, choice of models, model calibration, prediction, evaluation their credibility and applicability in a very comprehensive manner. While developing the species distribution models with respect to climate change, bioclimatic variables of WorldClim (Hijmans *et al*., 2005) are widely used these days. Berry *et al*. (2002) used an artificial neural network model to predict the changing bioclimate envelope of 54 species of Britain representing 15 habitats. They have taken two climate change scenarios of HADCM2 for 2020 and 2050 with high and low concentrations. Their results showed that species response to changing climate could be categorized into three classes, (a) those losing suitable climate space (b) little change in potential future climate space and (c) expanding their future climate space.

Alpine heath communities show less suitable climate space and pine woodland species showed range loss in climate change scenarios. The species of other habitats showed mixed effect and the authors suggest that land use decision management practices may be important factor for their future distributions. Bioclimatic variables were also used in simulated studies of distribution of dominant tree species of Tibetan plateau (Song *et al*., 2004). They used the climatic extremes such as minimum temperature of in the warmest month, minimum value of soil moisture availability in the growing season. Future distribution of trees was done under climate change scenario with CO_2 concentration of 500 ppm in 2100. Their results were very similar with their actual natural distribution except in case there were shrinkage in the area in model simulations. They predict the shift of trees on northwest under climate change scenario. There are many SDMs which show the effect of climate change. The explicit ecological explanations along with the climate change scenarios might be useful in explaining the models. Modelling biodiversity and species distribution under climate change should consider the ecological phenomenon such as species migration, population dynamics, biotic interaction and community ecology within SDM frameworks (Guisan & Thuiller, 2005).

Phillips *et al*. (2006) introduced Maxent (maximum entropy) modelling technique using presence only data of species occurrences. They compared Maxent with Genetic Algorithm for Rule-Set Prediction (GARP). Both models performed well. However, while comparing the models, Maxent showed higher area under receiver operating characteristic (ROC) curve (AUC), showing more precision while discriminating the suitable versus unsuitable areas of the species. Elith *et al*. (2006) compared 16 models which were commonly used and some novel methods during that time. Some of the new methods such as Maxent outperformed the established modelling methods such as GARP. They also found that presence only data were sufficient for species distribution modelling. Elith & Leathwick (2009) have reviewed SDM techniques with their applicability in the prediction of the distribution across different habitats along with the ease and convention of usage. They argue that, although SDMs are tools to predict the distribution by combining the species occurrence and the environmental estimates, the ecological linkages with such SDMs are weak. They put emphasis on the improvements of methods for modelling the species occurrence and their selection and evaluation with due consideration to biotic interactions. Furthermore, studies started to model the effect of climate change on the species distribution under future climatic scenarios (Elith *et al*., 2010; Watling *et al*., 2012). Nobis *et al*. (2009) investigated the relationships of environmental variables with the neophyte species richness (richness of non-native plants introduced after 1500 AD to their study area). Generalized linear models were used to find the relationships of predictors with the species richness. They applied the calibrated models to project the non-native species richness for the year 2020 and 2050 using climate change urban sprawl scenarios. Mean annual temperature and the urban area had high effects on neophyte species richness. Climate warming showed a stronger increase in species richness than urban sprawl. While most of the studies use average climate data like mean annual temperature or mean annual precipitation, inclusion of climatic extremes seem to improve the SDMs significantly (Zimmermann *et al*., 2009). Instead of conventional use of mean values, the inclusion of climatic extremes improved in adjusted D^2 by 20%, cross validated True Skill Statistic by 8% and AUC by 3%. The inclusion of the climatic extremes in the parametrization of the model, over-predictions and under-predictions were reduced. This approach, they suggested, will improve SDM predictions under future climate where "changes in the mean climate and increased variability are expected". Watt *et al*. (2011) used a process-based niche model (CLIMEX) to project the potential distribution of Douglas-fir under different climate change scenarios. They also modelled the abundance of the pathogen *Phaeocryptopus gaeumannii* and severity of foliage disease, Swiss needle cast. They assumed that inclusion of pathogen will reduce the fir distribution. They predicted the suitable area for the Douglas fir in the North Island will be reduced markedly from 100% under current climate to 36-64% of the total land area by 2080. Elmendorf *et al*. (2012) studied plant communities in *in situ* warming experiments at 61 sites for a period of up to 20 years at Tundra sites. The results of the sites varied according to ambient summer temperature, soil moisture and experimental duration. Shrubs increased with warming only when the ambient temperature was high whereas the graminoids increased primarily in the coldest study sites. They argue that, since the tundra vegetation differed at regional scale, cumulative effect of climate change might be more than observed till date.

Austin & Van Niel (2011a) also revisited the environmental and ecological assumptions prevailing in the SDMs. They reviewed the effect of aspect and slope on the plant distributions. Local aspect will change the light regimes and thus energy supply too. Such local topography may create refugia important for SDM which are not considered very often. Further testing of SDMs may clarify the scale, extent and choice of predictors improving SDMs for climate change modelling of biodiversity. Rinnhofer *et al*. (2012) aimed to predict the distribution of short-range endemic species alpine jumping bristletail (*Machilis pallida*). They used the known location to model the species distribution by Maxent modelling. They discovered the distribution area increased from 470 to 4890 sq km. They emphasize both iterative modelling and ground validation to evaluate the level of endemism and ecological niche. Singh *et al*. (2012) observed the upward shift of alpine vegetation in Indian mountains by 388 ±80 m within three decades. The author states that though these tree line shifts are response to long term climatic changes, the rate of shift varies according to the species and their sensitivity to climate. Tanaka *et al*. (2012) used Generalized Additive Model (GAM) and Multivariate Regression Spline (MARS) to predict the potential habitat of endemic *Abies* species of Japan. They found that the plants will lose large areas of current habitat and will gradually be replaced by other species under changing climate. Ellis *et al*. (2012) argue that the species losses induced by anthropogenic activities are compensated by the exotic and dispersive plant species at regional landscape level. They combined the estimates of native species losses together with the gains in exotics caused by invasions, agricultural domesticates and ornamental exotics. They suggest an integrated framework that should observe, model and forecast the different forms of Anthropocene biodiversity change processes which will help in conserving novel plant communities. Flower *et al*. (2013) used bioclimatic envelope model to assess the effect of climate change on spruce and Douglas-fir. They used downscaled climate data from a collection of 10 climate projections with three emission scenarios. Their projection noticed rapid shift with regard to pace, extent and fine scale details of changes. Khanum *et al*. (2013) predicted the potential climate niches of three medicinal asclepiads of Pakistan namely *Pentatropis spiralis, Tylophora hirsuta* and *Vincetoxicum arnottianum* by Maxent modelling. All three models performed better than the random with high AUC from 0.59 to 0.84. The authors have also calculated the possible areas of loss of gain of the species in future climate change scenarios.

Wang *et al*. (2013) reinvestigated the rainfall gradients of primate species richness in South East Asia, where previous studies were contradicting with that of Africa, Madagascar and the Neotropics. They used reduced major axis and OLS regression methods to examine the relationship. They found a positive correlation of species richness of primates of South East Asia with the rainfall pattern. In case of Nepal Himalaya, Shrestha and Bawa (2014) performed the Maxent modelling to predict the distribution of *Ophiocordyceps sinensis* in the current and future climate change scenarios of Nepal Himalaya. They used the RCP 2.6, RCP 4.5, RCP 6.0 representative concentration pathways in three different time period of 2030, 2050 and 2070. They predicted the future distribution of the species would increase from 0.11 to 4.87% from the current suitable habitat.

CHAPTER 3

3. MATERIALS AND METHODS

To carry out the research we selected six river valleys in three regions of Nepal. All the valleys have dry winter and wet summer season, and monsoon rain prevails between June to September. The eastern valleys receive more monsoon rain than the western valleys (Kansakar *et al*., 2004; Shrestha, 2000). The species records were collected from the sampling plots in four different land use types along elevation gradients. Some of the environmental variables were recorded in the field and others were obtained from secondary sources. The details are presented in the following paragraphs.

3.1 Study area

The study was conducted in the six river valleys of the three regions (districts) of Nepal. Two river valleys are from Manaslu Conservation Area region in Gorkha district, two from Sagarmatha region in Solukhumbu district and two from the Kanchenjunga Conservation Area region in Taplejung district (Figure 3.1 and Figure 3.2). The study was conducted during 2011 to 2013. The valleys were chosen according to precipitation regime. About 80% of annual rainfall is supplied by summer monsoon which enters from east of Nepal. The mean annual precipitation goes on decreasing from east to west in our study area (Kansakar *et al*., 2004; Shrestha, 2000). Taplejung and Solukhumbu regions are on the eastern Nepal and Gorkha region lies in the central Nepal.

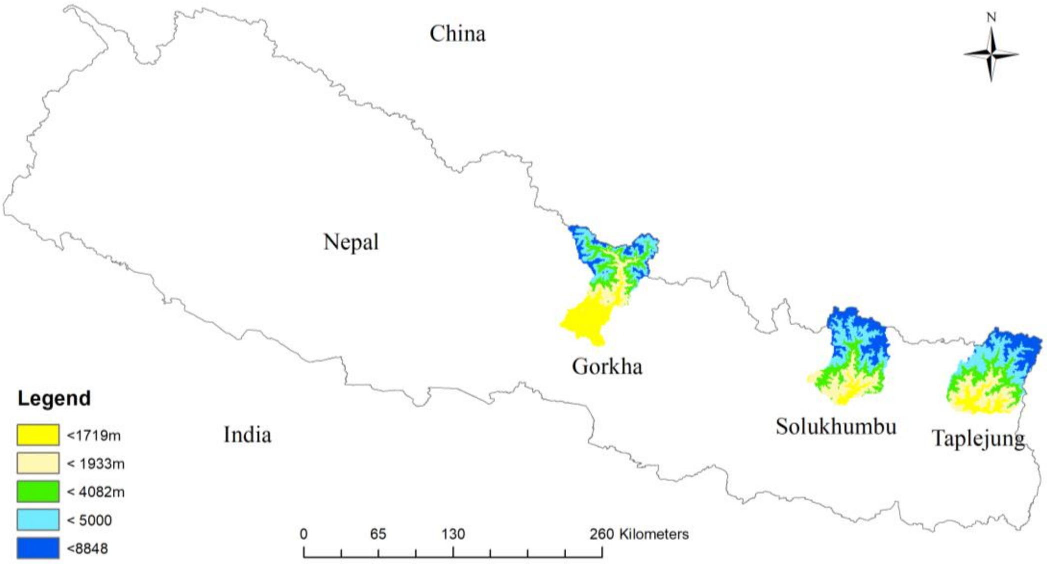

Figure 3.1: Map of Nepal showing three regions of study sites

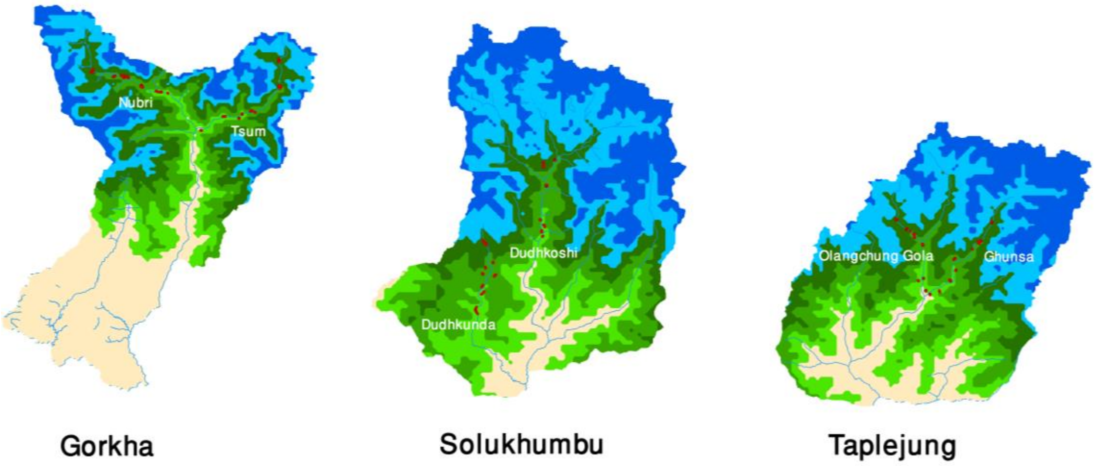

Figure 3.2: Maps of three districts showing the study plots as red circles in six valleys

In Manaslu Conservation Area (MCA) region, two river valleys namely Nubri and Tsum were selected for the study. The Nubri valley starts from the confluence of Budhi Gandaki River and Siyar khola river near Lokpa. This valley runs along the Budhi Gandaki River upwards in north-west direction. Our study plots started from Ghap (2200 m) to Samagaun (3700 m) located between 28˚31'48.9" N to 28˚35'22.5" N latitudes and 84˚38'29.6" E to 84˚49'51.9" E longitudes. The broad-leaved forest between 2200-2500 m consists of species such as *Cornus capitata, Magnolia kisopa, Castanopsis, Litsea* and *Quercus* species. The dry area of the forest also has scattered populations of *Pinus wallichiana. Fragaria indica, Pteris, Adianatum* species are some herbaceous plants of the understory vegetation. Above 2500 m, there is a dense forest of *Tsuga dumosa,* and above 3000 m, the forest is changed into *Abies spectabilis*. A dense forest of *Abies spectabilis* associated with *Hippophae salicifolia* and *Cotoneaster* species is present at Shyala (3400 m). The upper tree lines near Samagaun are built by *Juniperus indica* on sunny faces and *Betula utilis* on shady area. The valley was code named as VAL1 for our study.

Another study site, Tsum valley is oriented towards the north-east along the Siyar river after the confluence with the Budhi Gandaki River. Our study area is located between 28˚26'19.3" N to 28˚36'56.2" N latitudes and 84˚54'44.3" E to 85˚06'40.4" E longitudes. The lower elevation consists of *Alnus nepalensis* and *Pinus wallichiana* forests. They are replaced by *Tsuga dumosa* and *Abies spectabilis* at around 3000 m elevation. The north facing slope of the valley harbors dense forest. South facing slope has forest patches on the river banks. Forest clumps are sparse in the localities having human settlements near Chumling, Gho and Chhekampar and Nile. *Larix* *potaninii* var. *himalaica* forest is dominant at around 3400 m elevation near Rachen Gumba on the north facing slope. The north facing slopes possess more vegetation cover than the south facing slopes. *Betula utilis* is found up to 3800 m elevation near Kalung. Kalung is an open pasture where livestock kept in Chhule and Nile migrate during summer season. In Tsum river valley, most of the south-facing slopes consist of open meadows intersected by small human settlements such as Chumling, Gho, Chhekampar, Chhule, Phurpen and Nile. *Galium*, *Thalictrum*, *Artemisia* species were found in lower elevations, where higher herbs were mostly grass and *Carex* species. The valley was code named as VAL4 for our study.

In Sagarmatha region, we studied the Dudhkoshi and the Dudhkunda river valleys. The region is famous for the world's highest mountain, Sagarmatha (the Mt. Everest, 8848 m) and the Sagarmatha National Park. The Dudhkoshi river valley runs northwards along the bank of Dudhkoshi River. The studied plots are located between 27˚40'18.1" N to 27˚49'48.3" N latitudes and 86˚42'3.2" E to 86˚44'25.2" E longitudes. The plots are located at 2200 m at Surke and Nakchung and those at Muse and Sengma at 2600 m elevation are outside the Sagarmatha National Park whereas the rests of the plots are within the boundaries of the National Park. Our third elevation plots were studied at Jorsalle ca. 3000 m and fourth elevation plots were laid at Lausiasa at 3400 m. There are *Schima-Castanopsis* and *Alnus nepalensis* forests at 2,200 m and which are replaced by *Pinus-Rhododendron* at mid elevation (3000 m) and are further replaced by *Abies spectabilis-Rhododendron* and *Betula utilis* forest with *Morina nepalensis* and *Delphinium* species as herbs on the ground at Khumjung (3800 m). The valley was code named as VAL2 for our study.

The study area at the Dudhkunda valley is located between 27˚30'39.9" N to 27˚39'49.1" N latitudes and 86˚34'34.5" to 86˚37'01.6" E longitudes, and lies towards the west of Dudhkoshi river valley. The two valleys are separated by a chain of north-south mountains. The Dudhkunda valley does not fall inside the Sagarmatha National Park boundary. The plots at 2200 m and 2600 m elevations, are near the settlements and the forests are managed by the local Community Forest User Groups (CFUGs). The upper settlement in this valley is Taksindu dada at 3000 m and there are no settlements above it. The forests above 3000 m elevation are managed by the Government as the national forest. Open pastures in high elevations are grazed seasonally by the livestock from lowland settlements. The crop fields are not found at and above 3000 m elevation. The study started at Boldok-Kholaghari (2200 m). Going upwards through Phera (2600 m), Taksindu (3000 m) and Sarkaripati (3400 m), our highest plot was located near Sasarbeni (3800 m). The vegetation at 2200 m is *Schima-Castanopsis-Alnus, Pinus* and then followed by *Pinus-Quercus-Rhododendron* at mid-elevation. *Abies spectabilis* is uppermost treeline species at Sasarbeni (3800 m). The lower elevation herbs included *Artemisia, Crassocephalum* species whereas high elevation herbs were mostly *Primula, Androsace, Corydalis* species. We used VAL5 code name for this river valley.

In the east region, two valleys namely Olangchung Gola and Ghunsa are there inside Kanchenjunga Conservation Area. Olangchung Gola valley runs towards northwest along the Tamor river from its confluence with the Ghunsa river. Ghunsa valley runs towards northeast along the Ghunsa river. Olangchung Gola is a historic and last settlement of Taplejung district connected with the Tibet province of China. Olangchung Gola site is located between 27˚34'05.6"N to 27˚42'58.4"N latitudes and 87˚44’04.1"E to 87˚48'04.7"E longitudes. The first plots were laid at Ilagaun (2200 m), then at Jongin (2600 m), at Olangchung Gola (3000 m), on the way to Dinga Samba (3400 m) and at Dinga Samba (3800 m). Ilagaun and Jongin have riverine forest of *Alnus nepalensis* and *Schima-Castanopsis* forest on both sides. Associated species are *Rhododendron arboreum, Lyonia ovalifolia, Lithocarpus pachyphylla* and *Rubus ellipticus.* The forest type changes into temperate coniferous while climbing up from Jongin to Olangchung Gola. *Pinus wallichiana*, *Rhododendron* species are in transition which convert into *Abies spectabilis, Juniperus indica* forest. Many species of *Rhododendron* are found up to our last plots on both sides of river. Associated species are *Ribes takare, Holboelia latifolia, Viburnum nervosum, Rosa sericea* and *Berberis* species. The herbs at lower elevations were *Hedychium*, *Nepeta*, *Ajuga* species, whereas high elevation herbs were *Potentilla*, *Anaphalis and Artemisia* species. The sites have settlements only at Ilagaun and Olangchung Gola. People of Olangchung Gola herd yaks and sheep and shifting their *goths* (temporary barn) upstream and downstream according to summer and winter season. The valley was named as VAL3 in our study.

Ghunsa is the last settlement while going towards the basecamp of Mt. Kanchenjunga (8586 m). Our study plots were located between 27˚32'06.5"N to 27˚42'37.4"N latitudes and 87˚48'20.6" E to 87˚57'54.8"E longitudes. The plots started above

Sekathum (2200 m), then to Amjilosa (2400 m), Gyabla (3000 m), Ghunsa (3400 m) and Lhambuk Kharka (3800 m). The lower belt has *Castanopsis-Rhododendron* Forest with clumps of *Lyonia ovalifolia.* The forests at Amjilosa area were of *Quercus lanata* and *Castanopsis indica.* Due to south facing aspect and steep slope, most of the area is grassland. The forest then becomes *Rhododendron-Quercus* at Gyabla (ca. 3000 m). The settlements are only a few households and most of the area is covered by dense forest. The forest along the way to Ghunsa (ca. 3400 m) from Gyabla is *Rhododendron* and *Quercus* dominated. The associated species are many shrubs of Ericaceae, *Daphne bholua*, *Arundinaria* sp. The forest at Ghunsa becomes coniferous. However, there are also many species of *Rhododendron.* The way to Lhambuk Kharka (3800 m) has a dense forest of *Abies spectabilis* and *Larix griffithiana.* Herbs at lower elevation were *Viola, Hemiphragma, Pteris and Dryopteris* species and high elevation herbs were mostly *Carex, Potentilla and Selinum* species. The associated species are *Salix* sp., *Hippophae tibetana.* The valley was codenamed as VAL6 for our study.

3.2 Study design

Five elevation levels were investigated with a regular elevation interval of 400 m starting from 2200 m to 3800 m (Figure 3.3). At each elevation level, four land use types were considered namely (i) natural forest, (ii) exploited forest, (iii) meadow and (iv) crop field (Scheidegger *et al*., 2010). The category of the land use types were based on the visual observation in accordance with the methods of FAO (Gregorio & Jansen, 2000). The crop fields are cultivated areas where the vegetative cover is artificially created by farming activities. Those cultivated land are ploughed thoroughly after crop harvesting. The wild species occurring in the fields are wiped out during agricultural activities. The meadows are isolated patch or wide area of grazing land where the tree coverage is less than 20%. Besides livestock grazing and grass collection the occasional trees are cut, lopped, and felled for livestock and household purposes. The natural forests are far from the human settlements which are rarely intervened by anthropogenic activities. Almost all the trees are intact without any human intervention. The shrubs were not even cut or disturbed. The exploited forests comprise the vegetation influenced by anthropogenic activities. The exploited forest contained the intact trees along with the cut-stumps, lopped trees, felled, and trimmed trees. The exploited forest also contained some open canopy (Scheidegger *et al*., 2010).

All the four land use types were assessed for species records on both sides of the river. Sample plots (25 m × 2.5 m) were selected randomly per land use type at each elevation level (e.g. 2200 ± 50 m) on the one side of the river, and the same number were replicated on the another side of the river (Scheidegger *et al*., 2010). Each plot was divided into 5 m × 2.5 m sub-plots for species record. Thus, each elevation level consisted of eight sample plots (Figure 3.3). Crop fields were not found at the elevations of 3400 m and 3800 m except in some valleys. Crop fields at 16 places, exploited forest at four places and meadow at three places were not available in our designed elevation and expositions. Crop fields are mostly absent in our fifth elevation (3800 m). Therefore, only 217 plots were sampled, although there are 240 plots in our research design. The plots were studied during the period of 2011 – 2013 (Annex I).

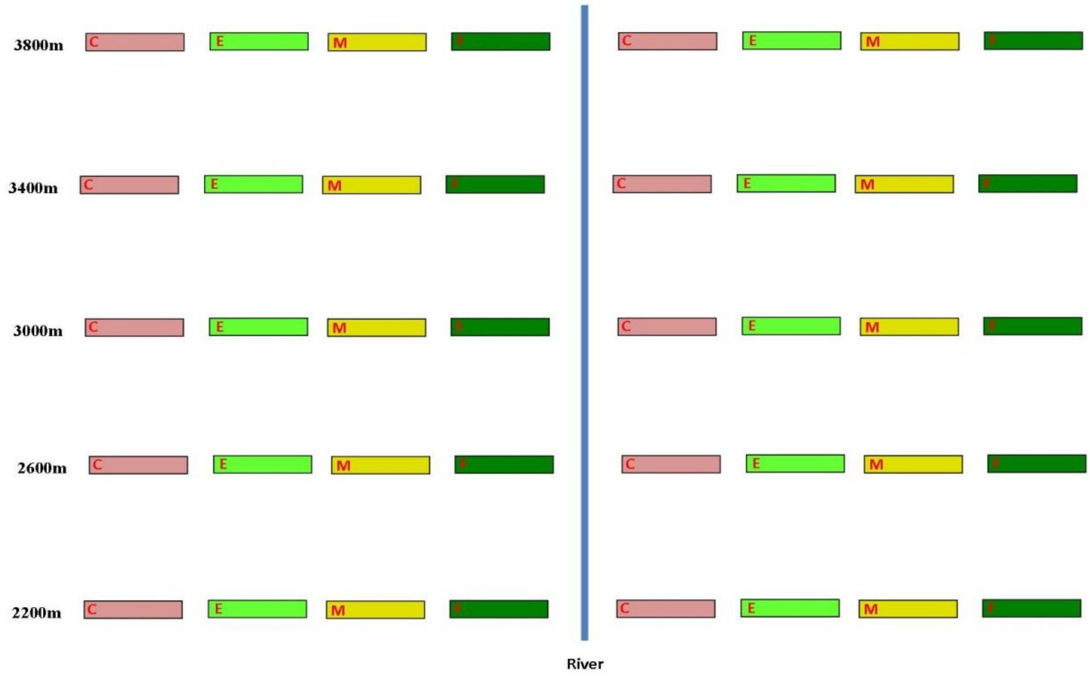

Figure 3.3: Schematic diagram of sampling plot design of the study per land use type in all elevation (C = crop field, E = exploited forest, M = meadow, F = forest and the straight line at the center represents the river)

All the vascular plant species within each plot were recorded. Each plot was visited twice in order to record as many species as possible (Annex I). The same method was applied for all six valleys of three regions of Nepal.

3.3 Data source

Plant occurrence records were taken as response variable and environmental variables were taken as predictor variables in our study. The schematic diagram showing the collection of data is given in Figure 3.4.

3.3.1 Plant species records

Plant species records were obtained from the field observation done on the study area. They were used for species richness and composition analysis. The occurrence data for the species distribution modelling (SDM) were taken from global biodiversity information facility (https://www.gbif.org/) along with field occurrence records (Annex II).

3.3.1. a Field observation

The plants were recorded in the plots of the study area from March, 2011 to April, 2013. Most of the flowering plant species were identified in the field by using the books written by Polunin & Stainton (1984) and Stainton (1988). The specimens unidentified in the field were identified at the National Herbarium and Plant Laboratories (KATH), Godawari, Lalitpur. The voucher specimens were submitted to the KATH Herbarium.

For nomenclature of the species, we followed the Angiospermic Phylogenetic Group (APG III) system (Chase & Reveal, 2009; Chase *et al.*, 2009). In the case of the unresolved names (according to APG III), the nomenclature of Press *et al*. (2000) was adopted. The pteridophytes were named according to the nomenclature of Iwatsuki (1998) and Fraser-Jenkins (2008).

The individual species' presence and absence data in each studied plot were used as the response variable in the current study. The geographic coordinates of each plot were used for the analyses of the climate change studies. Presence records of *Betula utilis* in Humla (4200 m) were taken from the study done in the Nepal Himalaya (Sigdel *et al*., 2018).

3.3.1. b Plant species selection for SDMs

We selected two plants, *Betula utilis* with wide distribution and *Larix potaninii* var. *himalaica* with limited distribution in the Nepal Himalaya. We wanted to know how the distribution of these two species are affected by climate change in the future.

Betula utilis (Betulaceae) is a broad-leaved deciduous plant growing on semi-humid to semi-arid upper montane slopes (Miehe *et al*., 2015). It occurs mostly on the north facing slopes from 2700 m up to treeline c. 4300 m (Polunin & Stainton, 1984). The plant is one of the treeline species which shows vulnerability with climate change and its habitat is shifting upwards (Dhakal *et al*., 2016; Gaire *et al*., 2014). This plant also has a wide distribution from the eastern Hindu Kush of Pakistan to Hengduan Shan mostly on north facing slopes of moraines (Miehe *et al*., 2015).

Larix potaninii var. *himalaica* is found only in the Central Nepal and adjacent mountains of Tibet, China. This is a deciduous conifer belonging to Pinaceae family. The leaves of this plant are needle like arranged in clusters on small lateral shoots. The distribution of this plant is also high mountains starting from 2400 m to 4000 m up to treeline (Polunin & Stainton, 1984). There are some pure stands of *Larix potaninii* var. *himalaica* forest in the Nubri valley, Tsum valley and Langtang valley. It is mostly abundant on mud slips and moraines as early colonizing species (Miehe *et al*., 2015). However, some tree stands are also associated with *Abies spectabilis* and *Pinus wallichiana* forest.

The species occurrence data of plants were extracted from the Global Biodiversity Information Facility (http://www.gbif.org/) on 2018/09/06 for *Larix potaninii* var. *himalaica* and on 2018/09/13 for *Betula utilis*. The longitude, latitude and elevation were extracted from the datasets which were used for the Maxent modelling. Duplicate values and species occurrences outside the boundary of Nepal were removed. Both field observation data and online database records were plotted on the digital elevation model of Nepal. There were some records outside the known elevation range of the species and only records between 2000 m and 4100 m were used for analyses and for species distribution modeling (Figure 3.4).

3.3.1.c Herbarium and field records

The geographic locations of the *Betula utilis* and *Larix potaninii* var. *himalaica* were also taken from the herbarium deposited at the National Herbarium and Plant Laboratories (KATH), Godawari, Lalitpur, Nepal. The herbarium specimens collected in earlier period do not have the geographic coordinates. The occurrence records were taken from those herbaria which have labeled the geographic coordinates. In case of the range given in the herbarium, the lowest limit of the coordinate system was taken. The occurrence points of the plants recorded during our field visits to the plots were also used. A total of 111 occurrence points of *Betula utilis* and 21 occurrence points of *Larix potaninii* var. *himalaica* were used in the modelling.

3.3.2 Environmental variables

The following sets of environmental variables were selected as predictor variables (Table 3.1).

3.3.2. a Microclimate

The first set of environmental variables included the microclimate data (temperature and humidity) recorded by the logger installed in the field, from 2011 to 2013. The HOBOs (Onset Computer Corporation, Bourne, MA 02532, USA) were used to record air humidity and air temperature 1 m above the ground level in each plot. The HOBOs recorded data every 30 minutes. The soil temperatures were recorded at 10 cm below the ground level using iButton (Maxim Integrated, San Jose, CA 95134, USA) in each plot. The soil temperature data were recorded at the interval of 3 hours. The mean, minimum and maximum values of the year-round data were derived using the recorded data afterwards (Table 3.1).

There were some gaps in the loggers’ data due to shortage of time limits while retrieving data in the field. Some data loggers in some valleys overwrote the previous data before we were able to reach the field to collect data. Such non-available (NA) values were replaced by the mean of the previous records and records done afterwards so that there would be no loss of data rows in the data frame.

3.3.2. b Bioclimatic variables

The second set of environmental variables included the bioclimatic variables extracted from the WorldClim-climate data (Hijmans *et al.*, 2005; Table 3.1). These data were obtained in 30 arc seconds (0.93 km × 0.93 km = 0.86 sq km.) resolution. The latitude and longitude of each plot recorded, with the help of Garmin 60S GPS, were supplied in the DIVA GIS ver. 7.5.0. The software extracted the interpolated values of the bioclimatic variables from the WorldClim layers for each plot.

3.3.2.c Plot characteristics recorded during the visits

The third set of data contained the information of the regions, river valleys, the topography, and the land use type of the plots, which were directly recorded in the field. Garmin GPS 60S was used to record the elevation of the plots. Brunton Compass was used to record the aspect while Clinometer was used to record the slope angle of the sample plots. The land use types, the regions and the valleys were considered as categorical variables and all the others were taken as the ratio variables (Table 3.1)

3.3.2. d Maps and GPS locations

Landcover map of Nepal 2010 was downloaded from ICIMOD (https://rds.icimod.org/Home/DataDetail?metadataId=9224). The shapefiles of Nepal with administrative boundaries were downloaded from the official website of DIVA-GIS software (http://www.diva-gis.org/). Plot coordinates were recorded as longitude and latitude using a Garmin 60S GPS with WGS-84 datum. The locations of the plots were exported in the degree decimal format.

3.3.2. e Future climatic data

The CCSM4 dataset of global atmospheric carbon concentration for 2050 and 2070 were used for modelling future distributions of the two selected tree species (Gent *et al*., 2011). The data were downloaded from the WorldClim dataset. The CCSM4 (Community Climate System Model version 4) is a coupled climate model for was used in IPCC Fifth Assessment Repot (IPCC, 2013). RCP 2.6, 4.5, 6.0 and 8.5 data were used which forecast the low emission scenario (2.6) of GHGs.

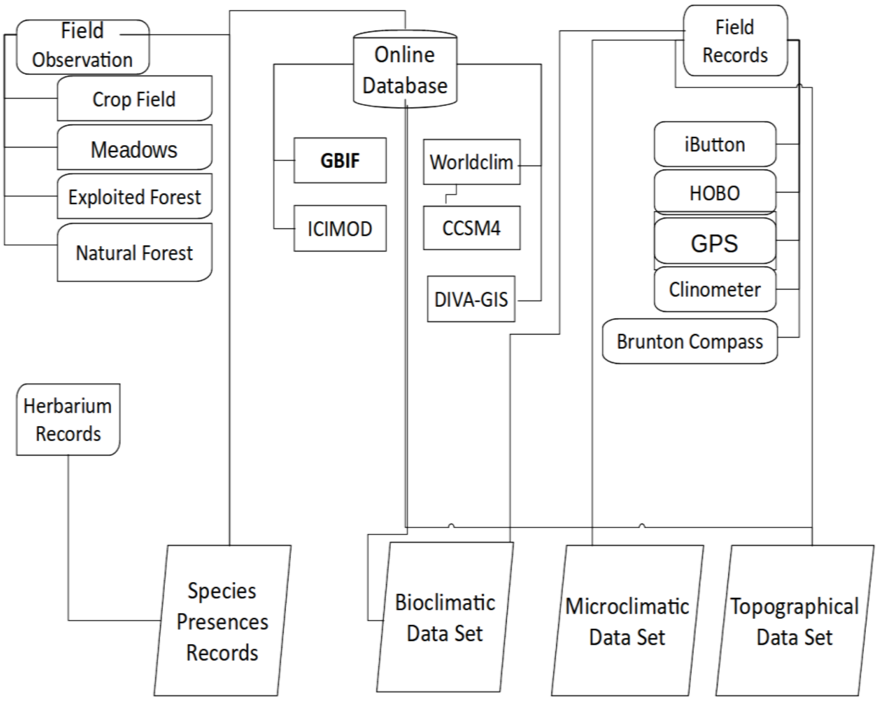

Figure 3.4: Schematic diagram of species data and environmental data collection process

Table 3.1: The list of environmental variables selected from three sets

Set	Variable acronym	Contained information
(1) Microclimatic	maxT.H	maximum air temperature recorded by HOBO
	MeanT.H	mean air temperature recorded by HOBO
	mint.H	minimum temperature recorded by HOBO
	maxT.iB	maximum soil temperature recorded by iButton
	MeanT.iB	mean soil temperature recorded by iButton
	minT.iB	minimum soil temperature recorded by iButton
	maxH.H	maximum air humidity recorded by HOBO
	meanH.H	mean air humidity recorded by HOBO
	minH.H	minimum air humidity recorded by HOBO
(2) Bioclimatic	BIO1	annual mean temperature
	BIO2	mean diurnal range
	BIO3	isothermality of temperature
	BIO4	temperature seasonality
	BIO5	maximum temperature of warmest month
	BIO6	minimum temperature of coldest month
	BIO7	annual temperature range
	BIO8	mean temperature of wettest quarter
	BIO9	mean temperature of driest quarter
	BIO10	mean temperature of warmest quarter
	BIO11	mean temperature of coldest quarter
	BIO12	mean annual precipitation
	BIO13	precipitation of wettest month
	BIO14	precipitation of driest month
	BIO15	precipitation seasonality
	BIO17	precipitation of the driest quarter
	BIO18	precipitation of warmest quarter
	BIO19	precipitation of the coldest quarter
(3) Spatial and Land Use	REG	three regions (Manaslu, Sagarmatha and Taplejung)
	VAL	six river valleys
	HABIC	crop field
	HABIE	exploited forest
	HABIF	natural forest
	HABIM	meadow
	ALTG	recorded elevation
	ASP	recorded aspect of the plot
	SLOP	recorded slope angle of the plot

The above list of variables contains large number of variables. The “rcorr” function of the *Hmisc* R-Package was used to check the collinearity among the environmental variables (Harrell *et al.*, 2015). The Pearson correlation coefficient was used to test the relationships between the variables. The highly correlated variables ($|r| \geq 0.7$)

were not taken for analysis (Booth *et al.*, 1994; Dormann *et al.*, 2013). The mean annual temperature and mean annual precipitations of all datasets as various studies show that they have good explanatory value for the ecological understandings (Dormann *et al.*, 2013). The topographic variables elevation, aspect and slope were used as the proxy of other used variables. Aspect of the plots were taken in bearing degrees ranging from 0º to 360º. Cosine transformation was used for these values. The river valleys of the study area are oriented north to south. All east facing plots bear negative values from 0 to-1 and all west facing plots bear positive values from 0 to 1. Sine transformation for the slope values of the plots were done. The slope angles fall between 0º to 90º. Sine transformation converts these degree values from 0 to 1, making further calculations easier and robust. This makes further analyses more meaningful and robust. The combination of climatic and topographic variables shows better predictive power in the distribution of the mountain plants (Hof *et al.*, 2012; Iverson & Prasad, 1998; Oke & Thompson, 2015; Stanton *et al.*, 2012).

3.4 Data analyses

Preliminary data recording and management were done using MS Excel and MS Access. The rows of excel formats were used for the species records and columns for the plots. They were stored in the MS Access database. The tab delimited “*.csv” formats were exported from MS Access and used as import for analyses in R ver. 3.1.2 (R Core Team, 2015). Cross tables were built using species records on the columns and the plots on the rows. The presence data of all the plots and subplots were converted as “1” unique value to denote the presence data and absence values were marked as “0”. The exploratory statistical tools were used to assess the species richness according to study sites and land use types. Similarly, trend of the climatic data was also analyzed. We produced charts, bar diagrams, scatter plots and box plots, which are more convenient and easily perceivable and assist in the further analyses (Borcard *et al.*, 2011; Rencher, 2002).

R-package ‘*vegan’* (Oksanen *et al.*, 2015) was used for the multi-variate ordination analyses. Detrended Correspondence Analysis (DCA) was performed for the species data (Hill & Gauch, 1980). The DCA showed the gradient length of the first ordination axis higher than 2.5 standard units. Therefore, we used as a constrained ordination method the unimodal model of the Canonical Correspondence Analysis

(CCA) (ter Braak, 1986). Based on CCA, all the predictors were compared among each other in order to find out the amount of variances explained by them (Oksanen *et al*., 2015).

General Linear Models (McCullagh & Nelder, 1989) were developed with species richness as response variable using the three separate sets of predictors. Microclimatic data recorded by the loggers in the plot constituted the first set of variables. Bioclimatic data were used as the second set and additional plot information about the location (i.e., region, river), land use and topography constituted the third set of predictors. The normality of the response variables, i.e., species richness was checked with the histogram, Q-Q plots taking first and third theoretical and sample quartiles were also made to check the normality. Kruskal-Wallis test was done to check the significance of normality. Because species richness can be considered as a count variable, Poisson family of the error distribution was applied for modelling.

The collinearity of the variables were checked by the Pearson correlation coefficient with the *rcorr* function of the *Hmisc* R package (Harrell *et al*., 2015). Pearson correlation coefficient shows the linear relation of the ratio data whereas the ordinal variables are tested by the Spearman correlation coefficient. It is the ratio of the covariance of two variables divided by the products of the standard deviations of the variables (Legendre & Legendre, 2012). The less correlated variable ($|r| < 0.7$, VIF >10) were taken for analyses (Booth *et al*., 1994; Dormann *et al*., 2013) (See Annex III). Some ecologically important topographical variables such as elevation, aspect, and slope were included in the analysis even though they show high correlation with some climatic variables (Dufour *et al*., 2006; Stein *et al*., 2014).

Generalized lineal model (GLM)

Four types of generalized linear models were developed in the current study, namely (i) microclimate model: used the data recorded by the data loggers in the study plots, (ii) bioclimatic model: used the bioclimatic variables based on WorldClim data, (iii) topographical model: used the topographical variables generated from the land use map of Nepal and data recorded in the field and (iv) Synthetic model: used all these variable sets together. The species richness was the response variable. Stepwise regression applying forward selection, backward elimination, or the combination of both were used for variable selection and the optimization of each model type. The species records show the Poisson distribution thus we applied log link function to develop the GLMs (Crawley, 2007). The *boot* package was used for the k=10 fold cross validation of the models (Guisan & Zimmermann, 2000). The model was fitted against the null model to check for its robustness and performance. The second order polynomial function was also tested, but Fisher's alpha was not significant. Thus, we proceeded with the first order linear model.

Those models with low AIC value (Akaike, 1974; Dormann *et al*., 2013) and high D^2 were selected as the best model (Schwarz & Zimmermann, 2005; Wohlgemuth *et al*., 2008; Nobis *et al*., 2009). The steps of analyses are given in the following schematic diagram (Figure 3.5).

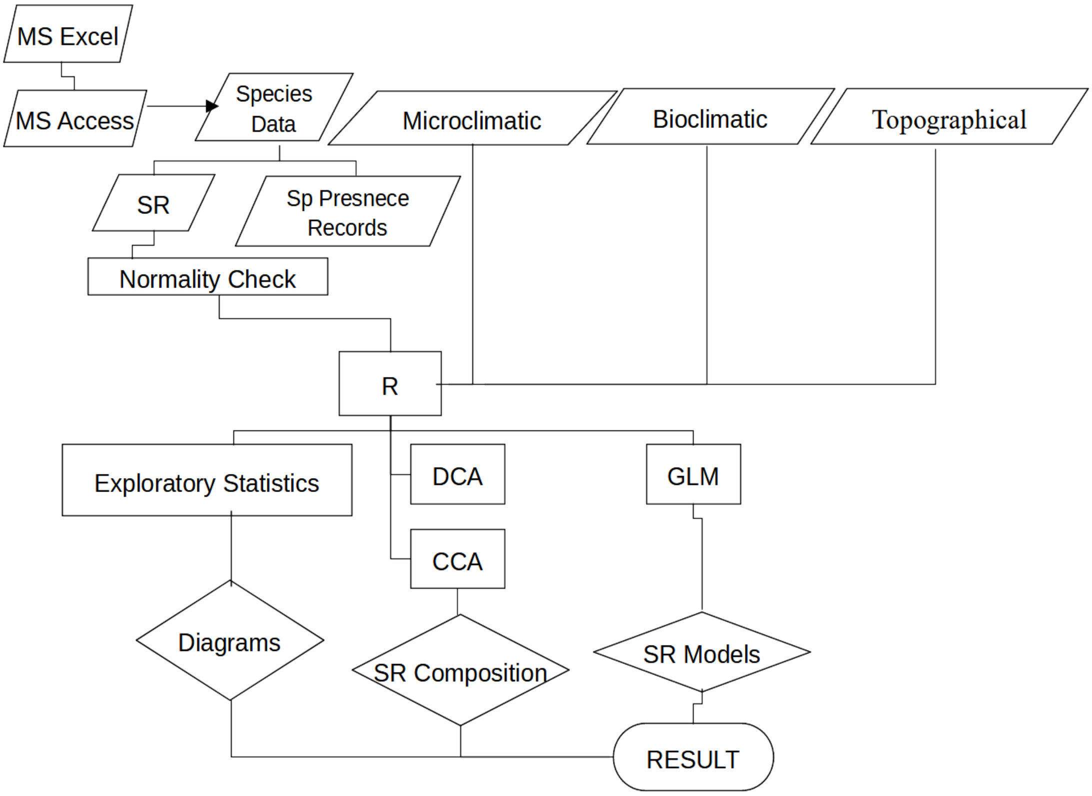

Figure 3.5: Flowchart showing of the analysis steps to explore species composition and drivers of species richness using GLMs

Maxent model

Maxent 3.3.3k (Phillips *et al*., 2006) was used for species distribution modelling along with ArcMap version 10.3 to analysis the maps. Maxent is based on the theory of maximum entropy which uses a machine learning algorithms and takes presence-only data for predictions (Phillips *et al*., 2006). It has been widely used with robust predictive power (Elith *et al*., 2006). The bioclimatic and topographic variables were used as the environmental variables (predictor variables) in the Maxent modelling and species occurrences of *Betula utilis* and *Larix potaninii* var. *himalaica* as the response variables. Random test percentage = 25%, regularization multiplier = 1, maximum number of background points =10000 with 15 replicates and 5000 iterations were set for the analyses. In the experimental tab of the Maxent, we checked "write background predictions" that would write the coordinates of the absent points in the experiment. Those absent points were used for the method validation. The occurrence data were divided into training set and test set by subsample function in the Maxent. Jackknife procedure was used for the percent variable contribution that estimated the relative and individual importance of the predictor variables (Sokal & Rohlf, 1995). The Area Under the ROC (receiver operating characteristic) curve (AUC) was used to evaluate the robustness of the models. AUC value ranges from 0-1 which measures the performance of the model (Fielding & Bell, 1997). AUC value between 0.5 and 0.7 indicates poor performance, 0.7-0.9 indicates good performance and >0.9 indicates high performance (Swets, 1988).

The bioclimatic variables extracted from the WorldClim database CCSM4 for years 2050 and 2070 with RCP 2.6, 4.5, 6.0 and 8.5 were used as predictors. Only less correlated variables were used for the modelling purpose. The original bioclimatic data contained a big tile for the geographical location which was more than the boundary of Nepal. Altitude and aspect of the locality were extracted from the Land Cover of Nepal 2010 data obtained from ICIMOD (ICIMOD, 2013) using ArcMap 10.3. The variables within the boundary of Nepal were cropped from the "Extract by Mask" function of the ArcMap ver. 10.3. The admin_3 layer downloaded from the DIVA_GIS database was used as the "input raster or feature mask data". First the bioclimatic variable 'bio1' was extracted which carries the information of the annual precipitation (O’Donnell & Ignizio, 2012). 'Bio1' was selected in output coordinate system within 'Output Coordinates', extent and snap raster within 'Processing Extent' and cell size within 'Raster Analysis' tabs all within the environmental settings while extracting the other variables. This method ensures the uniformity for in the geographical parameters of all variables to be similar.

3.4. a Map construction

Maxent requires the "ASCII" format for the predictor layers. Thus, all raster data were converted to "*. ascii" format in ArcMap 10.3. After conversion, the layers were selected from 1500 m to 4500 m elevation only. The observations of previous major climate change scenarios show that all species have climatic limits beyond which they cannot survive (Xu *et al.*, 2007). The models overpredicted in some cases and the distribution maps covered areas which were above current snowline. The average snow line in Nepal is approximately at 4750 m and treeline is in between 3800 m to 4250 m (Gaire *et al*., 2014; Khadka *et al*., 2020; Sigdel *et al*., 2018). We have decided to set upper limit of the predicted tree distribution to 4500 m according to field observation, expert consultation and available literature (Schickhoff, 2005).

The predicted suitability maps were reclassified in four intervals. The '10 percentile training presence of logistic threshold' value of Maxent analyses result was taken as the lowest base value and the high value was taken from the map itself with the highest limit. Probability of occurrence of the species was categorized into four groups. If the values fall below 25% probability, then it was classified as unsuitable habitat. Values above 25% probability are categorized as suitable habitats. Suitable habitats were calculated from the following formula

SV = HV-BV

Where,

SV = Suitable Value, HV= High Value and BV = Base Value

Low Suitability = 25-50%

= SV*(50/100) + BV

Medium Suitability = 50-75%

= SV*(3/4) +BV

High Suitability ≥ 75% probability of occurrence

Elevation, land use and aspect of the sites were also used as predictor variables. Those variables were used even though they are collinear with the 'bio1' (annual mean temperature) and 'bio12' (annual precipitation) (Dufour *et al*., 2006; Stein *et al*., 2014). Inclusion of those variable was significant in the Synthetic GLM to affect the present-day biodiversity and their inclusion in the future scenario were driven by two motives. They served as constants for the future state of biodiversity as Nepal has complex structure of topography and there are many variations within a small geographical area. Field observations showed that slight change in the aspect can lead to different vegetation types. For example, the north facing and north west facing slopes were favorable for the delicate and broad-leaved species *Betula utilis* and south facing and south east facing slopes were favorable for needle leaved species like *Abies spectabilis, Larix potaninii* var. *himalaica* and hard broad-leaved species as *Quercus semecarpifolia*.

3.4. b Model validation

The presence coordinates of the species were taken from the "_sample predictions.csv" file and the absence coordinated so the species were taken from the "_background predictions.csv". At the coordinates of these files the predicted species occurrences were extracted and used to calculate a confusion matrix (Table 3.2).

Table 3.2: Confusion matrix

		Actual Distribution	
		Presence	**Absence**
Predicted Distribution	Presence	True positive (a)	False positive (b)
	Absence	False negative (c)	True negative (d)

Where, Number of observations N=a+b+c+d.

From the above table the overall accuracy, error rate (ΔV) and true skill statistics (TSS) were calculated to know the robustness of the model (Allouche *et al.*, 2006; Swets, 1988).

a. Overall accuracy = $\frac{a+d}{N}$

b. Sensitivity = $\frac{a}{a+c}$

c. Specificity = $\frac{d}{b+d}$

d. TSS = sensitivity + specificity-1

e. Error rate (ΔV) = (b+c)/ N (Sykes *et al.*, 1999)

When $\Delta V < 0.15$ the agreement between the actual distribution and predicted distribution is excellent, 0.15-0.30 is very good, 0.30-0.45 is good, 0.45-0.60 as fair, 0.60-0.80 as poor and > 0.80 means very poor (Song *et al.*, 2004).

The AUC values obtained from the Maxent model were also assessed to see the performance of the model.

3.4.c Gain and loss

We calculated the probable gain and loss of the suitable area for both *Betula* and *Larix* using the future climate scenarios for 2050 (average for 2041-2060) and 2070 (average for 2061-2080) as in Khanum *et al*. (2013). ArcMap v.10.3 was used for the analysis. Two maps with present value and after climate change scenarios were overlayed by the *intersect* function. This produced the suitable stable probable area. The 'symmetrical differences' were calculated between present probable distribution and future probable distribution. The map values in attribute table with all '0' are loss area and maps with '2,3,4' are gain area. The suitable stable area was given 'quetzal green', gain area was given 'anemone violet', loss area was given 'mars red' and rest of unsuitable are was left as 'white'. Such produced maps were exported in picture formats (*.jpeg, *.tiff and *.png). The area of suitable stable, gain and loss were calculated in *.dbf format which were calculated using MS Excel.

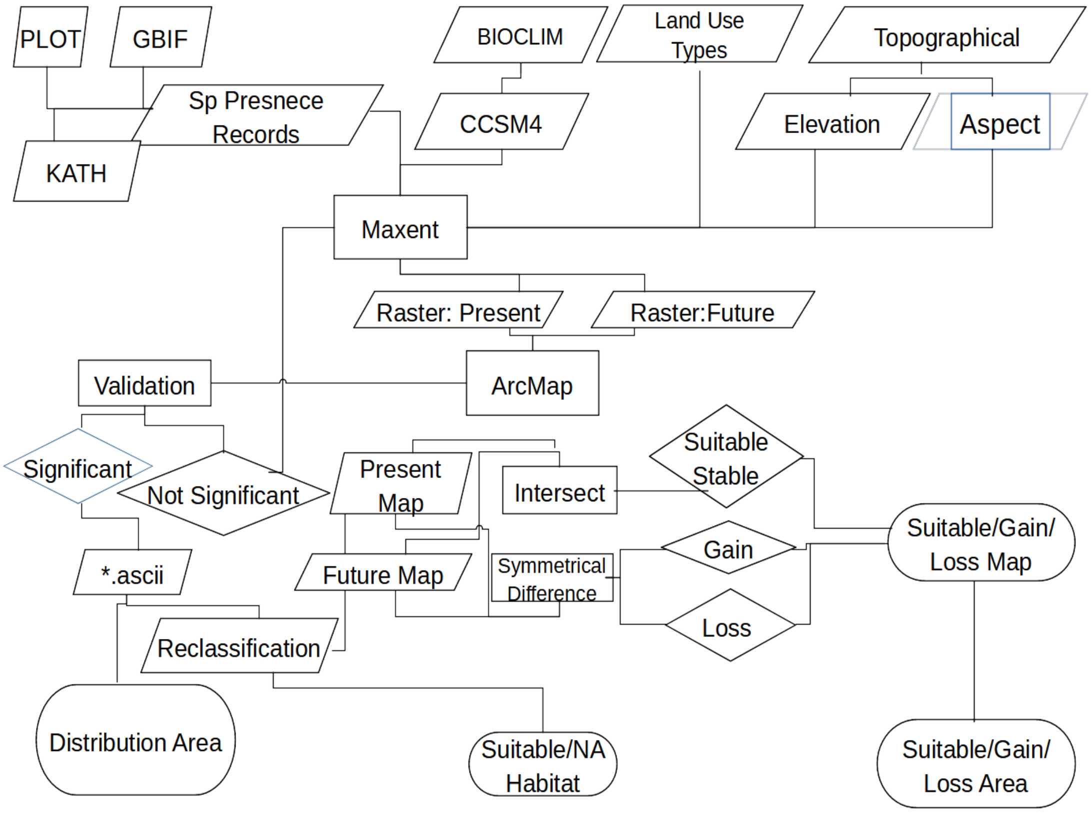

Figure 3.6: Flow chart of steps taken while developing species distribution models (SDMs)

CHAPTER 4

4. RESULTS AND DISCUSSION

The results of current study are presented in three sections. They are 4.1 Exploratory Analyses 4.2. Statistical Analyses and Model Development and 4.3 Species Distribution Modelling (SDM) under Climate Change Scenarios. The results are immediately followed by the discussions.

4.1 Exploratory analyses

The results obtained from the exploratory data analyses are presented in here. This section also contains the status of the species recorded, climatic and topographic data availability and the gradients according to elevation and different land use types

4.1.1 Vascular plant records

The survey of 217 plots studied in six valleys revealed 840 species of vascular plants belonging to 492 genera of 120 plant families (Annex I). Among them, there were 96 tree species, 110 shrubs, 586 herbs and 48 climber species (Figure 4.1). A total of 631 dicots, 159 monocots, 12 gymnosperm and 38 pteridophytes were recorded plant life forms (Figure 4.2).

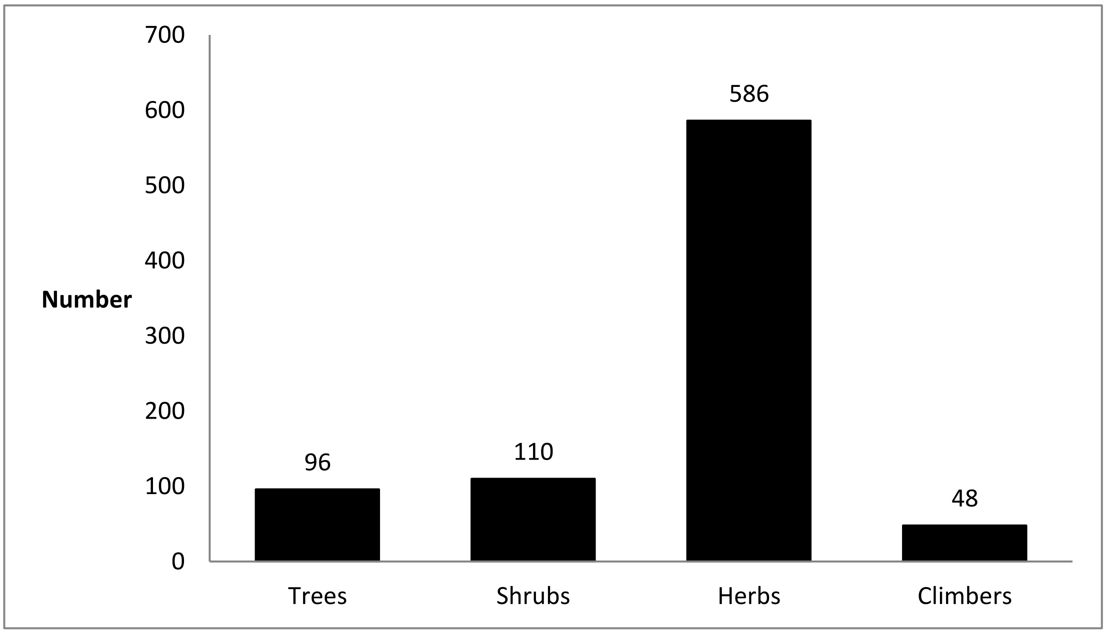

Figure 4.1: Species numbers of trees, shrubs, herbs, and climbers in the study area

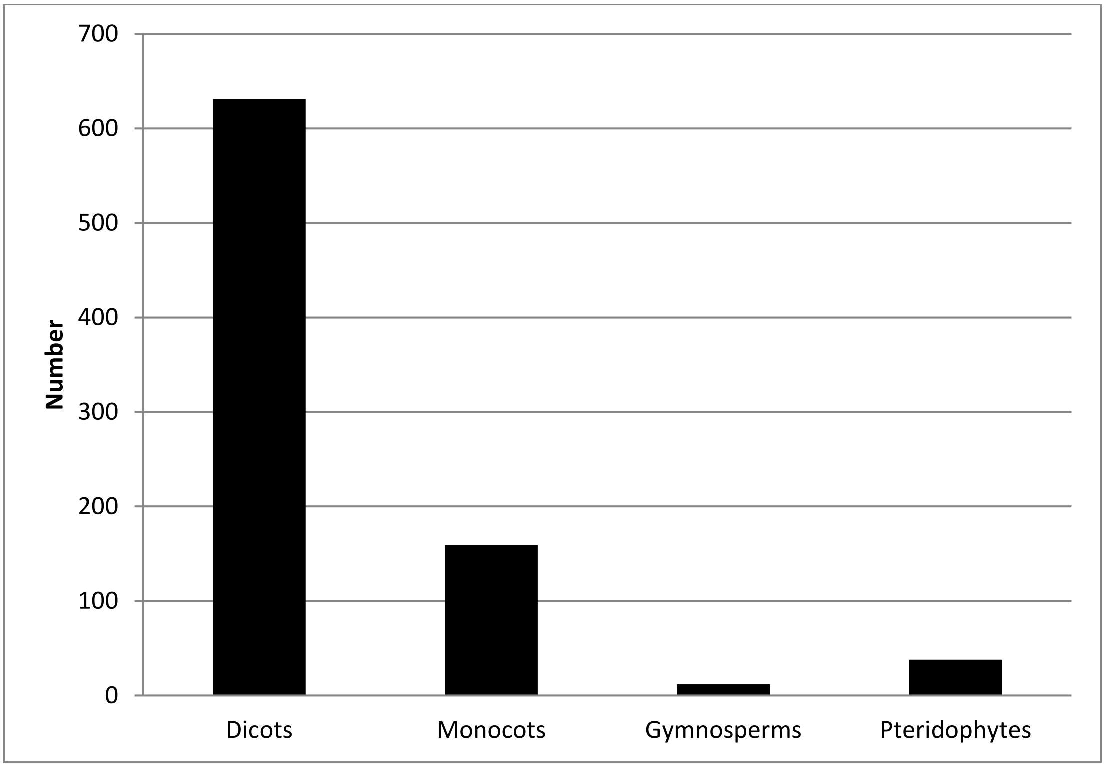

Figure 4.2: Species numbers of different life forms of plants recorded

Asteraceae was the largest family observed with 85 species followed by Poaceae (53 spp.), Rosaceae (52 spp.), Fabaceae (39 spp.), Lamiaceae (32 spp.) and Ranunculaceae (31 spp.). Out of 120 families 78 families had less than or equal to five (5) species per family (Table 4.1 & Figure 4.3).

Table 4.1: Top 10 of the most species-rich families

Family	**No. of species**
Asteraceae	85
Poaceae	53
Rosaceae	52
Fabaceae	39
Lamiaceae	32
Ranunculaceae	31
Ericaceae	28
Orchidaceae	27
Apiaceae	18
Gentianaceae	17
Polygonaceae	17

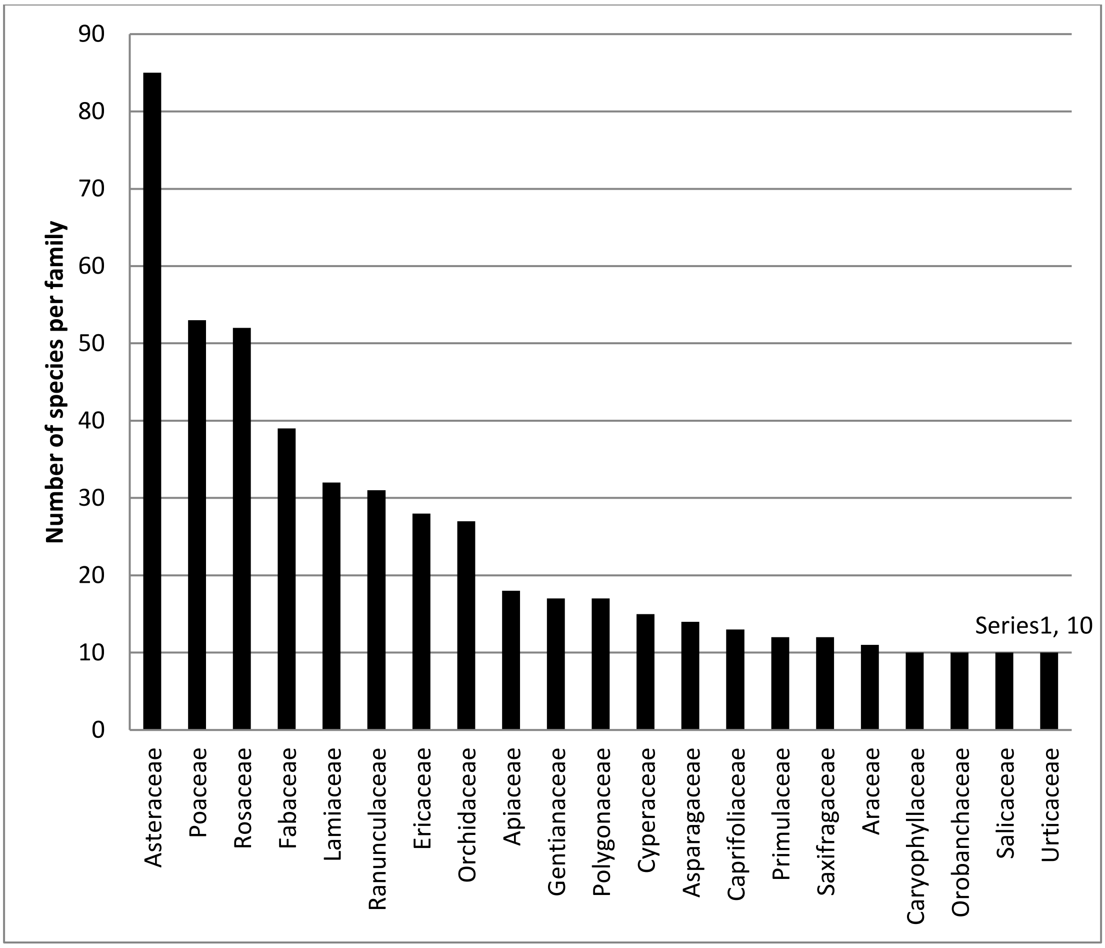

Figure 4.3: Bar diagrams showing the plant families which have more than 10 species in the study area

4.1.1. a Species observation records

More species were recorded in the first visit than the second visit (Figure 4.4). Heavy snowfall at Tsum valley (v4) and Dudhkunda valley (v5) during the second visits impeded our field works. We could not collect the species' records from 3800 m elevation from both valleys. Thus, the number of species observation was lower in the second visit of these two valleys (Figure 4.5). The overall species record diagram (first bar in Figure 4.5) shows that the number of species which were recorded only during the first visit, only during the second visit, or during both visits have almost equal proportions.

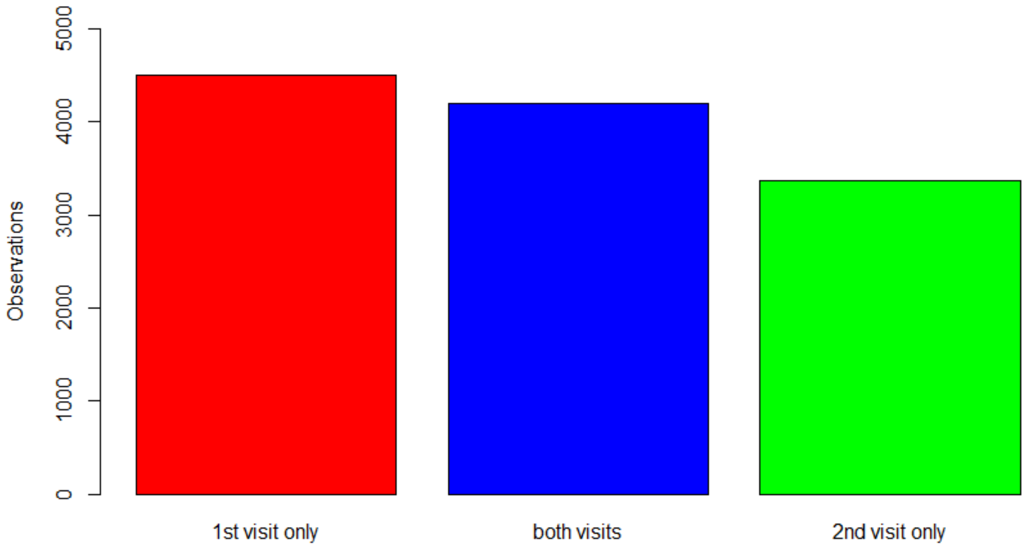

Figure 4.4: Bar diagram showing the species number recorded during first and second visit and blue bar with common records.

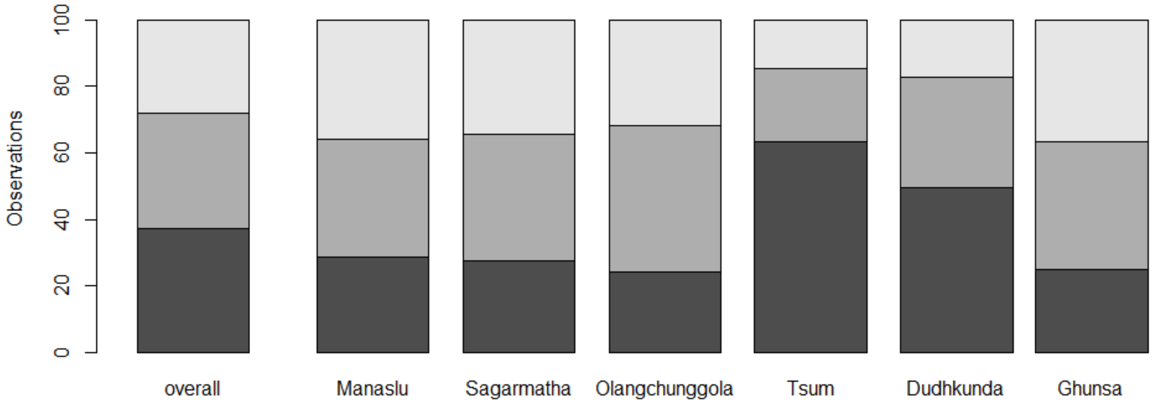

Figure 4.5: Valley-wise relative numbers of species number records: dark grey = the first visit only, grey = species common on both visits and light grey = the second visit only.

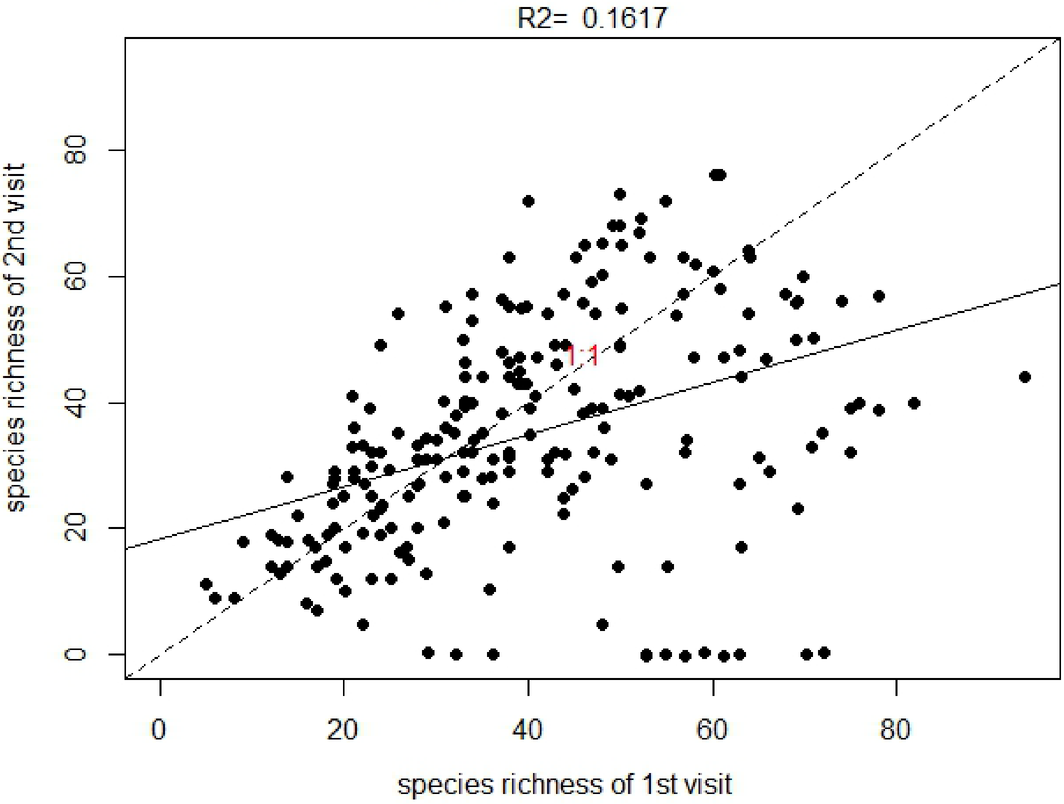

Figure 4.6: Correlation between species richness of the 1st and 2nd visit

We checked the relationships between two visits. The plots aligning towards first axis have high number of species recorded in the first visit and less in the second visit and vice versa. The coefficient of determination in the above figure is R^2 =0.1617, which indicates that the first and the second observations have a lot of independent records and neither visit shadows one another (Figure 4.6). The seasons of the first visit and second visit were different, thus the probability of recording new species on the same plot was high. The date, time, elevation, slope, aspect of the plots are given in Annex I.

4.1.1. b Species richness

The species richness of plants according to valley, elevations, exposition, and land use types have been presented in Figure 4.7. The species richness was lowest in Ghunsa valley, while Sagarmatha, Tsum and Dudhkunda valley showed highest species richness. Species richness declined as we climb up the elevation from 2200 m to 3800 m. The species richness is similar up to 3000 m and then declined gradually. The species richness at the exploited forest was highest, followed by that of meadow and forest. The species richness was lowest in the crop fields in all valleys (Figure 4.7).

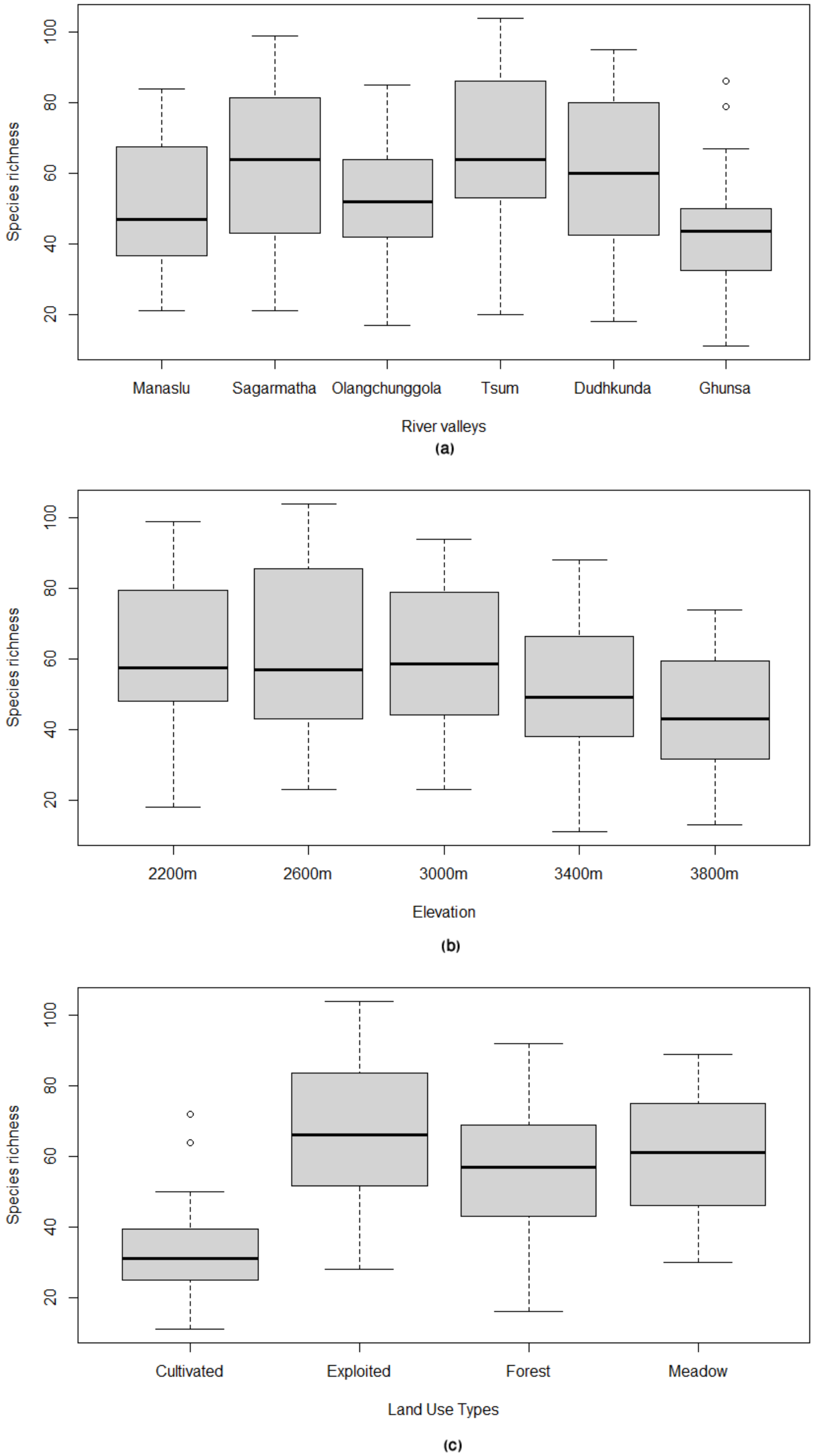

Figure 4.7: Species richness of the plants a) per valley b) per elevation and c) per land use type

4.1.2 Records of microclimates

The results presented here were recorded at the individual plots by HOBO and iButton, the data loggers installed during consecutive field visits.

4.1.2. a Status of data availability

The data loggers were established in two phases. Data loggers were established in the Manaslu (v1), Dudhkoshi (v2) and Olangchung Gola (v3) valleys in 2011. Data loggers were established in Tsum (v4), Dudhkunda (v5) and Ghunsa (v6) river valleys in 2012. We checked the continuity of the data when collected from the field. The following diagram shows the data continuous availability of soil and air temperature and air humidity. The small gap in the v1 and v2 (HOBO) are non-available data. The second visits were delayed by one month than expected. The data loggers overwrote the previous data (Figure 4.8).

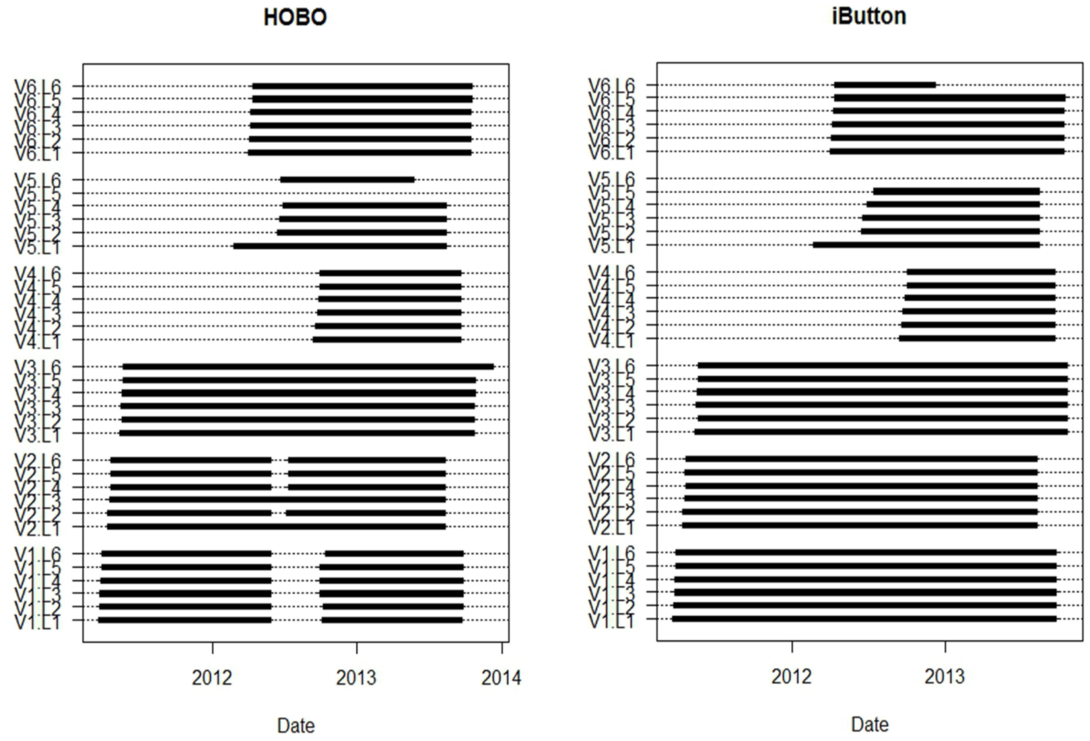

Figure 4.8: The period of data loggers that were established in all elevation, land use types and all valleys. [HOBOs recorded the relative humidity and air temperature of the plots 1 m above ground level. iButton recorded the soil temperature 10 cm below ground surface of plots in all valleys in all elevations. (V1: Manaslu valley; V2: Dudhkoshi valley, V3: Olangchunggola valley, V4: Tsum valley, V5: Dudhkunda valley, V6: Ghunsa valley, L1: 2200 m, L2: 2600 m, L3:3000 m, L4: 3400 m, L5: 3800 m, L6:4000 m)]

4.1.2. b Soil and air temperature

Elevation is used as a proxy for temperature. The soil temperatures of the iButton dropped almost linearly along the elevational gradient. (Figure 4.9).

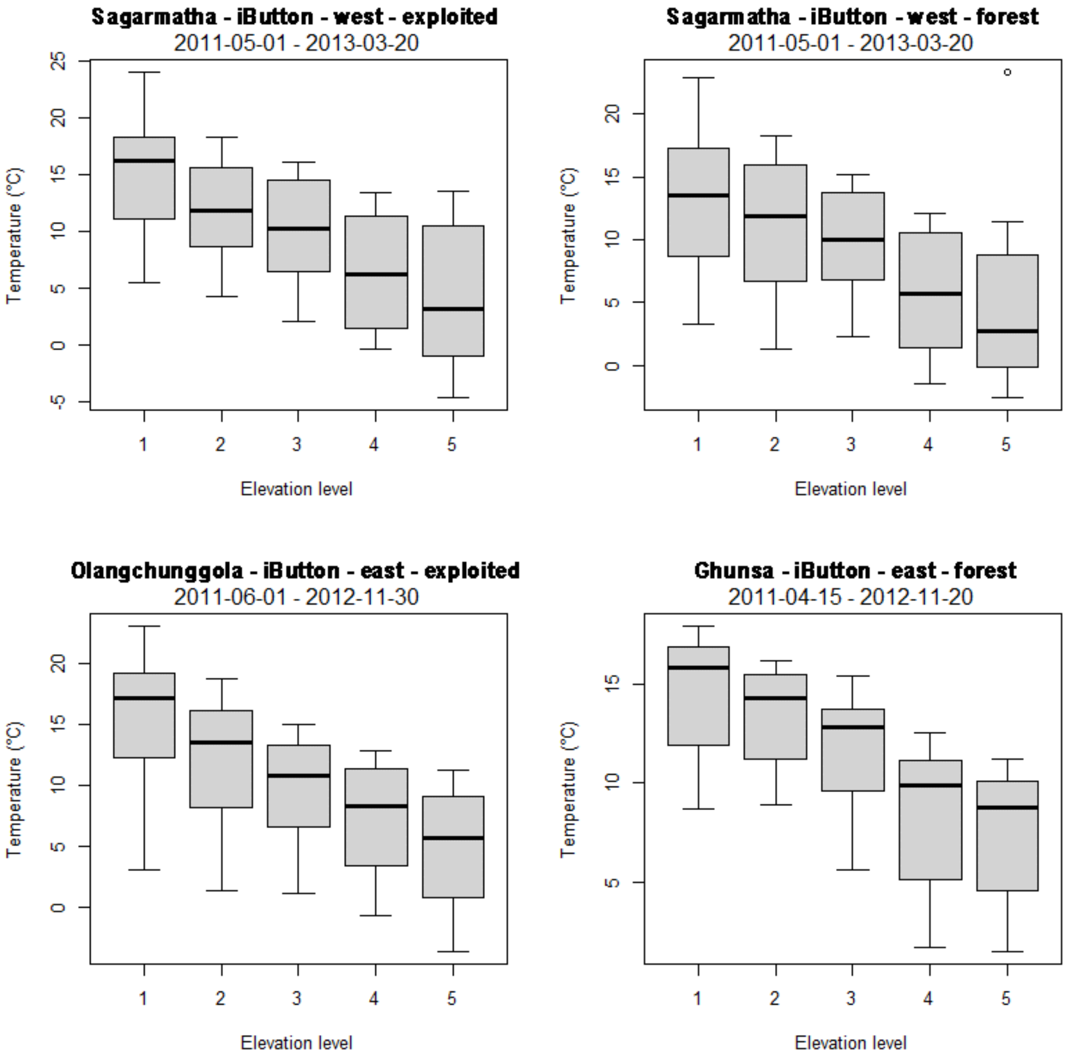

Figure 4.9: Soil temperature recorded at study areas using iBottons. Here, 1 to 5 refers to the elevation level, i.e., 1 refers to 2200 m, 2 to 2600 m, 3 to 3000 m, 4 to 3400 m, and 5 to 3800 m

Similar cases were observed in case of air temperatures recorded by the HOBOs (Figure 4.10). The following figures show air temperatures in the study area. Some of the boxplots show outliers in the air temperature. The HOBOs which record the air temperatures are sometimes exposed to direct sunlight and sometimes masked by the rainfalls in the area.

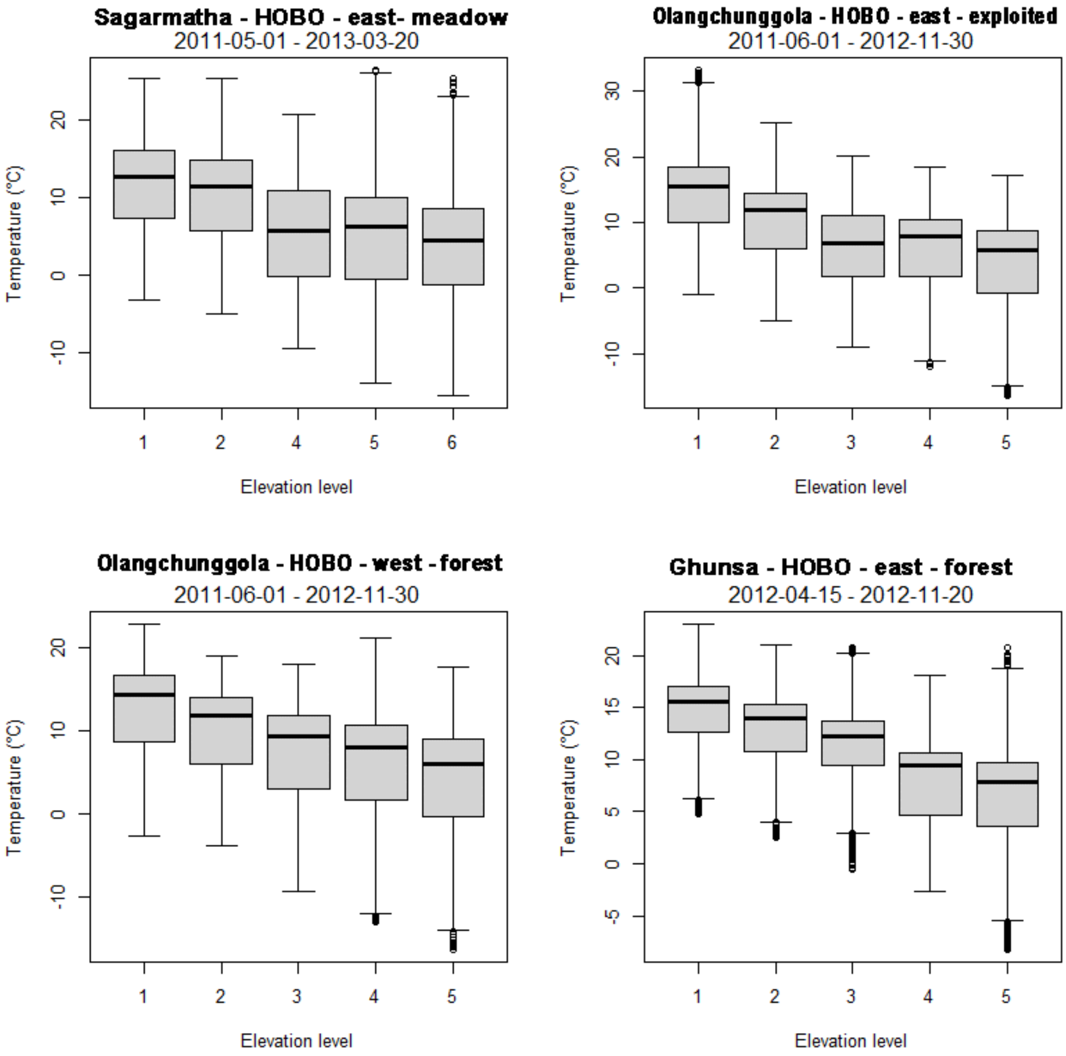

Figure 4.10: Air temperature recorded at study areas. Here, 1 to 5 refer to as the elevation level, i.e., 1 refers to 2200 m, 2 to 2600 m, 3 to 3000 m, 4 to 3400 m, and 5 to 3800 m

4.2 Composition and richness of vascular plants

4.2.1 Species composition

Species composition of all six valleys were measured with Detrended Correspondence Analysis (DCA) (Hill & Gauch, 1980). The first axis of DCA was 5.3 standard unit followed by 4.2, 3.5 and 2.6 standard units for second, third and fourth axes, respectively. The length of the first two DCA axes were greater than 4.0 standard units, indicating a complete turnover of the species along these axes. Such a high species turnover implies a high beta diversity, i.e., strong changes in the species composition between plots (Table 4.2).

Table 4.2: DCA summary of species composition of all valleys

	DCA1	DCA2	DCA3	DCA4
Eigenvalues	0.4904	0.4264	0.3093	0.2503
Decorana values	0.5343	0.4149	0.2987	0.2416
Axis lengths	5.3262	4.2064	3.4904	2.5784

The centroids of the DCA site scores for each land use type and elevation level are plotted on the DCA scatter plot of the first two axes in Figure 4.11. The first DCA axis shows a gradient of different land use types. Crop field was placed far away from the rest of the plots. Exploited forest and natural forest were very near to each other in the plots. These two land use types shared more common species than with meadow or cultivated crop field. Crop fields are intensely managed by farmers and the species diversity also changes with the cropping pattern and crop rotation. The centroid of meadows is located between those of crop fields and forest because meadows share some common species with both. The meadows are mostly grasslands grazed seasonally and people also collect the grass from there. The elevational gradient is aligned in between the first axis and the second axis. Our study plots were between 2200 m and 3800 m with 400 m of elevational gradient in each level. The species composition is also affected by the elevational gradients along the second axis. The distinct and different results for centroids of land use types and elevation levels show the species composition at the plot level is mainly driven by land use and elevation.

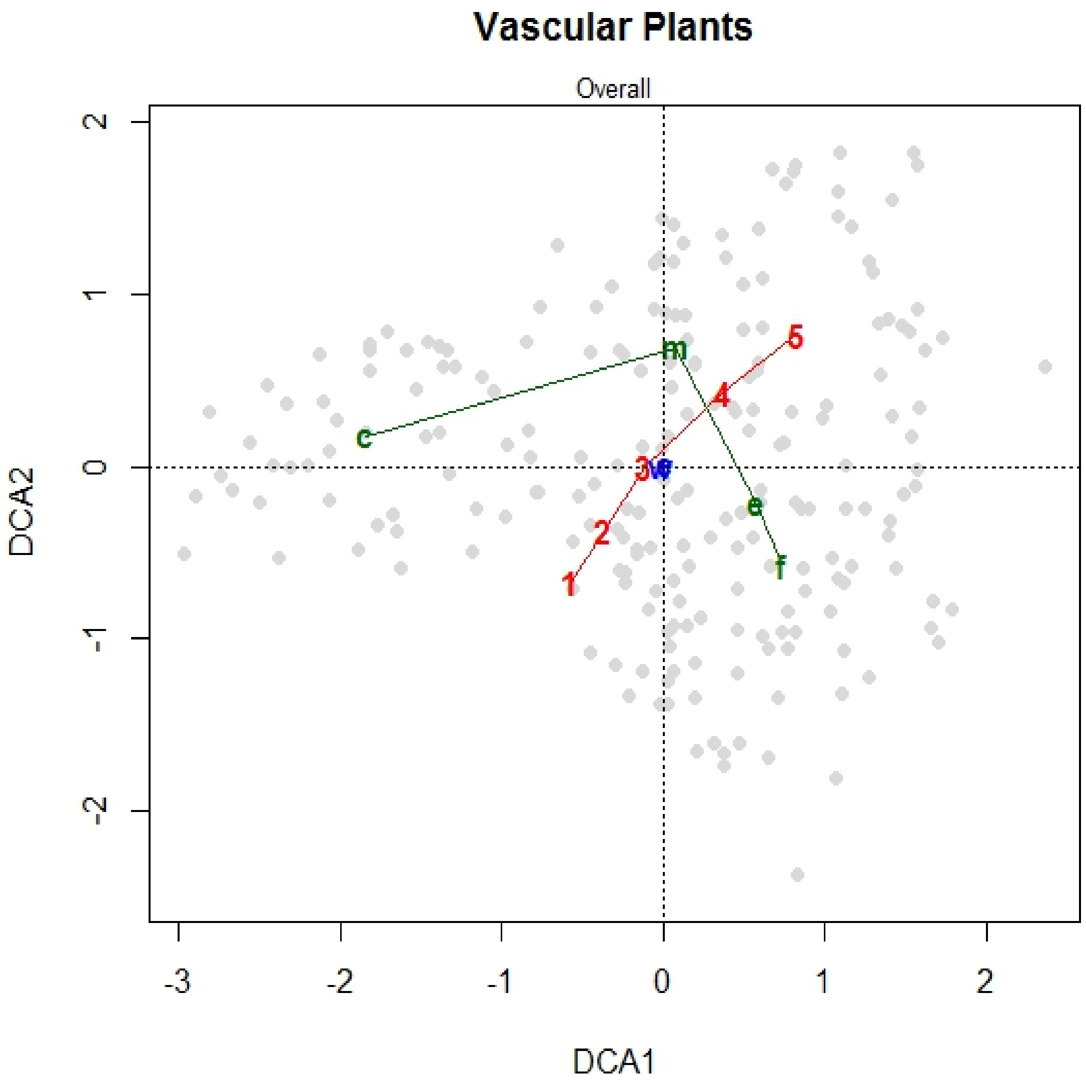

Figure 4.11: DCA scatter plot showing the species composition of sites along with centroids for sites of different land use types and elevation levels (c= crop field, m= meadow, e=exploited forest, f=natural forest; 1:5 is elevation band, 1=2200 m, 2=2600 m, 3=3000 m, 4=3400 m and 5=3800 m)

DCA is an indirect gradient analysis where environmental variables are not included in the calculation of sites and species scores. Thus, CCA was used to calculate the effect of environmental variables on the species composition. In the CCA analysis, the isothermality (BIO3), minimum temperature of the coldest month (BIO6), precipitation seasonality (BIO15) and precipitation of the coldest quarter (BIO19) show significant constraint contribution as climatic predictors in the CCA analysis (Table 4.3). Similarly, exposition, land-use types, elevation, aspect, and slope of the plots are also significant contributing variables. The studied valleys and region show different species composition (Table 4.3).

Table 4.3: Table showing the CCA test statistics of environmental variables

Variable	**Code**	**Df**	**Chisq**	**F**	**N. Perm**	**Pr(>F)**
Isothermality	BIO3	1	0.1045	1.8435	199	0.005 **
Min.temp. coldest month	BIO6	1	0.1045	1.844	199	0.005 **
Precipitation seasonality	BIO15	1	0.1421	2.5072	199	0.005 **
Ppt. colded quarter	BIO19	1	0.1115	1.9686	199	0.005 **
Exposition	EXPO	1	0.0659	1.1628	199	0.010 **
Land-use types	HABI	3	0.4771	2.8067	199	0.005 **
Elevation	ALTG	1	0.1867	3.2942	199	0.005 **
Aspect	ASP	1	0.1016	1.7926	199	0.005 **
Slope	SLOP	1	0.081	1.4292	199	0.005 **
Region	REG	1	0.1653	2.9179	199	0.005 **
Valley	VAL	1	0.1862	3.2854	199	0.005 **
	Residual	203	11.5025			

Signif. codes : 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

The CCA triplot of Figure 4.12 shows the relative effect of different predictor variables on the first two axes CCA1 and CCA2. These axes are the orthogonal dimensions obtained after constraining the species and site scores by the environmental variables. The species composition is affected more by elevation (ALTG) than other variables, which is proxy for the annual mean temperature (BIO1). The effect of elevation, thus mean temperature is inversely correlated with other bioclimatic variables such as the minimum temperature of the coldest month (BIO6), and precipitation seasonality (BIO15). In addition to the elevational gradient which is highly correlated with aspect, the slope of the study site plays another major role in shaping the species composition of the plots (Figure 4.12).

Rainfall is more frequent during the summer months of July to September in the study area due to monsoon from the eastern site the Bay of Bengal (Kansakar *et al*., 2004). However, the rainfall pattern changes in the winter when the westerlies penetrate from the western side of Nepal with mostly dry atmosphere which is replaced by the pre-monsoon with strong westerly winds with occasional rainfall (Nayava, 1980). The ecological significance of this seasonal fluctuation is well required for the growth and survival of the plants thus forming the species composition (Tanaka *et al*., 2012). Similar results have been documented for annual plants in Mongolia (Yan *et al*., 2015).

The species composition is influenced by the land use types (the cross marks in Figure 4.12). Grazing in the meadows shape the composition differently (Huston, 1994; Oiong *et al*., 2010). The species composition in the crop fields are different from those of the forest and meadow as they are managed by farmers more intensively

(Maren & Vetaas, 2007). The competition of the plants in the crop fields are changed seasonally and the diversity becomes low in such crop fields. This is in line with the competitive displacement theory of Huston (1979). However, the species richness and compositions are affected synergistically by various variables (Moura *et al*., 2016). The plant successional stage representing different land use history also play role in shaping the species composition (Kouba *et al*., 2015). Baniya *et al*. (2009) have assessed the species diversity in different land use types taking temporal gradient as the explanatory variable. They found the hump shape of species diversity along the gradient which agrees with intermediate species richness hypothesis (Connell, 1978).

The topographical variables elevation, aspect, slope angle also plays significant role in the species composition (Table 4.3). The difference in the slope and aspect of the sites have different microclimates with different water nutrient regimes (Cornwell & Grubb, 2003) and sometimes change in the aspect also changes in the solar radiation (Austin & Van Niel, 2011b). The species composition of the Nepal Himalaya also seem to affected by environment, land use history, land use types and land use change along with the slope and aspect of the sites (Paudel & Vetaas, 2014; Sharma *et al*., 2014, Rai *et al*., 2016, Rai *et al*., 2017).

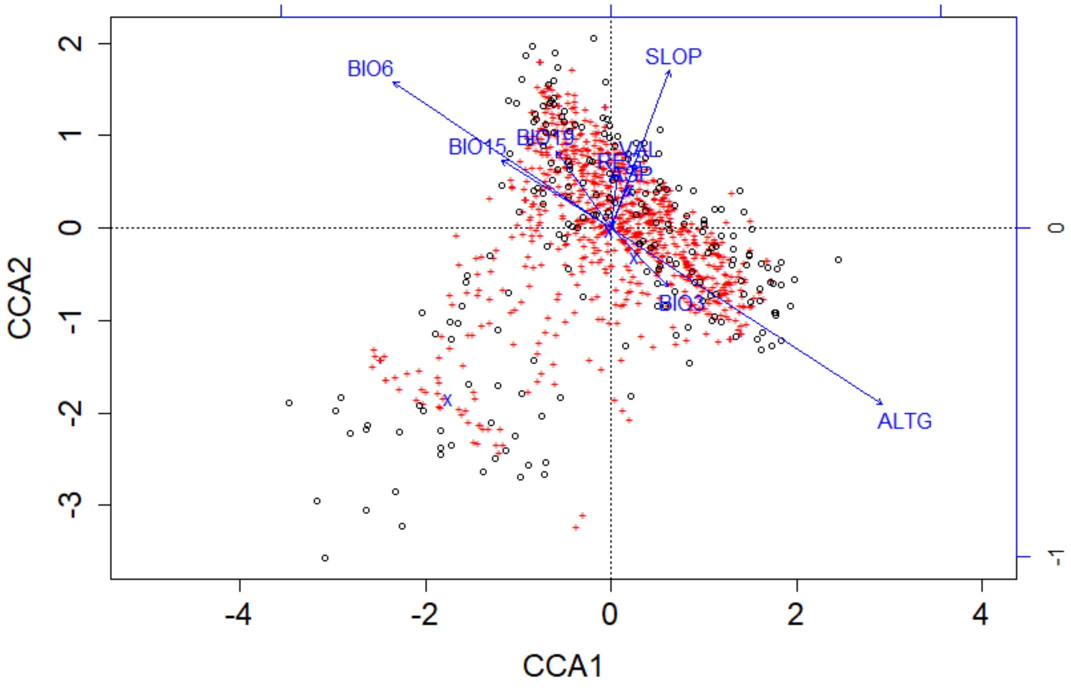

Figure 4.12: CCA scatter plot showing the species composition of plots shaped by the topographical and bioclimatic variables; the red crosses indicate the species, the circles indicate the plots, the blue cross indicate the land use types and the arrows showing the predictor variables.

4.2.2 Generalized linear models of species richness

In case of the microclimatic model, the linear combination of mean soil temperature, mean and minimum values of air humidity (MeanT.iB+meanH.H+ minH.H) was the best model (AIC=2950, D^2=0.07) based on forward selection. Backward elimination improved the model by reducing the AIC value to 2947.5. In this model the mean air humidity (meanH.H) was discarded and maximum air humidity (maxH.H) was used instead. Stepwise regression using backward elimination and forward selection returned the best model with AIC=1923.2 and D^2=0.09. The D^2, sometimes referred to as pseudo R^2, are very low in case of these microclimate model (Table 4.4).

For the bioclimatic model, the linear combination of maximum temperature of warmest month (BIO5), precipitation of driest month (BIO14) and precipitation seasonality (BIO15) produced the almost best model in forward selection (AIC = 2790.9 & D^2 = 0.16). The addition of other predictors did further improve the model only marginally. Backward elimination of the selected variables reduced the AIC to 2741.7 and increased D^2 to 0.19. The percentage variation explained further increased in stepwise regression with backward elimination and forward selection model (AIC = 2526 & D^2 = 0.32). Inclusion of all 19 bioclimatic variables produced better result with decrease in the AIC and increase in the D^2, however, interpreting the individual contributions of the variables would become too complex (Table 4.4).

In case of topographic model, the linear combination of three regions (MCA, SNP, KCA), six valleys, land use types elevation, latitude, longitude, aspect, and slope (REG+VAL+HABI+LAT+LONG+ASP+SLOP) produced the best model in forward selection (AIC = 2755.2 & D^2 = 0.19). Backward elimination improved the model by removing land use types and elevation from the previous model. The model performance was equal with that of stepwise regression (AIC = 2749.8 & D^2 = 0.19). The Inclusion of all variables to construct the linear model did not improve model performance (AIC = 2760.3 & D^2 = 0.19).

The significance of each variable was tested with ANOVA (Table 4.5). The significant variables from all three sets were taken to develop the synthetic model. Linear combination of mean soil temperature, mean humidity, minimum humidity, maximum temperature of warmest month, precipitation of the driest month, precipitation seasonality, valleys, land use types, elevation, and latitude (MeanT.iB+meanH.H+minH.H+BIO5+BIO14+BIO15+VAL+HABI+ALTG+LAT) produce the best model in forward selection procedure (AIC = 2641.1 & D^2 = 0.25). Backward elimination did not improve the model (AIC = 2749.8 & D^2 = 0.19) however, stepwise regression and all variable regression reduced the AIC to 2336.6 and 2355.3, respectively and the variation explained was also high (D^2 = 0.44).

Table 4.4: Variable selection for Generalized Linear Models (GLMs) using forward selection, backward elimination, and both in stepwise regression

Name of variables	**AIC**	**Residual deviance**	**D^2**	**Percentage change in D^2**
Microclimatic model				
Forward selection				
MeanT.H	3047.8	1785	0.02	
MeanT.H+MeanT.iB	3003.1	1738.2	0.04	2.62
MeanT.H+MeanT.iB+meanH.H	2986.9	1720.0	0.05	1.05
MeanT.iB+meanH.H+minH.H	2950.5	1683.6	0.07	2.12
Backward elimination (MeanT.iB+maxH.H+minH.H)	2947.5	1680.7	0.07	0.17
Stepwise regression (Backward elimination and forward selection)	2923.2	1648.4	0.09	1.92
All variables	2925.5	1646.7	0.09	0.10
Bioclimatic model				
Forward selection				
BIO3	3069.9	1807	0.00	
BIO3+BIO5	3015.2	1750.3	0.04	3.14
BIO3+BIO5+BIO14	2899.4	1632.6	0.10	6.72
BIO5+BIO14+BIO15	2790.9	1524.1	0.16	6.65
BIO3+BIO5+BIO14+BIO15	2792	1523.2	0.16	0.06
BIO3+BIO5+BIO14+BIO15+BIO17	2793.5	1522.7	0.16	0.03
BIO3+BIO5+BIO14+BIO15+BIO17+BIO19	2794.5	1521.7	0.16	0.07
Backward elimination (BIO3+BIO12+BIO14+BIO15+ BIO17)	2741.7	1470.9	0.19	3.34
Stepwise regression (Backward elimination and forward selection)	2526.2	1235.4	0.32	16.01
All variables	2477.6	1180.8	0.35	4.42
Topographical model				
Forward selection				
REG	2983	1720.1	0.05	
REG+VAL	2951.1	1686.3	0.07	1.97
REG+VAL+HABI	2954	1683.2	0.07	0.18
REG+VAL+HABI+ALTG	2934.3	1661.5	0.08	1.29
REG+VAL+HABI+ALTG+LAT	2908.4	1633.6	0.10	1.68

REG+VAL+HABI+ALTG+LAT+LONG	2765	1488.2	0.18	8.90
REG+VAL+HABI+ALTG+LAT+LONG+ASP	2760.4	1481.6	0.18	0.44
REG+VAL+HABI+ALTG+LAT+LONG+ASP+SLOP	2755.2	1474.4	0.19	0.49
Backward elimination (REG+VAL+LAT+LONG+ ASP+SLOP)	2749.8	1477	0.19	-0.18
Stepwise regression (Backward elimination and forward selection)	2749.8	1477	0.19	0.00
All variables	2760.3	1473.4	0.19	0.24
Synthetic model				
Forward selection				
ALTG	3045.2	1782.4	0.02	
MeanT.iB+meanH.H+BIO15	2929.3	1662.5	0.08	6.73
BIO5+BIO15+SLOP+REG+VAL	2838.1	1567.3	0.14	5.73
BIO1+BIO12+BIO15+SLOP+REG	2859.5	1588.6	0.12	-1.36
MeanT.iB+meanH.H+BIO15+SLOP	2922.7	1653.9	0.09	-4.11
BIO1+BIO12+BIO15+SLOP+REG+VAL	2850.8	1577.9	0.13	4.60
MeanT.iB+meanH.H+minH.H+BIO5+BIO14+BIO15+ HABI+ALTG	2670.5	1389.6	0.23	11.93
MeanT.iB+meanH.H+minH.H+BIO5+BIO14+BIO15+ HABI+ALTG+LAT	2672.1	1389.2	0.23	0.03
MeanT.iB+meanH.H+minH.H+BIO5+BIO14+BIO15+ VAL+HABI+ALTG+LAT	2641.1	1356.3	0.25	2.37
Backward elimination	2749.8	1477	0.19	-8.90
Stepwise regression (Backward elimination and forward selection)	2336.6	1021.8	0.44	24.66
All variables	2355.3	1014.5	0.44	0.71

The relative significance of each variable on the model performance was calculated and presented as follows (Table 4.5). In case of Microclimatic model mean air temperature (MeanT.H) and mean soil temperature (MeanT.iB) were the significant variables ($p < 0.001$). All the bioclimatic variables were highly significant ($p < 0.001$). In the topographical set, region, valley, latitude, longitude and aspect and slope showed significant contributions, while the impact of land use types was not significant. The effects of land use types, however, showed significant estimates for the best model in combination with other variables (Table 4.5). The interpretation of the effect of land use type is complicated by the fact that the fourth type is a perfect linear combination of the three others (if all others are absent, it is present, and if one of the others is present it is absent). The fourth land use type is therefore one of the first variables eliminated during stepwise regression.

Table 4.5: Summary statistics showing the effect of environmental variables on species richness shown as calibration results of generalized linear models (* if $p \leq 0.5$, ** if $p \leq 0.1$, *** if $p \leq 0.01$).

Data Set	Variables	Estimate	S. E	z value	p	
Microclimatic	(Intercept)	4.33E+00	8.99E-02	48.189	<2e-16	***
	MeanT.iB	-2.13E-02	2.46E-03	-8.676	<2e-16	***
	meanH.H	-9.26E-03	2.34E-03	-3.952	7.74E-05	***
	minH.H	1.09E-02	1.80E-03	6.028	1.66E-09	***
Bioclimatic	(Intercept)	3.58E+00	9.82E-02	36.45	<2e-16	***
	BIO5	-4.46E-03	3.59E-04	-12.41	<2e-16	***
	BIO14	3.22E-02	2.53E-03	12.76	<2e-16	***
	BIO15	1.08E-02	9.64E-04	11.19	<2e-16	***
Topographical	(Intercept)	-8.39E+01	8.03E+00	-10.449	<2e-16	***
	REG	-1.13E+00	9.43E-02	-11.927	<2e-16	***
	VAL	2.19E-02	6.09E-03	3.59	3.31E-04	***
	HABIE	1.02E-02	2.93E-02	0.349	7.27E-01	
	HABIF	-8.52E-03	3.13E-02	-0.272	7.86E-01	
	HABIM	1.17E-02	2.83E-02	0.415	6.78E-01	
	ALTG	2.44E-05	1.89E-05	1.295	1.95E-01	
	LAT	3.45E-01	6.69E-02	5.16	2.47E-07	***
	LONG	9.29E-01	7.80E-02	11.91	<2e-16	***
	ASP	3.61E-02	1.35E-02	2.673	7.53E-03	**
	SLOP	1.61E-01	5.98E-02	2.683	7.30E-03	**
Synthetic	(Intercept)	-3.88E+00	2.17E+00	-1.791	7.32E-02	.
	MeanT.iB	-3.80E-02	4.56E-03	-8.338	<2e-16	***
	meanH.H	-7.09E-03	2.65E-03	-2.68	7.37E-03	**
	minH.H	6.70E-03	1.97E-03	3.399	6.77E-04	***
	BIO5	-2.93E-03	6.69E-04	-4.387	1.15E-05	***
	BIO14	5.59E-02	5.03E-03	11.127	<2e-16	***
	BIO15	1.57E-02	1.84E-03	8.531	<2e-16	***
	VAL	4.13E-02	7.18E-03	5.75	8.95E-09	***
	HABIE	-5.46E-02	2.94E-02	-1.856	6.34E-02	.
	HABIF	-8.43E-02	2.98E-02	-2.827	4.70E-03	**
	HABIM	2.91E-03	2.75E-02	0.106	9.16E-01	
	ALTG	-8.15E-05	4.08E-05	-1.996	4.59E-02	*
	LAT	2.59E-01	6.79E-02	3.811	1.38E-04	***

The diagnostic plot for the synthetic model shows the random dispersion of the residuals (Figure 4.13) and confirms that basic model assumption are fulfilled (Crawley, 2007).

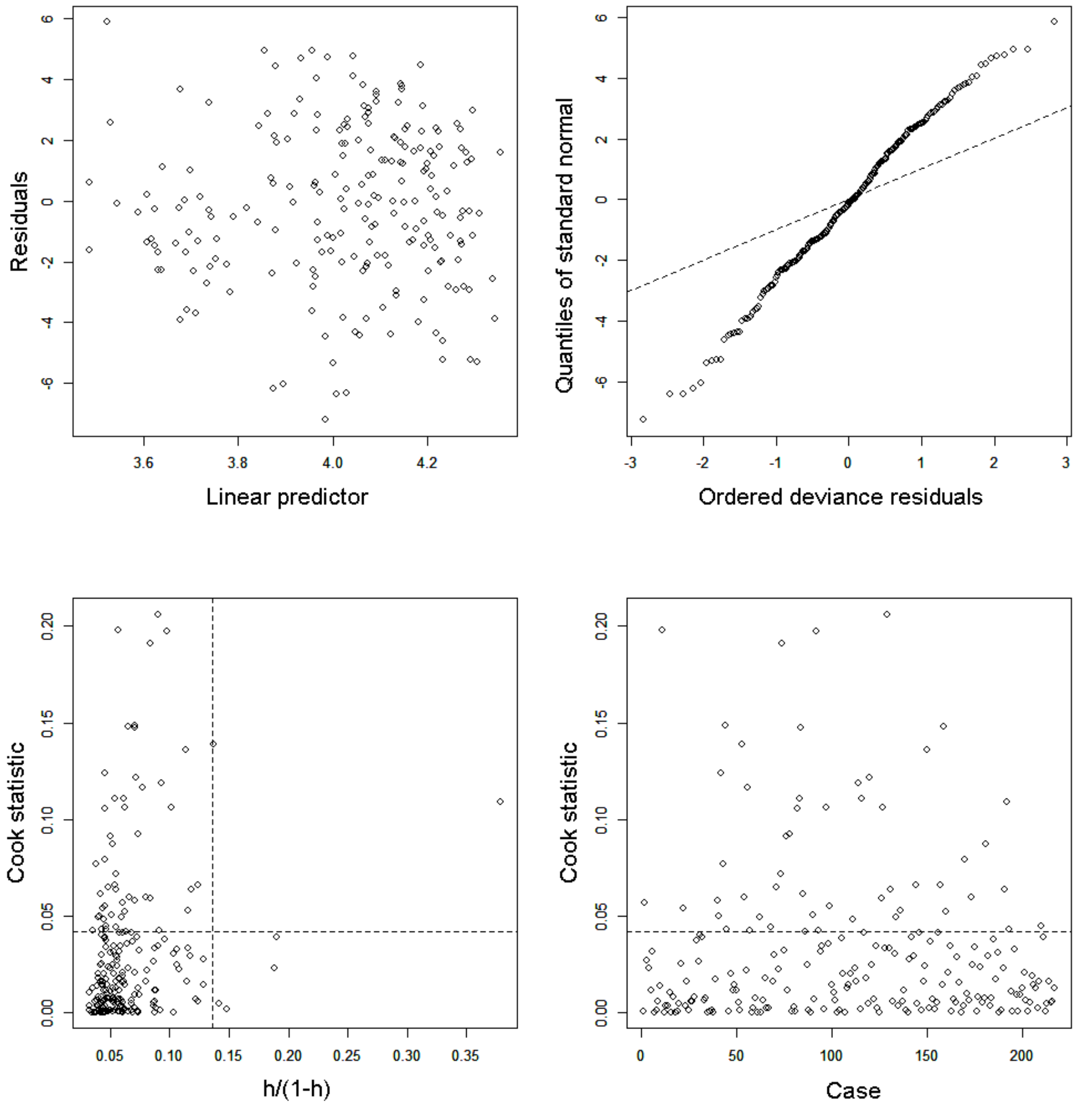

Figure 4.13: Diagnostic plots for the best performing synthetic model

Species richness was found low at the crop fields and high at the exploited forest. The richness of the meadow was also higher than that of natural forest (Figure 4.7). The crop fields are managed intensively annually and in lower elevation the land is managed up to two crop rotation a year. The weeds are rooted out selectively with preference to the agricultural crops. Thus, the low species richness at the crop fields are expected. The high species richness in the exploited forest is in line with the intermediate disturbance hypothesis (Connell, 1978). Light demanding species occupy the open areas cleared by the anthropogenic impacts in the exploited forest which is less probable in the natural forest. However, some studies also found the high species diversity at the center of the grassland and less at the forest interior (Sharma *et al.*, 2013).

The topographic models performed better compared to the microclimatic and bioclimatic models. The inclusion of elevation, slope, and aspect along with the region shows a better model performance. The studies related to elevational gradient on the species richness in Nepal Himalaya are many (vascular plants by Vetaas & Grytnes (2002), ferns by Bhattarai *et al*. (2004), bryophytes by Grau *et al*. (2007), lichens by Baniya *et al*. (2010), medicinal plants by Rokaya *et al*. (2012) and gymnosperms by (Pandey *et al*., 2020). Recently works are now directing attention towards the effect of topography, land use change and land use history on the species richness and composition too (Baniya *et al*., 2009; Panthi *et al*., 2007; Paudel & Vetaas, 2014, Tamang *et al*. 2018).

The seasonality of precipitation and temperature and the precipitation in the driest quarter seem to affect the species richness as shown by the bioclimatic model. The similar trend have been observed in annual dry steppes (Yan *et al*., 2015). The low deviance explained by the model can be attributed to the coarse scale and interpolated bioclimatic data for the plots. The initial bioclimatic layers have a resolution of 30 arc second which is 0.86 sq km (0.93 km × 0.93 km). Often all the land use types and plots at a given site fall within that area, thus resulting the same bioclimatic values for each plot studied.

The synthetic model combining all three variable set resulted in the best preforming models. The synergistic association between climatic variables and vegetation might have contributed for the betterment of the model (Moura *et al*., 2016, Rai *et al*. 2016, Rai *et al*., 2017).

There is sharp difference in the species richness when fitted with the microclimate model. The fluctuations in local ambient air and soil temperature are much pronounced in the higher elevation. In microclimate model, the minimum humidity was also found to be significantly affecting the species richness which are in line with observation in case of bryophytes (Hettenbergerova *et al*., 2013). The species richness of the vascular plants increases in the crop field when fitted in the bioclimatic and topographic model, the richness of other land use types increased in bioclimatic model and decreased in the topographical model. Land use types are also considered as biotic factor influencing the species diversity (Moura *et al*., 2016). The topography also play important role in controlling the soil moisture and water availability (Moeslund *et al*., 2013). In case of bryophytes the climate and habitat effect were found to be more pronounced than that of geographical factor (Aranda *et al*., 2014).

4.3 Species distribution models under climate change scenarios

The Maxent models of two species namely *Betula utilis and Larix potaninii* var. *himalaica* performed well. We present the results of the two species in separate paragraphs. Different test statistics were calculated and verified for the climate change models to evaluate and validate the models.

4.3.1 *Betula utilis*

4.3.1. a Model validation

The AUC values were produced while developing the Maxent models. The AUC values for all models were above 0.9. The highest AUC of 0.959 were shown by model at RCP 2.6 for years 2050 and 2070. The lowest AUC of 0.941 were shown at RCP 6.0 and 8.5 for 2050. The lowest value of accuracy was 88.4875 and the highest was 95.2858. The highest TSS value was 0.7613 shown by the model at RCP 2.6 in 2070 and the lowest value TSS was 0.6359 shown by the model at RCP 8.5 in 2050. Error rate of all models are below 0.1151, which shows the robustness of the models (Table 4.6).

Table 4.6: Model validation of *Betula utilis* for different RCPs in 2050 and 2070

Species	RCP	Year	Accuracy	Error rate	Sensitivity	Specificity	True skill statistics	AUC	Std. dev.
Betula utilis	2.6	2050	95.2858	0.0471	0.7632	0.9543	0.7175	0.959	0.011
	2.6	2070	93.1620	0.0684	0.8289	0.9324	0.7613	0.959	0.009
	4.5	2050	91.2961	0.0870	0.7895	0.9139	0.7034	0.95	0.018
	4.5	2070	89.4502	0.1055	0.7763	0.8954	0.6717	0.944	0.014
	6.0	2050	93.1223	0.0688	0.7763	0.9324	0.7087	0.941	0.021
	6.0	2070	90.0457	0.0995	0.8158	0.9011	0.7169	0.944	0.016
	8.5	2050	88.4875	0.1151	0.7500	0.8859	0.6359	0.941	0.022
	8.5	2070	92.3482	0.0765	0.7632	0.9247	0.6879	0.946	0.014

4.3.1. b Contributing variables for the model

The elevation was the main contributing variable for the distribution of *Betula utilis.* Annual mean temperature is the second most contributing variable. Elevation contributed for six climate change scenarios at different RCPs and annual mean temperature was most contributing factor for three models. Isothermality was the third contributing factor for the models. Maximum temperature of the warmest month does not seem to contribute (Table 4.7 & Figure 4.14).

Table 4.7: Relative contribution (percentage) of the environmental variables to the in the distribution of *Betula utilis* at different RCPs of climate change scenario in 2050 and 2070

Variable	Code	1990	RCP 2.6		RCP 4.5		RCP 6.0		RCP 8.5	
			2050	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**
Elevation	alt	**38**	**38**	**38.3**	**34.7**	34.4	34.6	**37.7**	**38.9**	34.7
Annual mean temperature	bio1	29.5	29.1	27.9	33.7	**36.5**	**36**	31.2	33.6	**36**
Isothermality	bio3	10.1	10.7	10.8	19.2	15.1	16.7	17.7	14.8	14.5
Precipitation of coldest quarter	bio19	6.4	7.9	8	4.3	3.8	3	3.2	4.2	3.4
Precipitation of driest month	bio14	3.4	3.4	3.6	2.5	2.4	1.7	2.2	2.4	2.1
Precipitation seasonality	bio15	3.6	2.9	3.5	1.8	2.5	3.2	2.9	2.1	3.2
Aspect	asp	3.3	2.8	2.6	0.7	1.1	0.9	1.4	1.2	1.4
Precipitation of driest quarter	bio17	2.9	2.3	2.2	0.3	0.5	0.6	0.9	0.6	0.7
Annual mean precipitation	bio12	2	2.1	2.4	2.7	3.1	3.1	2.7	2	3.9
Land use types	lut	0.8	0.8	0.7	0.1	0.6	0.3	0.2	0.2	0.2
Maximum temperature of warmest month	bio5	0	0	0	0	0	0	0	0	0

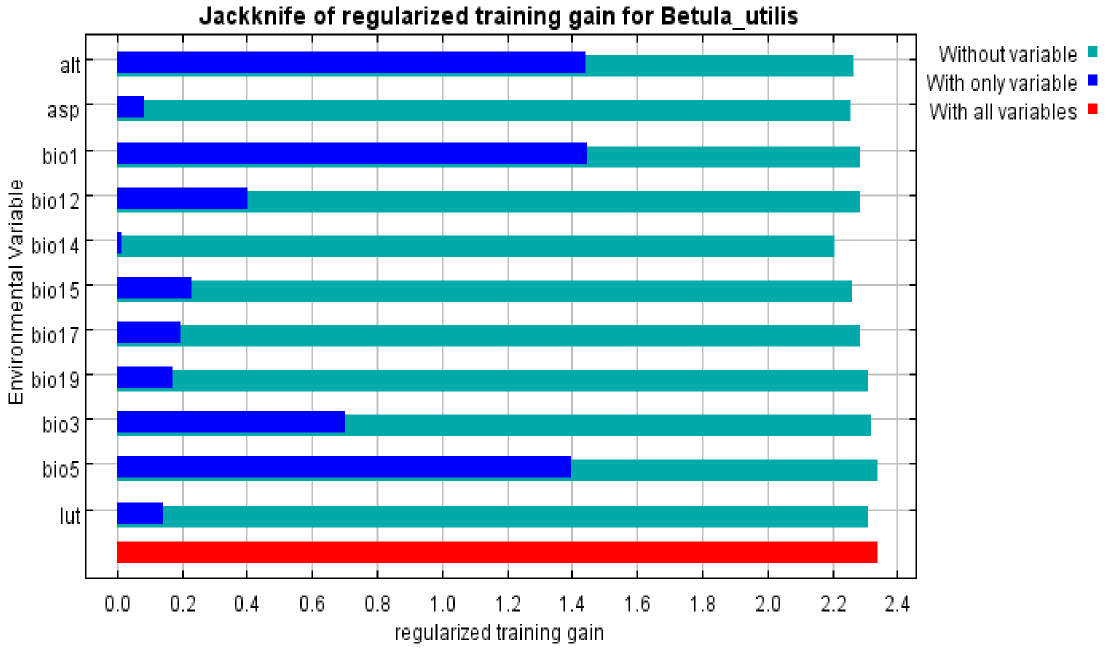

Figure 4.14: Jackknife of regularized training gain for *Betula utilis* in current scenario. The dark blue color is the percentage contribution of individual variable in the training set of data.

The elevation has the highest relative contribution for the distribution lot of the *Betula utilis*. The elevation is taken as the proxy of annual mean temperature. In the current study, the percentage contribution of annual mean temperature is second highest after the elevation in *Betula*. Mean annual temperature (BIO1) and annual precipitation

(BIO12) were included in the modelling though not selected according to the correlation coefficient selection criteria (Booth *et al*., 1994). Dormann *et al*. (2013) have suggested that variables showing ecological significance can be included in the further modelling. The effect of elevation on the species richness is agreed widely as sometimes extensions of Rapoport's rule (Bhattarai & Vetaas, 2006; Carpenter, 2005; Stevens, 1992). This proposition has received objections too (Rohde, 1996), however the contribution of elevation is high in a species distribution model as well.

Land cover categories have been included as the predictor variable in current analysis. The land cover map contains the information about the 12 categorical variables of forest types, shrub land, grassland, agriculture, water bodies and bare area (ICIMOD, 2013). Anthropogenic activities are evident in the agricultural field category of the map. The inclusion of such anthropogenic activities as predictor will be useful while developing the SDMs for conservation planning (Guisan & Thuiller, 2005).

The aspect, elevation and slope were used as predictor variables for the modelling. The percentage contribution seems less in the table, but the inclusion of these variable show compounding effect and the distribution of the species were greatly improved in the present study. The inclusion of aspect and slope will change the local light regime creating the refugia which are important for the precision of SDMs (Austin & Van Niel, 2011b).

The relative contribution of the precipitation (bio12) is low in the Jackknife test of regularized gain (Figure 4.14). The east of Nepal receives much rainfall on average during monsoon summers and trend diminishes as we move towards western mountains (Kansakar *et al*., 2004; Nayava, 1980).

Zimmermann *et al*. (2009) suggest the inclusion of climatic extremes in the SDMs will define the species range limits. Inclusion of climatic extremes in the model should correct especially for over-prediction. We did not include climatic extremes in this model. However, we have included the seasonal variation in the precipitations such as precipitation of the coldest quarter and that of dries month. The precipitation of the coldest quarter and driest quarter seem to affect less for the *Betula,* since it is deciduous.

4.3.1.c Suitability of habitat distribution of *Betula utilis*

Maxent models were also used to calculate the potential impact of climate change on the distribution of *Betula utilis*. The suitable area decreased in 2050 and increased again in 2070 at RCP 2.6. At RCP 4.5 and 6.0 the probable area increased by 2050 and 2070. At RCP 8.5 the probable area increased in 2050 but decreased in 2070. The predicted area of low probability (25-75%) is highest followed by medium probability (50-75%) and high probability (>75%) is very less in all cases (Table 4.8 & Figure 4.15).

Table 4.8: Suitable area predicted by Maxent for *Betula utilis* at different RCPs of climate change by 2050 and 2070

		Suitable probable area in sq km		
Year	**RCP**	**Low (25-50%)**	**Medium (50-75%)**	**High (>75%)**
Current	0.0	6911.91	1721.67	299.75
2050	2.6	5852.1	697.09	48.56
2070	2.6	7666.48	1579.89	204.01
2050	4.5	9321.47	2399.83	700.36
2070	4.5	11248.00	1584.52	581.8
2050	6.0	6806.95	1667.58	125.81
2070	6.0	8287.45	2048.14	468.38
2050	8.5	12505.07	949.47	338.32
2070	8.5	8064.57	741.19	262.56

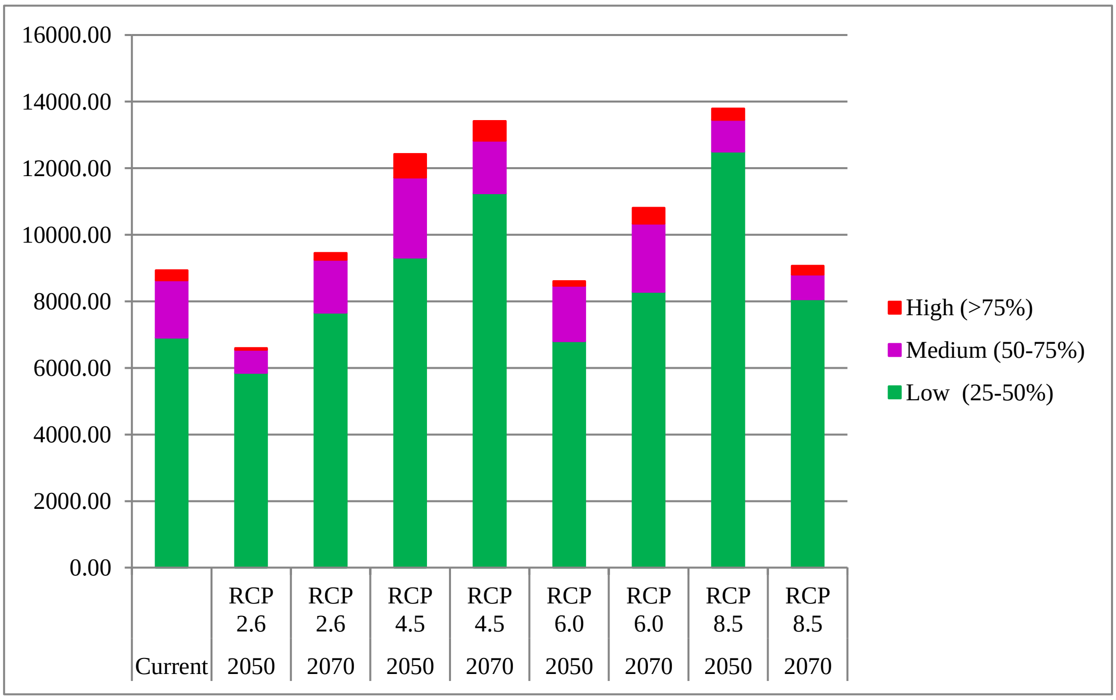

Figure 4.15: The estimated areas of the predicted distribution of the *Betula utilis* in Nepal under four different RCPs of CCSM4 climate change scenario in current, 2050 A.D. and 2070 A.D.

The probable map of *Betula utilis* is dense in the central and eastern Nepal. The species are abundant on north facing and west facing slopes where impact of direct sunshine is less than in east facing and south facing slopes in Nepal Himalaya. The western Nepal also comprises the forest of *Betula* but not so dense as in the east (Figure 4.16). The probable area is projected to increase in Mustang area of the Central Nepal and to decreases in areas which lie to the west of Mustang at RCP 2.6 in 2050. *Betula utilis* shows an increase in Mustang area at all RCPs. The western patches of *Betula* will be lost at RCP 6.0 but at RCP 8.5 the forest will reclaim its lost are in the western mountains (Figure 4.17). By 2070, the high probable area will be centered in the central and eastern Nepal at all RCPs. At RCP 2.6, the western habitat will decrease but at RCP 4.5 the habitat will increase. At RCP 6.0 and 8.5 western mountain habitats will decrease in the probable area, which will shift to east Nepal. Mustang area shows an increase in suitable habitats (Figure 4.18).

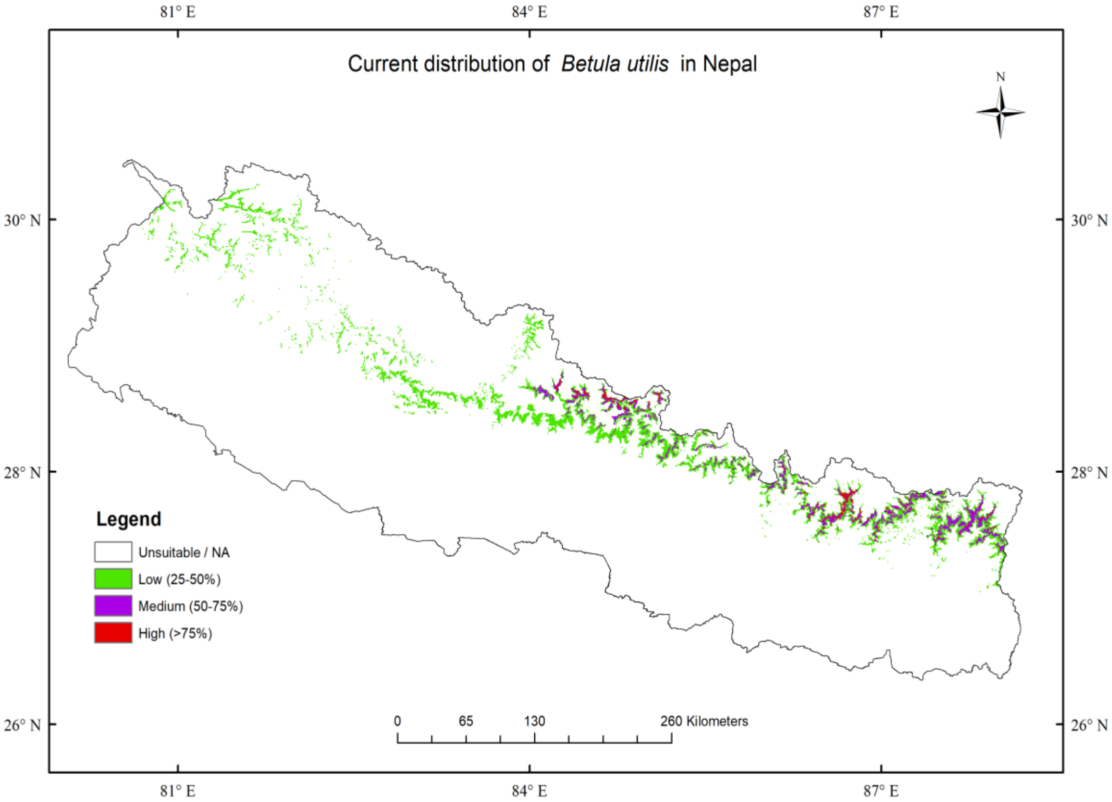

Figure 4.16: Current suitability map of *Betula utilis* in Nepal

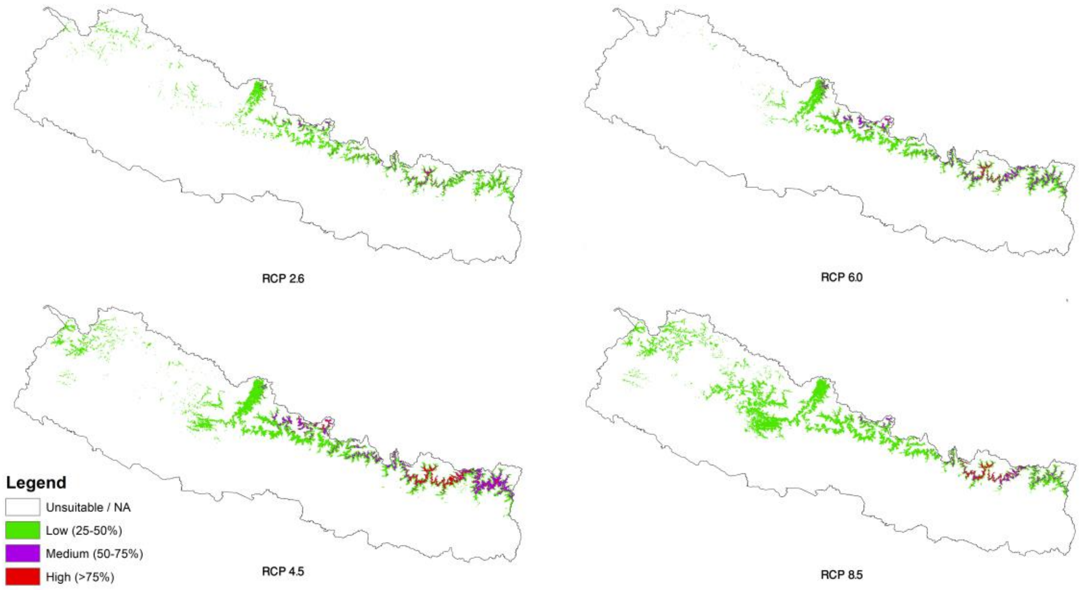

Figure 4.17: Suitability maps of *Betula utilis* in Nepal under four different RCPs of climate change scenario in 2050

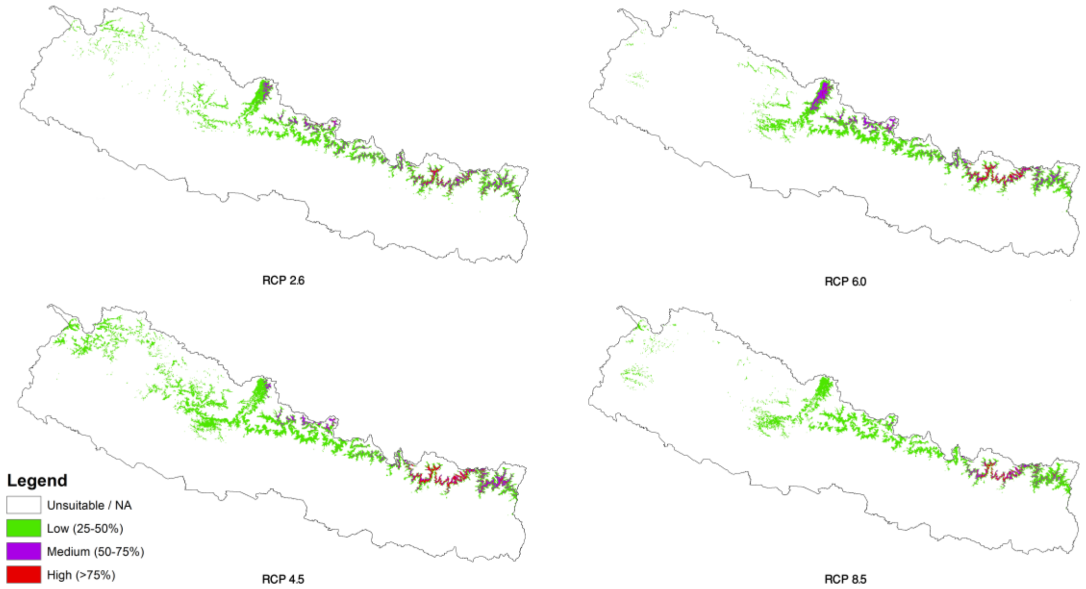

Figure 4.18: Suitability maps of *Betula utilis* in Nepal under four different RCPs of climate change scenario in 2070

4.3.1.d Predicted gain and loss in suitable area of *Betula utilis*

The suitable area of *Betula utilis* is projected to decrease by-18.72% under RCP 2.6, to increase by 61.05%, 12.41% and 64.89% under RCPs 4.5, 6.0 and 8.5, respectively by 2050. By 2070, the total of the suitable area will also increase by 13.32%, 61.07%, 36.07% and 11.93% at RCPs 2.6, 4.5, 6.0 and 8.5, respectively (Table 4.9, Figure 4.19).

Table 4.9: Predicted change in the suitable area of *Betula utilis* in Nepal under different RCPs of CCSM4 climate change scenario in 2050 and 2070

Year	RCP	Current area	Gain area	Loss area	Change in area	% Change in area
2050	2.6	8933.33	5589.99	7262.04	-1672.05	-18.72
	4.5	8933.33	11356.03	5902	5454.03	61.05
	6.0	8933.33	7746.61	6638.39	1108.22	12.41
	8.5	8933.33	12728.73	6931.45	5797.28	64.89
2070	2.6	8933.33	7685.16	6495.46	1189.70	13.32
	4.5	8933.33	12015.97	6560.82	5455.15	61.07
	6.0	8933.33	9667.98	6445.8	3222.18	36.07
	8.5	8933.33	8160.08	7094.03	1066.05	11.93

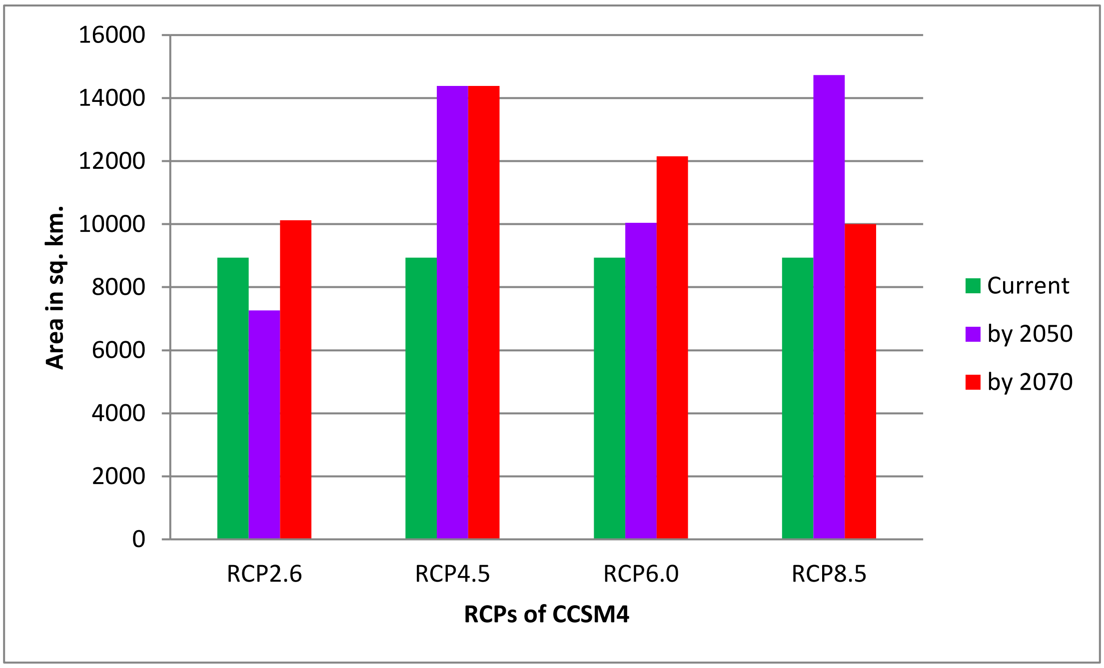

Figure 4.19: Predicted changes in suitable area of *Betula utilis* under different RCPs of CCSM4 in 2050 and 2070

The new gains will distributed towards the western mountains at all RCPs by 2050 which will be retained by 2070 too. By 2050, *Betula* seems to acquire new habitat in river valley of Mustang and west of it. The lower elevation habitat seems to be lost at RCP 2.6 in all over Nepal. The trend continues to other RCPs too. The loss is more prominent in western mountains at RCP 6.0. At RCP 4.5 the far western Himalaya will gain and suitable area between central and far western area will be lost at RCP 2.6, 4.5 and 6.0. But in case of RCP 8.5, *Betula utilis* habitat will increase in the western himalaya. The lower elevations in all over Nepal seem to be lost and the habitat will shift upward (Figure 4.20).

By 2070, *Betula utilis* will gain area in river valleys of Mustang and Baglung at RCP 2.6. The gain area is more prominent at RCP 4.5 in western mountains. The area will be lost in western mountains at RCP 6.0, however gain in the central mountains are intact. The lower elevation loss is predicted in all over Nepal at all RCPs. The suitable stable area of *Betula utilis* are distributed more in central and eastern Nepal. The probable distribution of *Betula utilis* seems to affected more in the western mountains of Nepal (Figure 4.21).

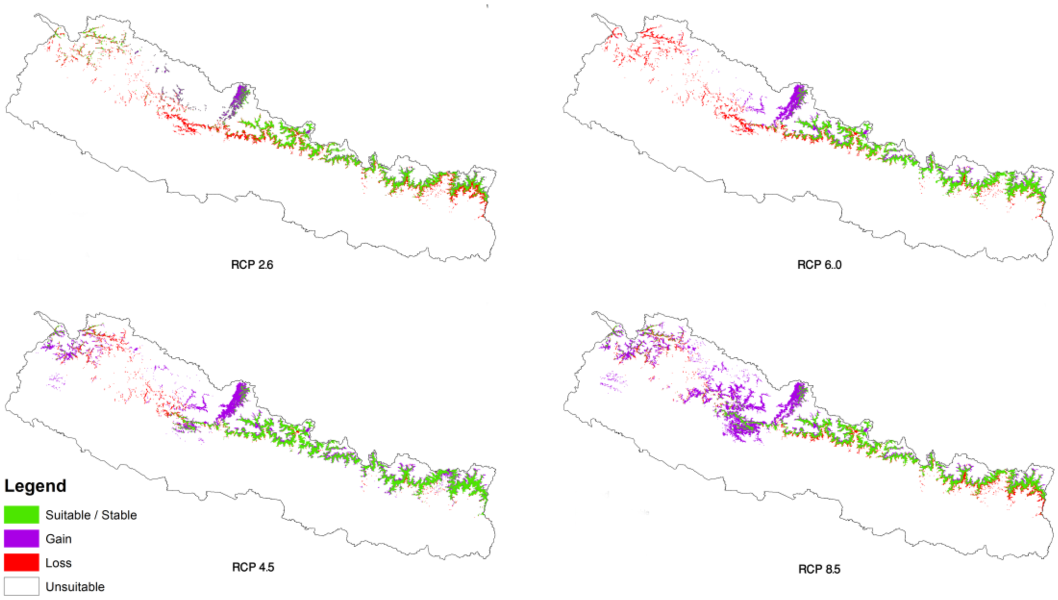

Figure 4.20: Predicted future (suitable/stable, lost and gain) habitat distribution of the *Betula utilis* in Nepal under different RCPs of CCSM4 climate change scenario in 2050

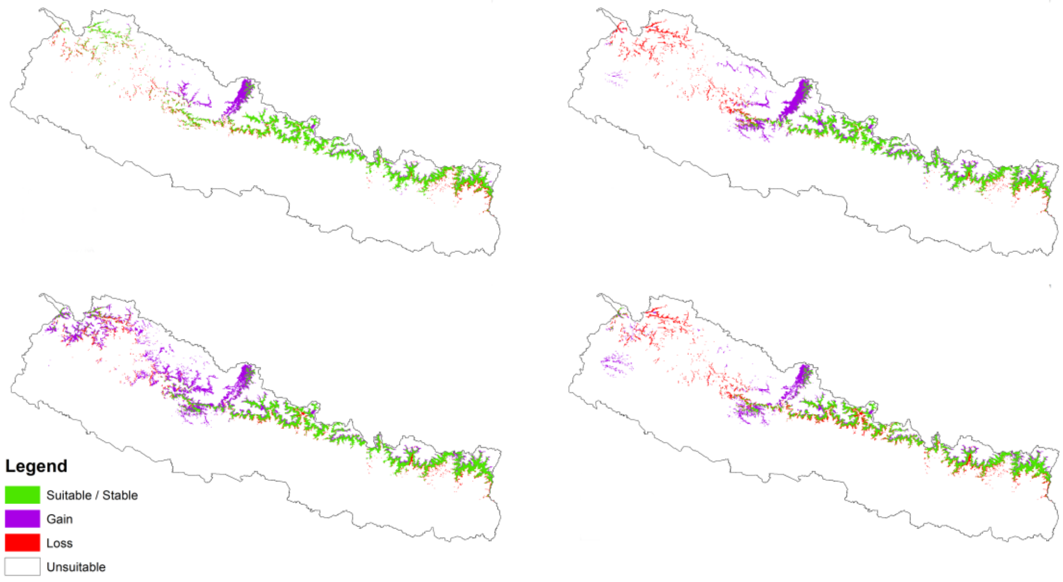

Figure 4.21: Predicted future (suitable/stable, lost and gain) habitat distribution of the *Betula utilis* in Nepal under different RCPs of CCSM4 climate change scenario in 2070

The occurrence of *Betula utilis* were mostly affected by temperature and precipitation related variables such as mean diurnal range, mean temperature of driest quarter, slope, mean temperature of wettest quarter, isothermality, precipitation seasonality, precipitation of driest quarter and driest month (Bobrowski *et al*., 2017; Singh *et al*., 2021). The precipitation of coldest quarter and driest month are also important factors in the current study. The melting of snow after winter months contribute the spring growth of *Betula utilis* (Bobrowski *et al*., 2017; Miehe *et al*., 2015). Increased temperature during pre-monsoon season due to climate change scenario may enhance drought stress which could be the limiting factor for the distribution of *Betula utilis* (Dawadi *et al*., 2013; Gerlitz *et al*., 2014; Liang *et al*., 2014).

The probable distribution of *Betula utilis* is high in the eastern parts of Nepal Himalaya than in the western part in current modelling. This result doesn't match some of the previous results (Bobrowski *et al*., 2017 and literatures cited therein). However, the habitat tend to shift from west to east in Himalaya in other study (Hamid *et al*., 2018). When the temperature rises in the climate change scenarios, west of Nepal gets moisture related stress more than east as it receives more rainfall and rainy days are more in monsoon (Kansakar *et al*., 2004). Thus, it is probable that the vegetation expands towards east where there is less stress on water availability and evapotranspiration (Gerlitz *et al*., 2014; Shrestha *et al*., 2007). The survival of *Betula utilis* forest are more related to drought stress (Liang *et al*., 2014). However, it is too early to conform the results from current projections which used only selected bioclimatic and some topographical variables. Additional mechanistic models may clarify the issue in detail (Guisan *et al*., 2017).

4.3.2 Larix potaninii var. himalaica

4.3.2. a Method validation

The AUC values were calculated by the Maxent models, all of them are above 0.9. The accuracies of all models for *Larix* in climate change scenarios are above 96%, the highest being 98.3% (error rate 0.0113) at RCP 4.5 in 2050. The maximum error rate is 0.0334 at RCP 2.6 in 2070. True Skill Statistics (TSS) of the models range from 0.4892 at RCP 6.0 in 2050 to 0.8415 at RCP 2.6 in 2070. The highest AUC of 0.990 were shown by the model at RCP 2.6 and 4.5 for 2050 (Table 4.10). Test parameters show the robustness of models in all climate change scenarios in 2050 and 2070.

Table 4.10: Model validation of *Larix potaninii* var. *himalaica* for different RCPs in 2050 and 2070

Species	RCP	Year	Accuracy	Error rate	Sensitivity	Specificity	True skill statistics	AUC	Std. dev.
Larix potaninii var. *himalaica*	2.6	2050	97.0822	0.0232	0.8125	0.9769	0.7894	0.990	0.003
	2.6	2070	96.0599	0.0334	0.8750	0.9665	0.8415	0.989	0.007
	4.5	2050	98.2731	0.0113	0.6875	0.9891	0.6766	0.990	0.008
	4.5	2070	97.7670	0.0164	0.6250	0.9841	0.6091	0.987	0.005
	6.0	2050	98.2533	0.0115	0.5000	0.9892	0.4892	0.989	0.005
	6.0	2070	96.7348	0.0267	0.8125	0.9734	0.7859	0.984	0.006
	8.5	2050	97.1020	0.0230	0.6875	0.9773	0.6648	0.987	0.007
	8.5	2070	97.9357	0.0147	0.5625	0.9859	0.5484	0.989	0.006

4.3.2. b Contributing variables for the model

The annual mean precipitation (bio12) is the most contributing variable in all models of *Larix*. The minimum value starts from 54.1% at RCP 6.0 in 2050 to maximum value of 56.7% at RCP 4.5 in 2070. The second most contributing factor is precipitation of the driest quarter (bio17) followed by precipitation of the coldest quarter (bio19). Maximum temperature of the warmest month and precipitation seasonality does not seem to affect much in the future distribution of the species (Table 4.11 & Figure 4.22). Elevation and the annual mean temperature contributing much less in case of *Larix potaninii* var. *himalaica.*

Table 4.11: Relative contribution of the environmental variables to the distribution model of *Larix potaninii* var. *himalaica* under different RCPs of CCSM4 climate change scenario in 2050 and 2070. All values are percentages

Variable	Code	1990	RCP 2.6		RCP 4.5		RCP 6.0		RCP 8.5	
			2050	2070	2050	2070	2050	2070	2050	2070
Annual mean precipitation	bio12	54.6	54.6	55.2	54.8	56.7	54.1	54.5	56.5	56.1
Precipitation of driest quarter	bio17	11.3	15.2	12.4	12.8	7.6	15.4	11.4	13.7	8.6
Precipitation of coldest quarter	bio19	10.6	8.1	9.7	8.5	12.9	6.2	11.2	8.1	13.5
Annual mean temperature	bio1	9.7	9.1	9.7	9	9.7	9.2	9.3	9.7	9.6
Precipitation of driest month	bio14	6.5	5.7	5.9	6.1	5.2	6.5	5.9	5.5	6
Elevation	alt	4.2	3.3	3.4	5.1	4.1	3	3.8	3.4	3.6
Isothermality	bio3	1.9	3.1	2.9	2.8	2.1	4.4	2.1	2	1.7
Land use types	lut	1.3	0.9	0.7	0.6	1.7	1.1	1.6	1	0.8
Aspect	asp	0.1	0	0	0.1	0.1	0	0	0	0.1
Precipitation seasonality	bio15	0	0	0	0.1	0	0	0.2	0.1	0
Maximum temperature of warmest month	bio5	0	0	0	0	0	0	0	0	0

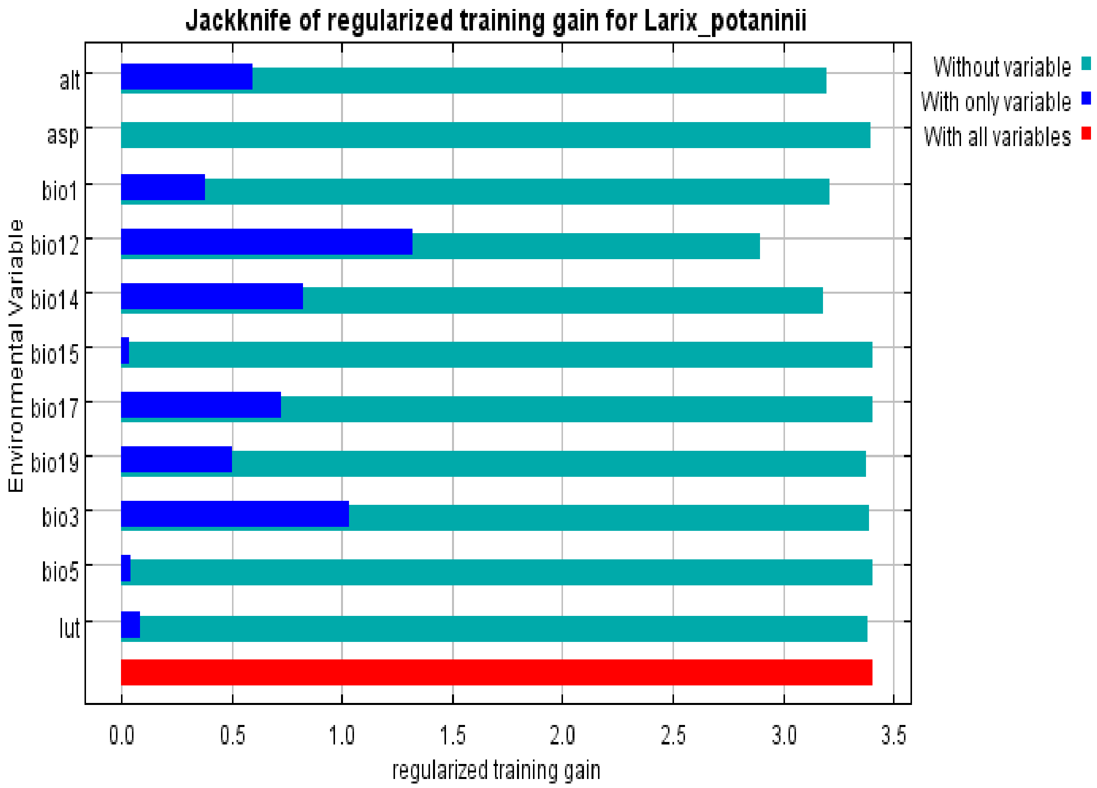

Figure 4.22: Jackknife of regularized training gain for *Larix potaninii* var. *himalaica* in current scenario. The dark blue color is the percentage contribution of individual variable in the training set of data.

The precipitation of the coldest quarter and driest quarter seem to affect less for the *Betula* but they have much contribution in case of *Larix.* In contrast to *Betula utilis*, precipitation related variables are more important for *Larix* than temperature related variables.

4.3.2.c Projected changes in suitable area for *Larix potaninii* var. *himalaica*

Maxent models were also used to calculate the potential impact of climate change on the distribution of *Larix.* In case of *Larix,* there is no strict pattern of increment or decrease of the suitable area. The area increased in 2050 and 2070 under RCP 2.6, but decreased in 2050 and increased again in 2070 under RCP 4.5. Under RCP 6.0, the suitable area decreased in 2050 and increase in 2070. The suitable area increased in 2050 again drop down heavily in 2070 at RCP 8.5. In all cases, the “low” suitability class (25-50%) is the largest followed by “medium” (50-75%) and “high” (>75%) which shows by far the smallest area (Table 4.12 & Figure 4.23).

Table 4.12: Predicted suitable area of *Larix potaninii* var. *himalaica* at different RCPs of climate change in 2050 and 2070

		Suitable probable area in sq km		
Year	**RCP**	**Low (25-50%)**	**Medium (50-75%)**	**High (>75%)**
Current	0	1649.55	275.18	40.68
2050	2.6	1981.73	190.15	44.43
2070	2.6	2538.32	298	95.7
2050	4.5	1204.89	176.33	47.46
2070	4.5	1468.7	116.17	18.09
2050	6	1127.76	57.29	14.32
2070	6	2015.01	199.85	37.66
2050	8.5	1788.4	248.23	27.11
2070	8.5	1051.05	108.58	19.59

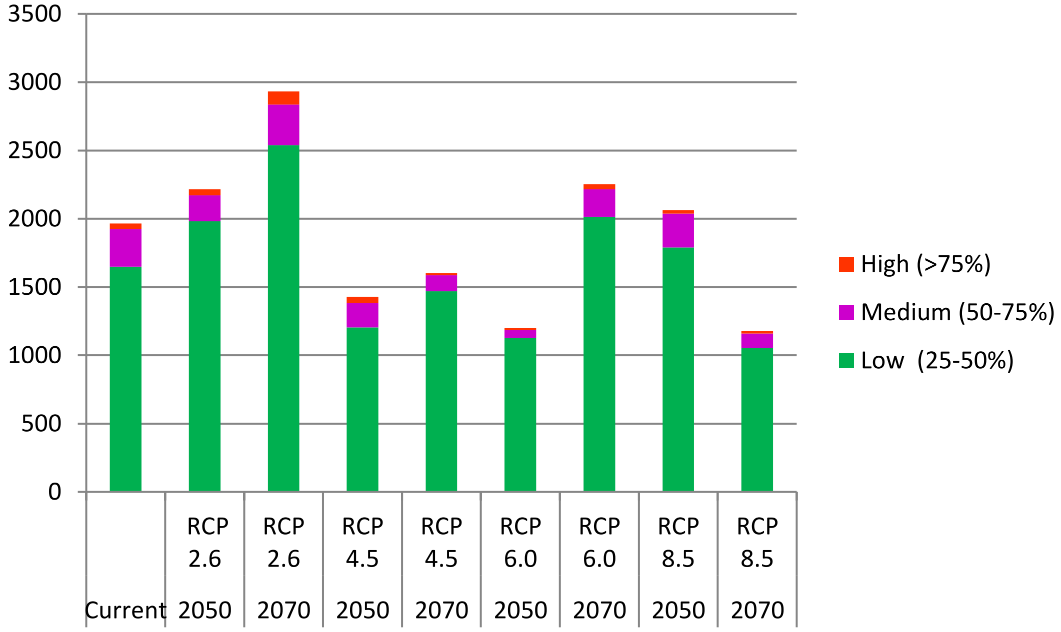

Figure 4.23: The suitable area of the *Larix potanini* var. *himalaica* in Nepal under four different RCPs of CCSM4 climate change scenario in current, 2050 and 2070

Current distribution of *Larix* shows limited area in the central Nepal Himalaya (Figure 4.24). Presence records were obtained only from the Rasuwa, Dhading and Gorkha districts of Nepal. However, the model also showed some suitable area in the eastern part of Nepal, but *Larix potaninii* var. *himalaica* has not been reported and collected from those area till now. Another species *Larix griffithiana* occurs in the forest above

Ghunsa, Taplejung the eastern district of Nepal. The suitable area of *potaninii* var. *himalaica* to increased towards east in 2050 under RCP 2.6. The suitable area decreased under RCP 4.5 but increase again at RCP 6.0 and 8.5 in 2050. In all cases, the high and medium suitability classes are confined to the central Himalaya (Figure 4.25). By 2070, the suitable areas of *Larix* moves towards west also under RCP 2.6 up to Manang and a small area of Mustang. However, it shrinks from west and suitable habitats will confine to the eastern Himalaya under other RCPs of 4.5, 6.0 and 8.5 (Figure 4.26).

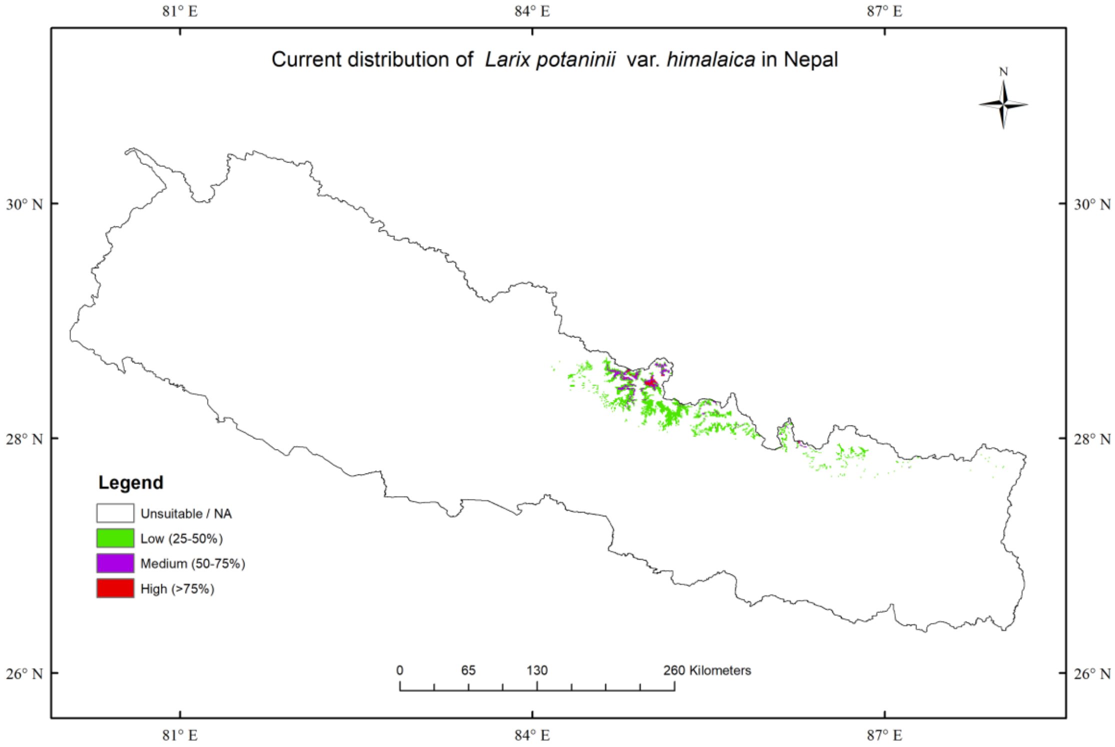

Figure 4.24: Current suitability map of *Larix potaninii* var. *himalaica* in Nepal

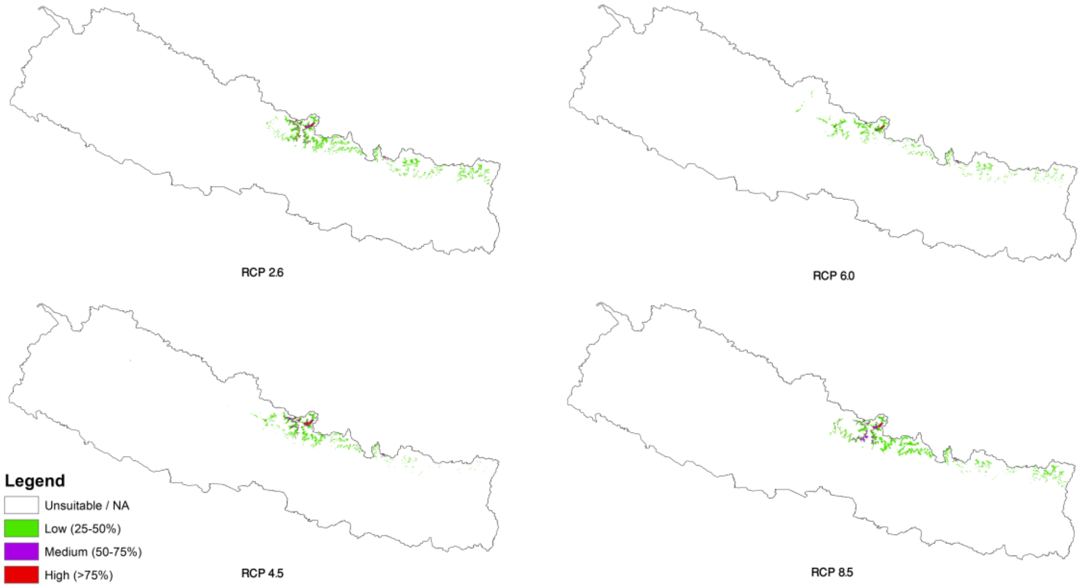

Figure 4.25: Suitability maps of *Larix potaninii* var. *himalaica* in Nepal under different RCPs of climate change scenario in 2050

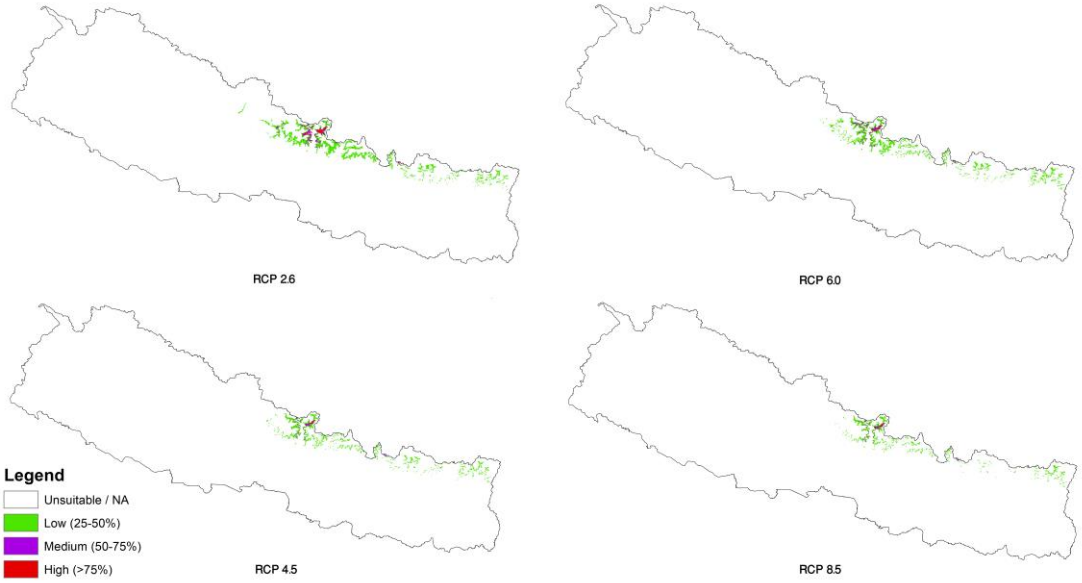

Figure 4.26: Suitability maps of *Larix potaninii* var. *himalaica* in Nepal under different RCPs of climate change scenario in 2070

4.3.2.d Predicted gain and loss in suitable area of *Larix potaninii* var. *himalaica*

The suitable area of *Larix* will increase by 17.05% at RCP 2.6 in 2050, but will decrease by 29.2% and 38.25% at RCPs 4.5 and 6.0, respectively and will increase by 2.98% at RCP 8.5 in 2050. In 2070, the area will increase by 56.45% and 16.57% at RCPs 2.6 and 6.0, respectively but will decrease by 21.6% an 44.50% at RCPs 4.5 and 8.5, respectively (Figure 4.27 & Table 4.13).

Table 4.13: Change in the suitable area of *Larix potaninii* var. *himalaica* in Nepal under different RCPs of CCSM4 climate change scenario in 2050 and 2070. Area in square kilometers

Year	RCP	Current area	Gain area	Loss area	Change in area	% Change in area
2050	2.6	1965.41	1925.67	1590.63	335.04	17.05
	4.5	1965.41	1067.22	1641.14	-573.92	-29.20
	6.0	1965.41	1037.70	1789.53	-751.83	-38.25
	8.5	1965.41	1820.07	1761.47	58.60	2.98
2070	2.6	1965.41	2672.52	1563.00	1109.52	56.45
	4.5	1965.41	1290.26	1714.75	-424.49	-21.60
	6.0	1965.41	1935.51	1609.92	325.59	16.57
	8.5	1965.41	913.40	1788.03	-874.63	-44.50

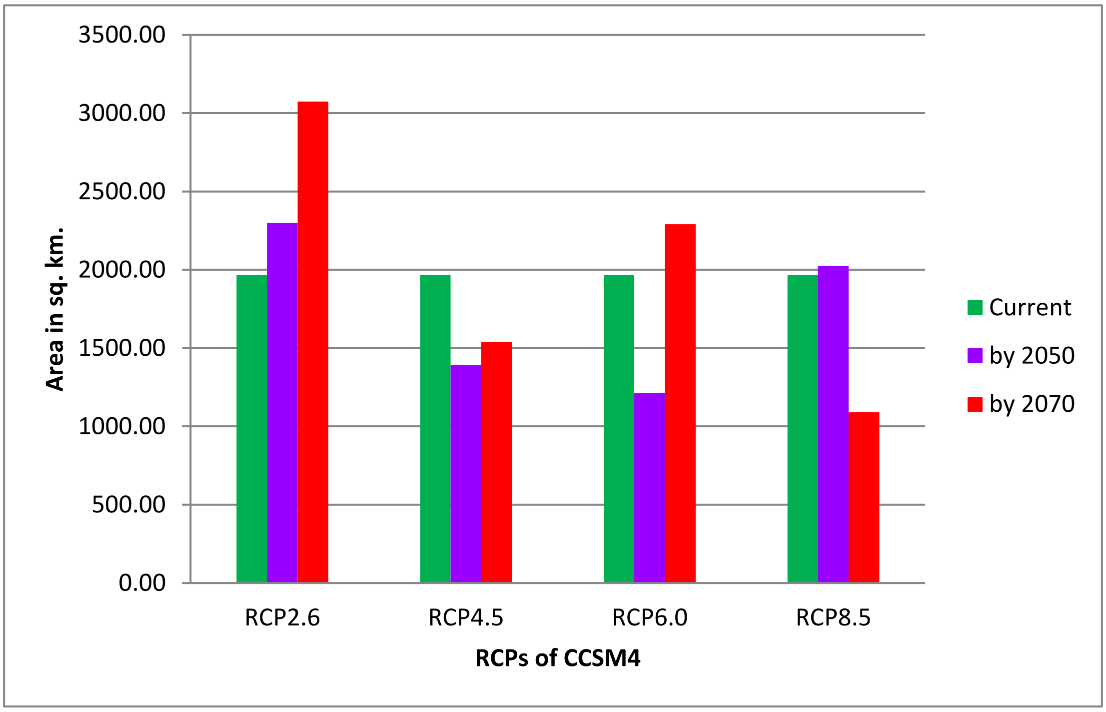

Figure 4.27: Suitable area predicted to be covered by *Larix potaninii* var. *himalaica* in different RCPs of CCSM4 in 2050 and 2070

The suitable habitats of *Larix* are projected to increase in the east Himalaya and some suitable habitats in the central Nepal will be lost with lower elevations at RCP 2.6 in 2050. Suitable habitats will move a little west up to Manang at RCP 4.5 and up to Mustang at RCP 6.0 but much of such areas will be lost in the central Nepal in 2050. Under RCP 8.5, there will be very little gain in area in the east and central Nepal (Figure 4.28). By 2070, the habitat will grow in the east and west at RCP 2.6 and 6.0 but the area will decrease at RCP 4.5 and 8.5. The suitable habitats at lower elevation in the central Nepal will be lost then. More area will be gained in the western part under RCP 2.6 (Figure 4.29).

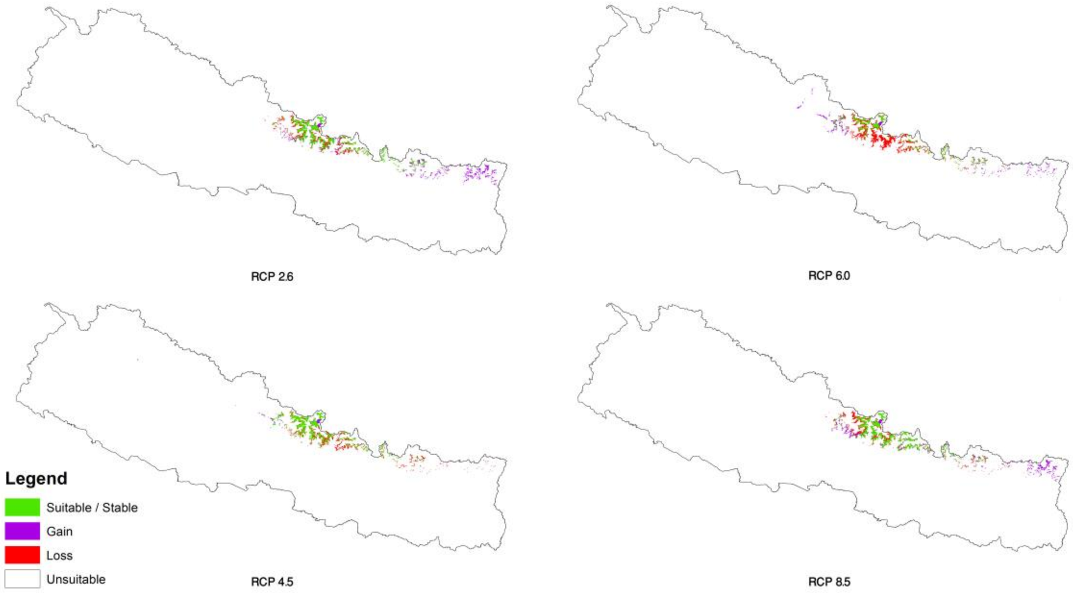

Figure 4.28: Predicted future (suitable/stable, lost and gain) habitat distribution of the *Larix potaninii* var. *himalaica* in Nepal under different RCPs of CCSM4 climate change scenario by 2050

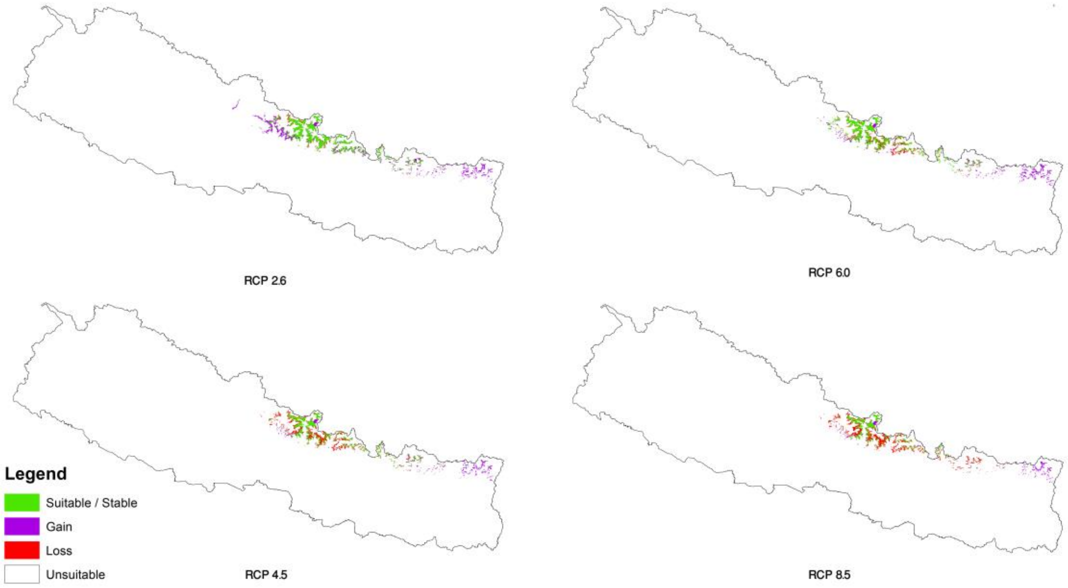

Figure 4.29: Predicted future (suitable/stable, lost and gain) habitat distribution of the *Larix potaninii* var. *himalaica* in Nepal under different RCPs of CCSM4 climate change scenario by 2070

Although the distribution of *Larix potaninii* var. *himalaica* seems to expand in the future climate change scenarios, inclusion of biotic factors and anthropogenic disturbances may shrink the actual distribution (Aryal *et al*., 2016). Anthropogenic disturbances are accelerated by climate change impacts which will slow down the regeneration process and limit the distribution of the species (Dhamala *et al*., 2020). The distribution of gymnosperms in Nepal Himalaya are also affected by energy-water relations (Pandey *et al*., 2020). Increase only in the temperature might not enhance the tree growth and regeneration. The moisture stress limits the regeneration and growth. Increasing temperature without summer rain may accelerate the evapotranspiration. Instead, winter precipitation seems to increase the growth response in *Larix* species (Aryal *et al*., 2020; Bhatta *et al*., 2018). While devising the proper plans for the conservation of vulnerable species like *Larix potaninii* var. *himalaica*, the policy planner should consider both climate induced impacts and anthropogenic pressure on the forest stands and species (Aryal *et al*., 2016; Dhamala *et al*., 2020).

The potential distribution of many groups of plants seem to move upwards alpine habitat in the climate change scenarios (Singh *et al*., 2012). Different SDMs show that current distribution of the species will be lost and new areas will be gained in future under climate change scenario, e.g., for asclepiads (Khanum *et al*., 2013), for *Ophiocordyceps sinensis* (Shrestha & Bawa, 2014), *Abies* species (Tanaka *et al*., 2012), Douglas-fir (Berry *et al*., 2002). The lost habitat of such species shall be occupied by neophytes in faster rate and larger extent (Nobis *et al*., 2009; Tanaka *et al*., 2012). There are also views that loss of the species and their habitat are also compensated by exotic and dispersive plant species (Ellis *et al*., 2012). Since the northern parts of Nepal are high mountains with fewer settlements, the invasion of neophytes is doubtful (field observation). Current SDMs also project losses in some area and gain in some habitat. The probable distribution of the modelled species is predicted to gain in the area in climate change scenarios. However, there are chances of overprediction or underprediction of the probable distribution of the species (Song *et al*., 2004). Inclusion of climatic extremes such as climatic maxima or minima seem to correct the over or underprediction of the species (Zimmermann *et al*., 2009). Ground validation is another suitable method to calibrate such over-predictions (Rinnhofer *et al*., 2012). Sometimes the SDMs also predict the shift of probable suitable habitat which have no possible biological connectivity to current habitat, e.g., the habitat of *Bufo calamita* in Britain and Ireland (Berry *et al*., 2002). Such models shall be useful for the conservation policies where the species with less area of habitat and fragmented distribution should have the emphasis of conservation. The ecological linkages of the current SDMs are found to be weak although the predictions are reliable on the ground of mathematical calculations (Elith & Leathwick, 2009). The incorporation of good collection and measurement of data with sound statistical methods and due consideration of ecological theory is needed to develop more realistic models (Austin, 2002).

Tree-line structures are much affected by the climate change issues and there are evidences of upward shift in the high mountains (Peili *et al*., 2020). The rate of tree-line shift was noted in Indian mountains at the rate of c. 95m per decade (C P Singh *et al*., 2021). The rate and trend are different in different mountains such as c.8-15m per decade in Yunnan, China (Baker & Moseley, 2007), 14-19m per decade in Himanchal Pradesh, India (Yadav *et al*., 2004), 110m per decade in western Himalaya, India (Singh *et al*., 2011). Additionally, warming induced temperature not only favours the upward movement of trees but also the shrubs above treeline grow well which will impart competition to trees moving upward (Liang, *et al*., 2016). When warming induced droughts prolong, the regeneration and area coverage seems unlikely due to shortage of soil moisture and enhanced rate of transpiration (Liang *et al*., 2016; Sigdel *et al*., 2018).

Identification of suitable habitats for the conservation strategies are equally important (Singh *et al*., 2021). While we are assessing the future climate change scenarios, we must compare them with the previous suitable habitats which could be more useful to locate the suitable habitat of the vulnerable treeline species as well as widely distributed species. Long term impact of climate change in the past have been assessed through the satellite images with Normalized Difference Vegetation Index (NDVI) (Lal *et al*., 1991; Singh *et al*., 2011). In case of future projections, not all the areas predicted as suitable habitat (fundamental niche) are inhabited by the climatically modelled species, instead the species require other optimal ecological niche to inhabit (Singh *et al*., 2021). Thus, even if the future predictions show increase in area and upward movement the actual distributions may not reach the predicted area (Chhetri *et al*., 2018; Guillera-Arroita *et al*., 2015). Inclusion of ecological variables which show the mechanistic relationships in the spatial modelling may improve the model further (Guisan *et al*., 2017). All the area calculated as suitable habitat in the map are not occupied by neither *Betula utilis* nor *Larix potaninii* var. *himalaica*. The suitable habitat predicted could reach up to 6156m far above snowline (Singh *et al*., 2013). There are many other tree species such as *Abies spectabilis, Rhododendron* species, *Quercus* species. Furthermore, there are other species of trees, shrubs, and herbs. They must compete with other species to locally available resources of moisture and prevailing temperature regimes.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study revealed 840 species of vascular plants from the six river valleys of three regions of central and eastern Nepal. There were 96 tree species, 110 shrubs, 596 herbs and 48 climber species of vascular plants. The dicotyledonous plants were prevalent (631 species of 840 spp.) there and 159 monocots, 12 gymnosperms and 38 pteridophytes were recorded. The highest number of species was found within the Asteraceae family (85 spp.) followed by Poaceae (53 spp.) and Rosaceae (52 spp.). Out of 120 recorded plant families 78 families had less than or equal to five (5) species.

The DCA results of the species composition showed high length of gradient (5.3) which indicated the high beta diversity in the study area. The elevation and land use types were important factors for determining the diversity of the area. The species composition is different on different land use types. The CCA results show that isothermality, minimum temperature of the coldest month, precipitation seasonality and precipitation of the coldest quarter (BIO19) were significant in case of bioclimatic set of variables. In case of topographical variables, elevation, exposition, land use types, aspect, slope, region, valley were affecting the species composition significantly.

In case of microclimatic model of species richness, mean air temperature, mean soil temperature and minimum air humidity were significantly affecting the species richness in case of forward selection. In case of bioclimatic set, linear combination of maximum temperature of the warmest month, precipitation of driest month and precipitation seasonality produced best model with lowest AIC value. In topographic model, linear combination of valleys, elevation, latitude, longitude, aspect, and slope produced best model in forward selection. The removal of land use types and elevation from this model also reduced the AIC value. However, the ecological significance of such variables cannot be overlooked (Dormann *et al.*, 2013). In the synthetic model, linear combination of mean soil temperature, mean humidity, minimum humidity, maximum temperature of the warmest month, precipitation of the driest month, precipitation seasonality, valleys, land use types, elevation and latitude constructed the best model.

Distribution of *Betula utilis* was mostly affected by the elevation (34.7%-38%) followed by annual mean temperature 27.9% to 36.5%. Elevation being the proxy of the temperature in ecological studies, its habitat distribution can be attributed as the function of annual mean temperature. The probable distribution area of the species will increase in Central Nepal in Mustang area at all RCPs scenarios. The western patches of *Betula* will be lost at RCP 6.0 however seem to reclaim at RCP 8.5 in the western mountains in 2050. At RCP 6.0, habitats on the western mountain will decrease and the probable area will shift to east Nepal. In 2070, the high probable area will be in central and eastern Nepal at all RCOs. While assessing the gain and loss of habitat, *Betula* will gain more at all RCPs in 2050 and 2070 except at RCP 2.6 in 2050 where the loss of area will be 18.72%.

Unlike to that of *Betula utilis*, the distribution of *Larix* is mainly shaped by annual mean precipitation (54.1% to 56.7%), followed by precipitation of driest quarter (7.6% to 15.2%). Water availability is more important than the temperature in this case. There is no strict pattern of increment and decrease of the probable area of *Larix* at different RCPs by 2050 and 2070. *Larix* is reported from Central Nepal and adjacent area of Tibet till date, however, the probable distribution of the species extends toward some valleys of east Nepal where no records are available till date. *Larix griffithiana* is recorded from Ghunsa river valley in Taplejung district, which is morphologically different from current species, however their ecological niche might be same. The distribution seems to increase towards east Nepal in 2050 at RCP 2.6, shrink at RCP 4.5 and increase again at RCP 6.0 and 8.5. In 2070, the distribution of the species extends towards Manang and small area Mustang at RCP 2.6, however at other RCPs the distribution seems to shift to east Nepal. Furthermore, the geographical barrier may block their distribution to west Himalayas.

The habitat of *Larix* will increase in the east Nepal and some suitable habitats in the central Nepal with low elevation will be lost at RCP 2.6 in 2050. By 2070 the habitat will shift towards east Nepal at RCP 2.6 and 6.0 but will decrease at RCP 4.5 and 8.5.

Finally, it is important to note that such models can only predict habitat suitability of a species which is not the same as the species' distribution. Suitable areas only directly correspond to species distributions under the unrealistic assumption of unlimited dispersal and the immediate colonization of new habitats even over long distances (Nobis & Normand, 2014).

5.2 Recommendations

We mainly relied on the interpolated climatic data from the world climatic database with the resolution of 30 arc second. Future studies could improve the resolution by working at the local scale. The future ecological studies should focus on the collection of comprehensive and elaborate local weather and climate data to assess the present status of the species composition and distribution. The government of Nepal could also build up its climatological database to plan and assist future scientific and management strategies regarding the species selection and forest management.

Elevation range of current study of species composition started from 2200m to 3800m only. This elevation covers only temperate and sub-alpine region of Nepal Himalaya. There is future scope on extending the elevation range further down and up so that a comprehensive structure of the vegetation. Species composition in different land use patterns and elevation showed a clear difference in the species composition and richness. Species composition of land use types play a crucial role while devising the future management plan of land use policy and actions.

The combination of microclimatic, bioclimatic, topographic and land use variables are important factors which contribute the composition and richness of vascular plants. We recommend testing the combined effect of bioclimatic and topographic variables in other ecological studies too. Once the generality of such variables is tested sufficiently, we could apply that in management of species in different land use types.

The SDMs of *Betula* and *Larix* show a promising result and their future distribution in different climate change scenarios have shown a change in the habitat of such species in the future. Provided the climate change accelerates the warming of the planet and change in the precipitation regime, there could be change in other ecologically important bioclimatic factors that will affect the future distribution of many keystone species. The shift of the habitat of the mountain species will also affect the watershed regions and ultimately the flora and fauna and human settlements too. The current study will have implication in devising proper government policies to adapt and mitigate the negative impacts of climate change issues. Accordingly, the policies could be translated into good plan of actions to minimize the negative impact of climate change. The machine learning software packages sometimes overestimates the future distributions of the habitats of different species. The evidence-based interventions are required when the models either overpredict or underpredict the distribution of species.

CHAPTER 6

6. SUMMARY

Species diversity patterns are determined by a diverse set of biotic and abiotic factors. The use of environmental predictors on the studies of species diversity is increasing day by day. The composition of the species and their richness are also affected by the land use gradients. Climate change scenarios estimate increase of annual mean temperature in coming days. The increasing temperature also affect the distribution of the species, especially in high mountains. Since mountains are rich in endemic species diversity and overall species richness, maintaining the diversity has become a global issue by now. Current study tries to find out the environmental drivers of species diversity change, land use and topographical drivers of species richness. Additionally, we also aim to find out the future probable distribution of vascular plants in climate change scenarios.

Six river valleys of Nepal Himalaya were chosen for the current study. Nubri and Tsum valleys are situated in Manaslu Conservation Area (MCA), Gorkha district, Sagarmatha and Dudhkunda valleys lie in the Solukhumbu district and Olangchung Gola and Ghunsa valleys lie in the Taplejung district of Nepal. Crop field, meadow, exploited forest and natural forest were four land use types selected for the study. The land use categories were chosen according to methods of FAO (Gregorio & Jansen, 2000). The study was conducted from 2200 m to 3800 m altitude with an interval of 400 m vertical gradient. Plant occurrence records were noted in the field. Some of the data were taken from the national herbarium as well as from the online database (http://gbif.org). Observation data were used for species composition, richness and developing Generalized Linear Models (GLMs). Plant records data were used to develop species distribution modelling in different the climate change scenarios. Environmental variables were recorded in the field. Bioclimatic variables were downloaded from the world climatic database (http://worldclim.org/). Future climate data CCSM4 was obtained and useful data were extracted from the Worldclim database (http://worldclim.org/).

R ver. 3.1.2 (R Core Team, 2015) was used as the data analysis platform. R-package “vegan” (Oksanen *et al*., 2015) was used for ordination and regression analysis. Detrended Correspondence Analysis (Hill & Gauch, 1980), Canonical

Correspondence Analysis (ter Braak, 1986) were performed for ordination analyses. Generalized Linear Model (McCullagh & Nelder, 1989) was developed for species richness modelling. “Hmisc” (Harrell *et al*., 2015) an R package was used for the correlation coefficient determination. Maxent ver. 3.3.3k (Phillips *et al*., 2006) was used for species distribution modelling along with the ArcMap ver. 10.3 to construct and analyze the maps and images.

Out study found 840 species of vascular plants belonging to 492 genera of 120 plant families. Among them, 96 were tree, 110 shrub and 586 herb and 48 climber species. 631 dicots, 159 monocots, 12 gymnosperms and 38 pteridophytes were recorded. High number of species was recorded for Asteraceae (85 spp.) followed by Poaceae (52 spp.). 78 plant families had less than or equal to five (5) species. The species richness of crop field was lowest and that of meadow was highest. The species richness decreases as the elevation increases. The record of microclimate data displayed a well-defined temperature and precipitation gradient along the elevation of the study area. The microclimate data also exhibited the seasonal and diurnal fluctuations.

Study sites have high species turnover according to elevation and land use types. The CCA results show that isothermality (BIO3), minimum temperature of the coldest month (BIO6), precipitation seasonality (BIO15) and precipitation of the coldest quarter (BIO19) were significant in case of bioclimatic set of variables. In case of topographical variables, exposition, Land Use types, aspect, slope, region, valley were affecting the species composition significantly. In case of microclimatic GLM, mean air temperature, mean soil temperature and minimum air humidity were significantly affecting the species richness in case of forward selection. In case of bioclimatic set, linear combination of maximum temperature of the warmest month, precipitation of driest month and precipitation seasonality produced best model with lowest AIC value. In topographic model, linear combination of valleys, elevation, latitude, longitude, aspect, and slope produced best model in forward selection. The synthetic model included all variables from three sets of predictors. Linear combination of mean soil temperature, mean humidity, maximum temperature of the warmest month, precipitation of the driest month, precipitation seasonality, valleys, land use types, elevation and latitude constructed the best model.

Species distribution models of two species namely *Betula utilis* and *Larix potaninii* var. *himalaica* were developed under CCSM4 climate change scenarios at different RCPs. The elevation was the main contributing variable (36-38%) for the distribution of *Betula utilis*. Annual temperature was the second most contributing variable (29.1 to 36.5%), followed by the isothermality. While assessing the suitability of habitat in future climate change scenarios, the probable areas decreased in some climate change scenarios and increased in some at different RCPs. In all cases the low probability (25-50%) occupied the major portion. The probable area will increase in Central Nepal in all possible RCPs. The western mountains seem to lose *Betula* forest at RCPs 2.6 but reclaim at RCP 8.5. The area of *Betula* distribution will decrease by-18.72% at RCP 2.6 but will increase by 61.05%, 12.41% and 64.89% at RCPs 4.5, 6.0 and 8.5, respectively in 2050.By 2070, the total area of distribution will also increase by 13.32%, 61.07%, 36/07% and 11.93% at RCPs 2.6, 4.5, 6.0 and 8.5, respectively. The new gains in area will be distributed towards the western mountains at all RCPs in 2050 and 2070. In all cases of climate change scenarios, *Betula utilis* seems to expand its area except in RCP 2.6 in 2050. Since it is a broad leaved and deciduous plant, the expansion shown by the models should also consider other climatic and ecological dimensions such as moisture index, in future.

Larix potaninii var. *himalaica* distribution was mostly affected by annual mean precipitation was the most contributing factor (54.1-56.7%). Precipitation of the driest quarter is the second most contributing factor (7.6-15.2%) followed by the precipitation of the coldest quarter. While assessing the suitability of habitat of *Larix* at different RCPs of climate change scenarios, there was no strict pattern of increment and decrease. The probable area increased at some RCPs and decreased at some in 2050 and 2070. Current distribution is limited only in the Central Nepal and adjacent parts of Tibet, China. The probable area in the model extends towards east Nepal, where another species *Larix griffithiana* is found in Ghunsa valley of Taplejung district. The predicted area of *Larix* will change by 17.05%, -29.20%, -38.25% and 2.98% at RCPs 2.6, 4.5, 6.0 and 8.5, respectively in 2050. By 2070, the area will change by 56.45%, -21.60%, 16.57% and-44.5% at RCPs 2.6, 4.5, 6.0 and 8.5, respectively.

Incorporation of local data of climatic variables is needed to enhance the understanding of ecological studies and formulation of government plans and policies.

Similarly, the topographic range of the study area could be extended in the future. Different land use types showed a clear gradient in species compositions. This could be helpful in the development of management strategies for species and land use programs. In the regression models, the combined effect of microclimate, bioclimate set and topographic set produced a more robust model than acting by single set of variables. This implies that use of combined set of variables will produce better models in future studies. The SDMs of *Betula* and *Larix* showed the change in the suitable habitat in climate change scenarios in the future. The shift of suitable habitat of mountain species will lead to other consequences such as change in local watershed regions. Which will affect the local flora and fauna and human settlements secondarily. We could incorporate the findings of the study in improvising the mitigation and adaptation strategies for the negative impacts of climate change in the future.

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ANNEXES

Annex I : Table showing the characteristics of plots with date and time of visit

TRAN	DATE1	TIME1	DATE2	TIME2	LAT	LON	ALTD	ALTG	ASP	CosASP	SLOP	SinSLOP
11ec	3/22/2011	8:03	7/16/2011	8:37	N28 31.815	E84 49.865	2200	2074	170	-0.98	10	0.17
11ee	3/21/2011	15:14	7/16/2011	12:03	N28 31.970	E84 48.760	2200	2144	180	-1	10	0.17
11ef	3/21/2011	17:15	7/16/2011	14:49	N28 31.976	E84 48.963	2200	2151	180	-1	10	0.17
11em	3/21/2011	16:22	7/16/2011	13:41	N28 31.988	E84 48.839	2200	2203	180	-1	35	0.57
11wc	3/21/2011	8:57	7/15/2011	8:24	N28 31.959	E84 48.848	2200	2145	10	0.98	20	0.34
11we	3/21/2011	12:12	7/15/2011	NA	N28 32.009	E84 48.401	2200	2160	0	1	15	0.26
11wf	3/20/2011	17:51	7/15/2011	11:52	N28 32.132	E84 48.117	2200	2141	350	0.98	20	0.34
11wm	3/21/2011	10:29	7/15/2011	14:08	N28 31.808	E84 48.169	2200	2158	20	0.94	10	0.17
12ec	3/23/2011	11:05	7/18/2011	20:16	N28 32.855	E84 45.991	2600	2570	220	-0.77	10	0.17
12ee	3/23/2011	14:55	7/18/2011	15:11	N28 33.017	E84 45.941	2600	2577	230	-0.64	20	0.34
12ef	3/23/2011	14:03	7/18/2011	14:50	N28 33.016	E84 45.958	2600	2623	170	-0.98	15	0.26
12em	3/23/2011	9:06	7/18/2011	13:20	N28 32.949	E84 46.026	2600	2603	220	-0.77	20	0.34
12wc	3/22/2011	16:00	7/17/2011	9:26	N28 32.715	E84 46.176	2600	2569	0	1	10	0.17
12we	3/22/2011	17:12	7/17/2011	16:12	N28 32.792	E84 45.929	2600	2547	70	0.34	10	0.17
12wf	3/23/2011	9:00	7/17/2011	14:58	N28 32.861	E84 45.834	2600	2593	70	0.34	35	0.57
12wm	3/23/2011	8:00	7/17/2011	16:58	N28 32.755	E84 45.959	2600	2544	60	0.5	10	0.17
13ec	3/25/2011	10:49	7/22/2011	10:11	N28 34.197	E84 43.898	3000	2938	190	-0.98	15	0.26
13ee	3/25/2011	11:43	7/22/2011	11:29	N28 34.118	E84 44.058	3000	2969	190	-0.98	25	0.42
13ef	3/25/2011	9:12	7/22/2011	12:26	N28 34.156	E84 44.045	3000	3010	200	-0.94	30	0.5
13em	3/25/2011	9:12	7/22/2011	9:00	N28 34.303	E84 43.749	3000	2973	190	-0.98	30	0.5
13wc	3/24/2011	15:20	7/20/2011	14:43	N28 34.173	E84 43.441	3000	2962	30	0.87	15	0.26
13we	3/24/2011	16:43	7/20/2011	16:00	N28 34.150	E84 43.423	3000	2980	30	0.87	25	0.42
13wf	3/24/2011	14:12	7/22/2011	14:40	N28 34.109	E84 43.301	3000	2989	350	0.98	35	0.57
13wm	3/24/2011	14:12	7/20/2011	16:08	N28 34.139	E84 43.446	3000	2976	40	0.77	25	0.42
14ec	3/25/2011	16:35	7/21/2011	9:25	N28 34.412	E84 43.416	3400	3031	190	-0.98	10	0.17
14ee	3/25/2011	15:50	7/21/2011	10:13	N28 34.419	E84 43.265	3400	3075	180	-1	40	0.64
14ef	3/25/2011	16:35	7/21/2011	12:53	N28 34.429	E84 42.970	3400	3059	170	-0.98	45	0.71
14em	3/25/2011	14:01	7/21/2011	10:52	N28 34.426	E84 43.267	3400	3083	220	-0.77	30	0.5
14wc	3/26/2011	11:24	7/23/2011	13:29	N28 34.405	E84 42.059	3400	3144	30	0.87	15	0.26
14we	3/26/2011	12:25	7/23/2011	10:27	N28 34.270	E84 41.776	3400	3287	20	0.94	25	0.42
14wf	3/26/2011	10:44	7/22/2011	11:42	N28 34.258	E84 41.905	3400	3284	330	0.87	30	0.5
14wm	3/26/2011	10:44	7/23/2011	9:21	N28 34.278	E84 41.793	3400	3270	10	0.98	20	0.34

15ec	3/28/2011	10:38	7/25/2011	9:00	N28 35.261	E84 38.893	3800	3471	220	-0.77	10	0.17
15ee	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
15ef	3/28/2011	10:38	7/25/2011	10:27	N28 35.376	E84 38.740	3800	3494	200	-0.94	40	0.64
15em	3/28/2011	10:15	7/25/2011	17:38	N28 35.296	E84 38.869	3800	3498	200	-0.94	25	0.42
15wc	3/27/2011	13:08	7/24/2011	16:00	N28 34.953	E84 38.715	3800	3500	20	0.94	10	0.17
15we	3/27/2011	15:19	7/24/2011	16:18	N28 34.973	E84 38.495	3800	3501	10	0.98	30	0.5
15wf	3/27/2011	13:23	7/24/2011	16:16	N28 34.899	E84 38.653	3800	3504	20	0.94	25	0.42
15wm	3/27/2011	13:23	7/24/2011	NA	N28 34.913	E84 38.731	3800	3503	20	0.94	15	0.26
21ec	4/13/2011	8:43	9/13/2011	7:46	N27 40.322	E86 42.875	2200	2228	310	0.64	40	0.64
21ee	4/13/2011	9:23	9/13/2011	9:07	N27 40.305	E86 42.824	2200	2202	280	0.17	35	0.57
21ef	4/13/2011	14:45	9/13/2011	9:43	N27 40.328	E86 42.868	2200	2209	310	0.64	40	0.64
21em	4/13/2011	10:17	9/13/2011	8:36	N27 40.301	E86 42.832	2200	2213	250	-0.34	30	0.5
21wc	4/14/2011	15:14	9/14/2011	15:08	N27 40.855	E86 42.761	2200	2226	100	-0.17	10	0.17
21we	4/14/2011	16:39	9/14/2011	19:34	N27 40.903	E86 42.756	2200	2212	100	-0.17	45	0.71
21wf	4/14/2011	13:50	9/14/2011	8:37	N27 41.034	E86 42.749	2200	2209	90	0	30	0.5
21wm	4/14/2011	13:50	9/14/2011	14:34	N27 40.822	E86 42.708	2200	2239	90	0	20	0.34
22ec	4/14/2011	9:44	9/15/2011	12:47	N27 41.441	E86 43.132	2600	2560	220	-0.77	10	0.17
22ee	4/13/2011	17:11	9/15/2011	11:42	N27 41.614	E86 43.094	2600	2569	180	-1	30	0.5
22ef	4/14/2011	8:21	9/15/2011	7:57	N27 41.733	E86 42.981	2600	2590	250	-0.34	35	0.57
22em	4/14/2011	9:44	9/15/2011	9:28	N27 41.660	E86 43.021	2600	2592	240	-0.5	10	0.17
22wc	4/15/2011	11:20	9/16/2011	12:22	N27 42.346	E86 42.520	2600	2624	140	-0.77	10	0.17
22we	4/15/2011	13:05	9/16/2011	8:25	N27 42.333	E86 42.608	2600	2543	140	-0.77	45	0.71
22wf	4/15/2011	12:05	9/16/2011	10:15	N27 42.359	E86 42.601	2600	2580	80	0.17	35	0.57
22wm	4/15/2011	12:05	9/16/2011	11:59	N27 42.338	E86 42.549	2600	2629	110	-0.34	15	0.26
23ec	4/17/2011	12:33	9/18/2011	7:35	N27 46.567	E86 43.307	3000	2771	280	0.17	10	0.17
23ee	4/17/2011	13:46	9/18/2011	8:29	N27 46.503	E86 43.332	3000	2791	275	0.09	35	0.57
23ef	4/17/2011	14:55	9/18/2011	7:57	N27 46.594	E86 43.232	3000	2788	300	0.5	35	0.57
23em	4/17/2011	7:42	9/18/2011	8:46	N27 46.493	E86 43.312	3000	2775	250	-0.34	30	0.5
23wc	4/17/2011	8:28	9/19/2011	10:38	N27 46.636	E86 43.402	3000	2646	110	-0.34	10	0.17
23we	4/17/2011	9:00	9/19/2011	11:14	N27 46.652	E86 43.277	3000	2711	120	-0.5	20	0.34
23wf	4/17/2011	16:36	9/19/2011	9:28	N27 46.669	E86 43.287	3000	2750	100	-0.17	35	0.57
23wm	4/17/2011	10:35	9/19/2011	9:41	N27 46.673	E86 43.302	3000	2785	120	-0.5	30	0.5
24ec	4/20/2011	9:01	9/23/2011	9:03	N27 49.806	E86 44.418	3400	3423	170	-0.98	10	0.17
24ee	4/20/2011	9:34	9/23/2011	7:12	N27 49.791	E86 44.383	3400	3387	240	-0.5	30	0.5

24ef	4/20/2011	10:08	9/23/2011	8:04	N27 49.788	E86 44.395	3400	3393	240	-0.5	35	0.57
24em	4/20/2011	12:46	9/23/2011	8:54	N27 49.797	E86 44.421	3400	3420	150	-0.87	35	0.57
24wc	4/20/2011	11:48	9/22/2011	8:53	N27 49.766	E86 44.313	3400	3435	120	-0.5	10	0.17
24we	4/20/2011	13:17	9/22/2011	8:12	N27 49.759	E86 44.327	3400	3423	20	0.94	30	0.5
24wf	4/20/2011	12:11	9/22/2011	7:25	N27 49.753	E86 44.352	3400	3426	50	0.64	40	0.64
24wm	4/20/2011	12:11	9/22/2011	8:33	N27 49.760	E86 44.321	3400	3423	150	-0.87	15	0.26
25ec	4/18/2011	17:30	9/21/2011	7:29	N27 49.479	E86 42.914	3800	3750	140	-0.77	10	0.17
25ee	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
25ef	4/19/2011	12:54	9/21/2011	8:49	N27 49.520	E86 42.969	3800	3753	160	-0.94	20	0.34
25em	4/19/2011	10:33	9/21/2011	9:06	N27 49.564	E86 42.983	3800	3789	200	-0.94	30	0.5
25wc	4/19/2011	9:48	9/20/2011	14:53	N27 49.176	E86 42.967	3800	3716	10	0.98	10	0.17
25we	4/19/2011	8:23	9/20/2011	13:51	N27 48.939	E86 42.916	3800	3788	30	0.87	25	0.42
25wf	4/19/2011	7:51	9/20/2011	13:31	N27 48.919	E86 43.004	3800	3759	10	0.98	35	0.57
25wm	4/19/2011	7:51	9/20/2011	8:33	N27 48.935	E86 43.031	3800	3746	40	0.77	10	0.17
31ec	5/13/2011	10:46	8/17/2011	12:18	N27 34.489	E87 48.079	2200	2206	270	0	19	0.33
31ee	5/13/2011	12:43	8/17/2011	9:32	N27 34.449	E87 48.067	2200	2170	330	0.87	30	0.5
31ef	5/13/2011	11:28	8/17/2011	10:41	N27 34.478	E87 48.062	2200	2194	240	-0.5	35	0.57
31em	5/13/2011	11:28	8/17/2011	11:20	N27 34.456	E87 48.073	2200	2183	300	0.5	35	0.57
31wc	5/12/2011	10:00	8/16/2011	8:56	N27 34.125	E87 47.324	2200	2210	80	0.17	25	0.42
31we	5/12/2011	10:32	8/16/2011	7:54	N27 34.139	E87 47.356	2200	2210	60	0.5	20	0.34
31wf	5/12/2011	10:35	8/16/2011	10:51	N27 34.094	E87 47.328	2200	2227	70	0.34	30	0.5
31wm	5/12/2011	11:50	8/16/2011	10:11	N27 34.182	E87 47.284	2200	2229	70	0.34	35	0.57
32ec	NA	NA	NA	NA	NA	NA	2600	NA	NA	NA	NA	NA
32ee	5/24/2011	13:22	8/20/2011	NA	N27 39.222	E87 47.983	2600	2600	290	0.34	20	0.34
32ef	5/24/2011	12:01	8/20/2011	7:44	N27 39.196	E87 47.989	2600	2621	290	0.34	30	0.5
32em	5/24/2011	12:01	8/20/2011	8:39	N27 39.255	E87 47.987	2600	2683	280	0.17	10	0.17
32wc	NA	NA	NA	NA	NA	NA	2600	NA	NA	NA	NA	NA
32we	5/19/2011	12:53	8/19/2011	9:11	N27 39.385	E87 47.931	2600	2606	90	0	10	0.17
32wf	5/19/2011	11:06	8/19/2011	8:32	N27 39.345	E87 47.897	2600	2632	100	-0.17	25	0.42
32wm	5/19/2011	11:06	8/19/2011	9:05	N27 41.222	E87 46.197	2600	2572	100	-0.17	10	0.17
33ec	5/15/2011	10:00	8/25/2011	10:20	N27 40.827	E87 46.645	3000	3166	230	-0.64	10	0.17
33ee	5/15/2011	12:23	8/26/2011	10:00	N27 40.836	E87 46.721	3000	3188	210	-0.87	30	0.5
33ef	5/15/2011	11:00	8/26/2011	9:37	N27 40.803	E87 46.801	3000	3186	230	-0.64	30	0.5
33em	5/15/2011	11:00	8/26/2011	10:09	N27 40.851	E87 46.667	3000	3180	210	-0.87	20	0.34

33wc	NA	NA	NA	NA	NA	NA	3000	NA	NA	NA	NA	NA
33we	5/16/2011	11:31	8/25/2011	8:43	N27 40.389	E87 46.748	3000	3171	90	0	30	0.5
33wf	5/16/2011	9:31	8/25/2011	8:21	N27 40.306	E87 46.836	3000	3167	70	0.34	15	0.26
33wm	5/16/2011	9:31	8/25/2011	8:59	N27 40.399	E87 46.771	3000	3157	70	0.34	10	0.17
34ec	NA	NA	NA	NA	NA	NA	3400	NA	NA	NA	NA	NA
34ee	5/17/2011	11:03	8/21/2011	8:55	N27 41.586	E87 45.678	3400	3380	180	-1	30	0.5
34ef	5/17/2011	9:22	8/21/2011	8:39	N27 41.451	E87 45.594	3400	3388	220	-0.77	30	0.5
34em	5/17/2011	8:00	8/21/2011	9:10	N27 41.600	E87 45.672	3400	3406	180	-1	25	0.42
34wc	NA	NA	NA	NA	NA	NA	3400	NA	NA	NA	NA	NA
34we	5/18/2011	12:09	8/22/2011	9:56	N27 41.566	E87 45.598	3400	3366	60	0.5	15	0.26
34wf	5/18/2011	10:30	8/22/2011	9:32	N27 41.545	E87 45.609	3400	3376	50	0.64	20	0.34
34wm	5/18/2011	10:30	8/22/2011	10:17	N27 41.583	E87 45.594	3400	3358	40	0.77	15	0.26
35ec	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
35ee	5/21/2011	10:43	8/23/2011	12:59	N27 42.858	E87 44.216	3800	3704	280	0.17	30	0.5
35ef	5/21/2011	12:00	8/23/2011	13:41	N27 42.870	E87 44.253	3800	3747	280	0.17	45	0.71
35em	5/21/2011	8:46	8/23/2011	11:24	N27 42.817	E87 44.167	3800	3653	300	0.5	30	0.5
35wc	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
35we	5/20/2011	11:00	8/24/2011	7:37	N27 42.974	E87 44.099	3800	3815	110	-0.34	30	0.5
35wf	5/20/2011	12:00	8/24/2011	8:05	N27 42.950	E87 44.073	3800	3812	60	0.5	35	0.57
35wm	5/20/2011	10:00	8/24/2011	7:53	N27 42.958	E87 44.080	3800	3807	100	-0.17	35	0.57
36wm	5/20/2011	14:50	8/23/2011	8:55	N27 43.009	E87 43.912	4000	3941	100	-0.17	45	0.71
41ec	9/13/2012	8:00	3/6/2013	7:45	N28 26.340	E84 54.739	2200	2160	345	0.97	10	0.17
41ee	9/13/2012	8:45	3/6/2013	8:40	N28 26.352	E84 54.799	2200	2179	350	0.98	30	0.5
41ef	9/13/2012	9:45	3/6/2013	9:15	N28 26.322	E84 54.864	2200	2210	350	0.98	35	0.57
41em	9/13/2012	10:20	3/6/2013	8:05	N28 26.327	E84 54.778	2200	2194	320	0.77	30	0.5
41wc	9/16/2012	7:50	3/8/2013	7:15	N28 28.360	E84 58.020	2200	2241	160	-0.94	10	0.17
41we	9/16/2012	8:40	3/8/2013	8:15	N28 28.392	E84 58.189	2200	2228	190	-0.98	15	0.26
41wf	9/16/2012	11:00	3/8/2013	9:50	N28 28.399	E84 58.350	2200	2266	250	-0.34	45	0.71
41wm	9/16/2012	10:00	3/8/2013	10:10	N28 28.400	E84 58.394	2200	2267	190	-0.98	15	0.26
42ec	9/19/2012	9:05	3/10/2013	8:25	N28 28.142	E85 00.420	2600	2586	20	0.94	25	0.42
42ee	9/19/2012	9:45	3/10/2013	8:50	N28 28.076	E85 00.377	2600	2638	20	0.94	30	0.5
42ef	9/19/2012	8:05	3/10/2013	8:00	N28 28.113	E85 00.486	2600	2563	30	0.87	35	0.57
42em	NA	NA	NA	NA	NA	NA	2600	NA	NA	NA	NA	NA
42wc	9/18/2012	10:00	3/11/2013	7:45	N28 28.732	E85 00.851	2600	2582	170	-0.98	15	0.26

42we	9/18/2012	8:10	3/11/2013	8:25	N28 28.790	E85 00.919	2600	2649	160	-0.94	30	0.5
42wf	9/18/2012	10:30	3/11/2013	7:20	N28 28.688	E85 00.861	2600	2559	280	0.17	45	0.71
42wm	9/18/2012	9:10	3/11/2013	8:00	N28 28.766	E85 00.875	2600	2635	130	-0.64	35	0.57
43ec	NA	NA	NA	NA	NA	NA	3000	NA	NA	NA	NA	NA
43ee	9/23/2012	9:00	3/13/2013	8:30	N28 28.983	E85 02.817	3000	3060	320	0.77	30	0.5
43ef	9/23/2012	10:00	3/13/2013	9:10	N28 29.005	E85 02.762	3000	3001	350	0.98	40	0.64
43em	NA	NA	NA	NA	NA	NA	3000	NA	NA	NA	NA	NA
43wc	9/22/2012	8:10	3/12/2013	9:05	N28 29.226	E85 02.389	3000	3014	150	-0.87	10	0.17
43we	9/22/2012	9:30	3/12/2013	7:25	N28 29.247	E85 02.188	3000	3036	170	-0.98	15	0.26
43wf	9/22/2012	10:30	3/12/2013	7:50	N28 29.144	E85 02.091	3000	2974	160	-0.94	20	0.34
43wm	9/22/2012	8:50	3/12/2013	8:30	N28 29.265	E85 02.271	3000	3035	150	-0.87	10	0.17
44ec	9/27/2012	12:30	3/16/2013	10:00	N28 32.756	E85 06.469	3400	3339	270	0	15	0.26
44ee	9/27/2012	8:50	3/16/2013	8:00	N28 32.675	E85 06.575	3400	3399	290	0.34	30	0.5
44ef	9/27/2012	8:10	3/16/2013	7:40	N28 32.619	E85 06.546	3400	3362	270	0	30	0.5
44em	9/27/2012	10:20	3/16/2013	9:05	N28 32.813	E85 06.672	3400	3449	270	0	40	0.64
44wc	9/26/2012	7:50	3/15/2013	11:40	N28 32.946	E85 06.337	3400	3310	80	0.17	10	0.17
44we	NA	NA	NA	NA	NA	NA	3400	NA	NA	NA	NA	NA
44wf	9/26/2012	12:10	3/15/2013	13:15	N28 32.515	E85 06.447	3400	3304	80	0.17	10	0.17
44wm	9/26/2012	8:25	3/15/2013	12:05	N28 32.876	E85 06.268	3400	3375	110	-0.34	30	0.5
45ec	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
45ee	9/29/2012	12:05	NA	NA	N28 36.936	E85 06.260	3800	3831	250	-0.34	15	0.26
45ef	9/29/2012	9:05	NA	NA	N28 36.742	E85 06.316	3800	3811	270	0	45	0.71
45em	9/29/2012	8:15	NA	NA	N28 36.625	E85 06.397	3800	3790	280	0.17	20	0.34
45wc	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
45we	9/30/2012	9:30	NA	NA	N28 36.498	E85 06.234	3800	3816	30	0.87	40	0.64
45wf	9/30/2012	8:45	NA	NA	N28 36.454	E85 06.281	3800	3821	50	0.64	45	0.71
45wm	9/30/2012	7:40	NA	NA	N28 36.460	E85 06.339	3800	3765	100	-0.17	35	0.57
51ec	6/11/2012	8:45	4/11/2013	8:05	N27 30.871	E86 34.626	2200	2208	250	-0.34	30	0.5
51ee	6/11/2012	9:15	4/11/2013	8:30	N27 30.666	E86 34.780	2200	2179	240	-0.5	30	0.5
51ef	6/11/2012	7:55	4/11/2013	7:35	N27 30.946	E86 34.589	2200	2217	270	0	40	0.64
51em	6/11/2012	7:05	4/11/2013	7:00	N27 31.078	E86 34.491	2200	2170	240	-0.5	10	0.17
51wc	6/10/2012	7:25	4/10/2013	7:00	N27 31.209	E86 34.460	2200	2196	160	-0.94	5	0.09
51we	6/10/2012	8:00	4/10/2013	7:30	N27 31.309	E86 34.540	2200	2201	110	-0.34	30	0.5
51wf	6/10/2012	9:40	4/10/2013	8:30	N27 31.493	E86 34.623	2200	2220	110	-0.34	43	0.68
51wm	6/10/2012	9:00	4/10/2013	8:00	N27 31.344	E86 34.543	2200	2201	110	-0.34	10	0.17
52ec	6/15/2012	10:05	4/14/2013	9:00	N27 33.437	E86 35.561	2600	2625	300	0.5	25	0.42
52ee	6/15/2012	7:40	4/14/2013	8:15	N27 33.097	E86 35.205	2600	2618	350	0.98	20	0.34
52ef	6/15/2012	9:10	4/14/2013	7:10	N27 33.287	E86 35.464	2600	2607	300	0.5	40	0.64

52em	6/15/2012	8:30	4/14/2013	7:50	N27 33.146	E86 35.317	2600	2632	350	0.98	15	0.26
52wc	6/14/2012	7:50	4/13/2013	7:50	N27 34.082	E86 35.337	2600	2593	130	-0.64	20	0.34
52we	6/14/2012	10:20	4/13/2013	9:50	N27 33.974	E86 35.277	2600	2595	120	-0.5	30	0.5
52wf	6/14/2012	9:30	4/13/2013	8:50	N27 34.212	E86 35.429	2600	2598	120	-0.5	30	0.5
52wm	6/14/2012	8:30	4/13/2013	8:10	N27 34.147	E86 35.386	2600	2594	150	-0.87	35	0.57
53ec	6/21/2012	11:55	4/19/2013	10:20	N27 35.513	E86 37.027	3000	3064	280	0.17	10	0.17
53ee	6/21/2012	8:05	4/19/2013	8:15	N27 35.396	E86 36.860	3000	3002	270	0	20	0.34
53ef	6/21/2012	8:45	4/19/2013	8:45	N27 35.315	E86 36.828	3000	2990	240	-0.5	35	0.57
53em	6/21/2012	7:15	4/19/2013	7:45	N27 35.461	E86 36.876	3000	3002	280	0.17	10	0.17
53wc	6/18/2012	8:45	4/17/2013	8:00	N27 35.578	E86 35.407	3000	2974	210	-0.87	20	0.34
53we	6/18/2012	9:15	4/17/2013	8:30	N27 35.634	E86 35.406	3000	2972	20	0.94	25	0.42
53wf	6/18/2012	10:15	4/17/2013	9:00	N27 35.681	E86 35.379	3000	2968	50	0.64	35	0.57
53wm	6/18/2012	10:45	4/17/2013	9:30	N27 35.679	E86 35.324	3000	2998	90	0	20	0.34
54ec	NA	NA	NA	NA	NA	NA	3400	NA	NA	NA	NA	NA
54ee	6/27/2012	9:15	4/18/2013	8:40	N27 37.054	E86 36.672	3400	3405	220	-0.77	20	0.34
54ef	6/27/2012	8:25	4/18/2013	8:15	N27 36.999	E86 36.678	3400	3370	220	-0.77	25	0.42
54em	6/27/2012	10:10	4/18/2013	9:10	N27 37.103	E86 36.707	3400	3440	220	-0.77	10	0.17
54wc	NA	NA	NA	NA	NA	NA	3400	NA	NA	NA	NA	NA
54we	6/28/1012	10:35	4/16/2013	10:15	N27 36.396	E86 35.732	3400	3369	60	0.5	30	0.5
54wf	6/28/1012	11:00	4/16/2013	10:30	N27 36.481	E86 35.727	3400	3376	80	0.17	20	0.34
54wm	6/28/1012	9:55	4/16/2013	9:10	N27 36.339	E86 35.753	3400	3357	150	-0.87	20	0.34
55ec	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
55ee	6/24/2012	9:20	NA	NA	N27 39.414	E86 35.783	3800	3797	230	-0.64	30	0.5
55ef	6/24/2012	10:50	NA	NA	N27 39.240	E86 35.867	3800	3764	140	-0.77	30	0.5
55em	6/24/2012	7:45	NA	NA	N27 39.518	E86 35.613	3800	3769	220	-0.77	20	0.34
55wc	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
55we	6/23/2012	9:10	NA	NA	N27 39.625	E86 35.504	3800	3789	100	-0.17	15	0.26
55wf	6/23/2012	11:10	NA	NA	N27 39.420	E86 35.585	3800	3764	100	-0.17	30	0.5
55wm	6/23/2012	8:00	NA	NA	N27 39.818	E86 35.407	3800	3852	90	0	10	0.17
61ec	4/2/2012	10:25	11/26/2012	9:35	N27 32.190	E87 49.001	2200	2222	340	0.94	15	0.26
61ee	4/2/2012	9:30	11/26/2012	8:50	N27 32.156	E87 48.965	2200	2184	310	0.64	25	0.42
61ef	4/2/2012	12:50	11/26/2012	10:50	N27 32.142	E87 49.054	2200	2288	310	0.64	30	0.5
61em	4/2/2012	11:35	11/26/2012	10:15	N27 32.109	E87 48.999	2200	2281	340	0.94	30	0.5
61wc	4/1/2012	13:45	11/27/2012	11:30	N27 32.754	E87 48.440	2200	2350	160	-0.94	10	0.17
61we	4/1/2012	14:45	11/27/2012	12:10	N27 32.706	E87 48.342	2200	2259	180	-1	35	0.57
61wf	4/1/2012	10:45	11/27/2012	9:30	N27 32.667	E87 48.425	2200	2201	135	-0.71	45	0.71

61wm	4/1/2012	9:35	11/27/2012	9:07	N27 32.656	E87 48.386	2200	2213	200	-0.94	35	0.57
62ec	4/16/2012	11:00	11/29/2012	8:45	N27 32.701	E87 50.315	2600	2355	350	0.98	10	0.17
62ee	NA	NA	NA	NA	NA	NA	2600	NA	NA	NA	NA	NA
62ef	4/16/2012	12:15	11/29/2012	9:30	N27 32.502	E87 50.391	2600	2559	50	0.64	20	0.34
62em	NA	NA	NA	NA	NA	NA	2600	NA	NA	NA	NA	NA
62wc	4/4/2012	8:35	11/30/2012	8:00	N27 34.072	E87 51.962	2600	2573	200	-0.94	35	0.57
62we	4/4/2012	9:40	11/30/2012	8:45	N27 34.141	E87 52.004	2600	2640	200	-0.94	45	0.71
62wf	4/4/2012	12:50	11/30/2012	10:05	N27 34.222	E87 51.797	2600	2690	220	-0.77	45	0.71
62wm	4/4/2012	10:40	11/30/2012	8:55	N27 34.136	E87 51.934	2600	2650	210	-0.87	40	0.64
63ec	NA	NA	NA	NA	NA	NA	3000	NA	NA	NA	NA	NA
63ee	4/14/2012	12:05	12/2/2012	9:40	N27 35.638	E87 52.726	3000	3030	320	0.77	10	0.17
63ef	4/14/2012	13:00	12/2/2012	10:05	N27 35.695	E87 52.729	3000	3046	320	0.77	20	0.34
63em	4/14/2012	11:30	12/2/2012	9:10	N27 35.585	E87 52.660	3000	2958	210	-0.87	35	0.57
63wc	4/6/2012	13:30	12/4/2012	11:30	N27 37.162	E87 52.401	3000	2900	180	-1	10	0.17
63we	4/6/2012	9:00	12/4/2012	9:05	N27 37.323	E87 52.548	3000	3003	190	-0.98	45	0.71
63wf	4/6/2012	10:00	12/4/2012	9:30	N27 37.331	E87 52.639	3000	3034	170	-0.98	45	0.71
63wm	4/6/2012	8:20	12/4/2012	8:25	N27 37.295	E87 52.575	3000	2963	180	-1	45	0.71
64ec	4/8/2012	11:55	12/7/2012	10:55	N27 39.621	E87 56.082	3400	3434	320	0.77	35	0.57
64ee	4/8/2012	8:55	12/7/2012	8:10	N27 39.854	E87 56.379	3400	3452	290	0.34	25	0.42
64ef	4/8/2012	13:50	12/7/2012	9:50	N27 39.470	E87 56.049	3400	3452	305	0.57	35	0.57
64em	4/8/2012	8:05	12/7/2012	8:30	N27 39.823	E87 56.326	3400	3448	290	0.34	5	0.09
64wc	4/13/2012	10:45	12/5/2012	12:35	N27 38.643	E87 55.097	3400	3272	120	-0.5	20	0.34
64we	4/9/2012	9:30	12/6/2012	8:15	N27 39.861	E87 56.281	3400	3436	140	-0.77	15	0.26
64wf	4/9/2012	11:50	12/6/2012	9:50	N27 39.695	E87 55.862	3400	3429	210	-0.87	35	0.57
64wm	4/9/2012	8:55	12/6/2012	7:55	N27 39.779	E87 56.151	3400	3430	140	-0.77	10	0.17
65ec	NA	NA	NA	NA	NA	NA	3800	NA	NA	NA	NA	NA
65ee	11/4/2012	13:45	12/9/2012	9:40	N27 42.542	E87 57.914	3800	3827	290	0.34	15	0.26
65ef	12/4/2012	7:25	12/9/2012	8:10	N27 42.418	E87 57.848	3800	3795	280	0.17	15	0.26
65em	11/4/2012	13:10	12/9/2012	10:05	N27 42.579	E87 57.880	3800	3812	260	-0.17	10	0.17
65wc	11/4/2012	7:30	12/10/2012	8:00	N27 42.623	E87 57.791	3800	3804	100	-0.17	10	0.17
65we	11/4/2012	8:35	12/10/2012	8:35	N27 42.550	E87 57.799	3800	3791	120	-0.5	10	0.17
65wf	11/4/2012	9:25	12/10/2012	8:55	N27 42.504	E87 57.776	3800	3787	120	-0.5	5	0.09
65wm	11/4/2012	7:55	12/10/2012	8:15	N27 42.592	E87 57.819	3800	3795	120	-0.5	10	0.17

Annex II : List of vascular plants recorded during the field visits at six valleys

Plant Names (APG III)	**Family**	**Lowest Elevation**	**Highest Elevation**	**Short Names**	**Life Form**	**Growth Form**
Abelia triflora R. Br. ex Wall	Caprifoliaceae	1500	4200	AbeTri	Dicot	Tree
Abies spectabilis (D. Don) Mirb.	Pinaceae	2400	4000	AbiSpe	Gymnosperm	Tree
Acer campbellii Hook. f. & Thomson ex Hiern	Sapindaceae	2100	3600	AceCam	Dicot	Tree
Acer oblongum Wall. ex DC.	Sapindaceae	1200	2400	AceObl	Dicot	Tree
Acer pectinatum Wall. ex G. Nicholson	Sapindaceae	2700	3800	AcePec	Dicot	Tree
Achyranthes bidentata Blume	Amaranthaceae	1200	2100	AchBid	Dicot	Herb
Acomastylis elata (Wall. ex G. Don) F. Bolle	Rosaceae	3500	4400	GeuEla	Dicot	Herb
Aconitum ferox Wall. ex Ser.	Ranunculaceae	2100	3800	AcoFer	Dicot	Herb
Aconitum lethale Griff.	Ranunculaceae	1800	4200	AcoLet	Dicot	Herb
Aconitum species	Ranunculaceae	2200	2600	AcoSpe	Dicot	Herb
Aconogonum molle (D. Don) H. Hara	Polygonaceae	1200	4000	AcoMol	Dicot	Herb
Acorus calamus L.	Araceae	1700	2300	AcoCal	Monocot	Herb
Acronema handelii H. Wolff	Apiaceae	380	4000	AcrHan	Dicot	Herb
Actaea cimicifuga L.	Ranunculaceae	3000	4000	ActCim	Dicot	Herb
Actaea spicata L.	Ranunculaceae	2500	3700	ActSpi	Dicot	Herb
Actinidia callosa Lindl.	Actinidiaceae	1300	3000	ActCal	Dicot	Shrub
Adiantum tibeticum Ching	Adiantaceae	2200	3800	AdiTib	Pteridophyte	Herb
Adiantum venustum D. Don	Adiantaceae	1000	3300	AdiVen	Pteridophyte	Herb
Agapetes serpens (Wight) Sleumer	Ericaceae	1200	3000	AgaSer	Dicot	Shrub
Agapetes species	Ericaceae	2600	NA	AgaSpe	Dicot	Shrub
Ageratina adenophora (Spreng.) R.M. King & H. Rob.	Asteraceae	850	2200	AgeAde	Dicot	Herb
Ageratum conyzoides (L.) L.	Asteraceae	200	2000	AgeCon	Dicot	Herb
Agrimonia pilosa Ledeb.	Rosaceae	1000	3000	AgrPil	Dicot	Herb
Agrostis micrantha Steud.	Poaceae	3200	3500	AgrMic	Monocot	Herb
Agrostis pilosula Trin.	Poaceae	2000	4600	AgrPio	Monocot	Herb
Ainsliaea aptera DC.	Asteraceae	1600	3500	AinApt	Dicot	Herb
Ajuga integrifolia Buch.-Ham.	Lamiaceae	1200	5100	AjuInt	Dicot	Herb

Ajuga lobata D. Don	Lamiaceae	1500	3300	AjuLob	Dicot	Herb
Alangium alpinum (C. B. Clarke) W. W. Sm. & Cave	Cornaceae	1900	2700	AlaAlp	Dicot	Tree
Aleuritopteris farinosa (Forssk.) Fée	Adiantaceae	2300	3000	AleFar	Pteridophyte	Herb
Allium ascalonicum L.	Amaryllidaceae	2600	3000	AllAsc	Monocot	Herb
Allium cepa L.	Amaryllidaceae	49	3500	AllCep	Monocot	Herb
Allium fasciculatum Rendle	Amaryllidaceae	2800	4500	AllFas	Monocot	Herb
Allium hypsistum Stearn	Amaryllidaceae	3000	5500	AllHyp	Monocot	Herb
Allium prattii C.H. Wright	Amaryllidaceae	2400	4500	AllPra	Monocot	Herb
Allium przewalskianum Regel	Amaryllidaceae	3900	4200	AllPrz	Monocot	Herb
Allium sativum L.	Amaryllidaceae	122	3065	AllSat	Monocot	Herb
Allium wallichii Kunth	Amaryllidaceae	2400	4650	AllWal	Monocot	Herb
Alnus nepalensis D. Don	Betulaceae	500	2600	AlnNep	Dicot	Tree
Amaranthus caudatus L.	Amaranthaceae	1000	2300	AmaCau	Dicot	Herb
Amaranthus lividus L.	Amaranthaceae	1500	2300	AmaLiv	Dicot	Herb
Amaranthus spinosus L.	Amaranthaceae	120	1200	AmaSpi	Dicot	Herb
Anagallis arvensis L.	Primulaceae	600	2700	AnaArv	Dicot	Herb
Anaphalis busua (Buch.-Ham.) DC.	Asteraceae	1500	2900	AnaBus	Dicot	Herb
Anaphalis contorta (D. Don) Hook. f.	Asteraceae	1700	4500	AnaCon	Dicot	Herb
Anaphalis margaritacea (L.) Benth. & Hook.f.	Asteraceae	1800	4100	AnaMar	Dicot	Herb
Anaphalis nepalensis (Spreng.) Hand.-Mazz.	Asteraceae	3800	4500	AnaNep	Dicot	Herb
Anaphalis species (decurrent lvs)	Asteraceae	2200	3400	AnaSpe	Dicot	Herb
Anaphalis subumbellata C.B. Clarke	Asteraceae	3000	4300	AnaSub	Dicot	Herb
Anaphalis triplinervis (Sims) Sims ex C.B. Clarke	Asteraceae	2900	4100	AnaTri	Dicot	Herb
Anaphalis virgata Thomson	Asteraceae	2700	3200	AnaVir	Dicot	Herb
Andropogon munroi C. B. Clarke	Poaceae	2100	4000	AndMun	Monocot	Herb
Androsace geraniifolia Watt	Primulaceae	2000	3400	AndGer	Dicot	Herb
Androsace sarmentosa Wall.	Primulaceae	910	5600	AndSar	Dicot	Herb
Androsace strigillosa Franch.	Primulaceae	2400	4700	AndStr	Dicot	Herb
Anemone griffithii J.D. Hooker & Thomson	Ranunculaceae	1600	3000	AneGri	Dicot	Herb

Anemone obtusiloba D. Don	Ranunculaceae	2300	4200	AneObt	Dicot	Herb
Anemone rivularis Buch.-Ham. ex DC.	Ranunculaceae	1600	4000	AneRiv	Dicot	Herb
Anemone vitifolia Buch.-Ham. ex DC.	Ranunculaceae	1300	3300	AneVit	Dicot	Herb
Angelica cyclocarpa (C. Norman) M. Hiroe	Apiaceae	2800	3500	AngCyc	Dicot	Herb
Anisodus luridus Link ex Spreng.	Solanaceae	2500	3800	AniLur	Dicot	Herb
Anthoxanthum hookeri (Griseb.) Rendle	Poaceae	2600	3400	AntHoo	Monocot	Herb
Apios carnea (Wall.) Benth.	Fabaceae	1800	2300	ApiCar	Dicot	Climber
Apluda mutica L.	Poaceae	800	2500	AplMut	Monocot	Herb
Araiostegia beddomei (C. Hope) Ching	Davalliaceae	2000	4000	AraBed	Pteridophyte	Herb
Aralia cachemirica Decne.	Araliaceae	2400	4200	AraCac	Dicot	Tree
Arenaria melandryiformis F. N. Williams	Caryophyllaceae	4200	4400	AreMel	Dicot	Herb
Arenaria orbiculata Royle ex Edgew. & Hook. f.	Caryophyllaceae	900	4400	AreOrb	Dicot	Herb
Argyrolobium roseum (Cambess.) Jaub. & Spach	Fabaceae	1900	3200	ArgRos	Dicot	Herb
Arisaema consanguineum Schott	Araceae	2200	2700	AriCon	Monocot	Herb
Arisaema costatum (Wall.) Mart. ex Schott	Araceae	1900	2800	AriCos	Monocot	Herb
Arisaema erubescens (Wall.) Schott	Araceae	1900	2600	AriEru	Monocot	Herb
Arisaema flavum (Forssk.) Schott	Araceae	2100	2900	AriFla	Monocot	Herb
Arisaema griffithii Schott	Araceae	2400	3000	AriGri	Monocot	Herb
Arisaema jacquemontii Blume	Araceae	2700	4000	AriJac	Monocot	Herb
Arisaema propinquum Schott	Araceae	2500	3800	AriPro	Monocot	Herb
Arisaema tortuosum (Wall.) Schott	Araceae	1300	2900	AriTor	Monocot	Herb
Aristolochia griffithii Hook. f. & Thomson ex Duch.	Aristolochiaceae	2000	2900	ArlGri	Dicot	Climber
Arnebia benthamii (Wall. ex G. Don) I. M. Johnst.	Boraginaceae	2800	4100	ArnBen	Dicot	Herb
Artemisia carvifolia Buch. -Ham. ex Roxb.	Asteraceae	3900	4600	ArtCar	Dicot	Herb
Artemisia gmelinii Weber	Asteraceae	2800	4300	ArtGme	Dicot	Herb
Artemisia japonica Thunb.	Asteraceae	1900	2900	ArtJap	Dicot	Herb

Artemisia roxburghiana Wall. ex Besser	Asteraceae	2600	4300	ArtRox	Dicot	Herb
Artemisia vulgaris L.	Asteraceae	1200	3400	ArtVul	Dicot	Herb
Arthraxon lancifolius (Trin.) Hochst.	Poaceae	600	2350	ArtLan	Monocot	Herb
Arundinella hookeri Munro ex Keng	Poaceae	2400	3500	AruHoo	Monocot	Herb
Arundinella nepalensis Trin.	Poaceae	500	2500	AruNep	Monocot	Herb
Arundo donax L.	Poaceae	2100	2440	AruDon	Monocot	Herb
Asparagus racemosus Willd.	Asparagaceae	600	2100	AspRac	Monocot	Herb
Aster ageratoides Turcz.	Asteraceae	1800	3400	AstAge	Dicot	Herb
Aster albescens (DC.) Wall. ex Hand. -Mazz.	Asteraceae	1500	4200	AstAlb	Dicot	Shrub
Aster falconeri (C. B. Clarke) Hutch.	Asteraceae	3700	4300	AstFal	Dicot	Herb
Aster flaccidus Bunge	Asteraceae	4200	4900	AstFla	Dicot	Herb
Aster himalaicus C. B. Clarke	Asteraceae	3500	5200	AstHim	Dicot	Herb
Aster molliusculus (Lindl. ex DC.) C.B. Clarke	Asteraceae	3000	3800	AstMol	Dicot	Herb
Aster tricephalus C. B. Clarke	Asteraceae	2900	4600	AstTri	Dicot	Herb
Astilbe rivularis Buch.-Ham. ex D. Don	Saxifragaceae	2000	3600	AstRiv	Dicot	Herb
Astragalus chlorostachys Lindl.	Fabaceae	2100	3700	AstChl	Dicot	Herb
Astragalus donianus DC.	Fabaceae	2900	4500	AstDon	Dicot	Herb
Astragalus strictus Benth.	Fabaceae	2000	5600	AstStr	Dicot	Herb
Asystasia macrocarpa Nees	Acanthaceae	300	2100	AsyMac	Dicot	Herb
Athyrium attenuatum (Wall. ex C.B. Clarke) Tagawa	Woodsiaceae	2500	3000	AthAtt	Pteridophyte	Herb
Avena fatua L.	Poaceae	2100	3700	AveFat	Monocot	Herb
Balanophora dioica R. Br. ex Royle	Balanophoraceae	400	2600	BalDio	Dicot	Herb
Begonia picta Sm.	Begoniaceae	600	2800	BegPic	Dicot	Herb
Begonia sikkimensis A. DC.	Begoniaceae	600	1600	BegSik	Dicot	Herb
Berberis angulosa Wall. ex Hook. f. & Thomson	Berberidaceae	3400	4500	BerAng	Dicot	Shrub
Berberis aristata DC.	Berberidaceae	1800	3500	BerAri	Dicot	Shrub
Berberis asiatica Roxb. ex DC.	Berberidaceae	1200	2500	BerAsi	Dicot	Shrub
Berberis erythroclada Ahrendt	Berberidaceae	3000	4000	BerEry	Dicot	Shrub
Berberis lycium Royle	Berberidaceae	1800	2900	BerLyc	Dicot	Shrub

Berberis mucrifolia Ahrendt	Berberidaceae	2100	4500	BerMuc	Dicot	Shrub
Berberis wallichiana DC.	Berberidaceae	1900	3300	BerWal	Dicot	Shrub
Betula utilis D. Don	Betulaceae	2700	4300	BetUti	Dicot	Tree
Bidens tripartita L.	Asteraceae	800	3400	BidTri	Dicot	Herb
Bistorta affinis (D. Don) Greene	Polygonaceae	3500	4800	BisAff	Dicot	Herb
Bistorta macrophylla (D. Don) Sojak	Polygonaceae	2700	4500	BisMac	Dicot	Herb
Bistorta vacciniifolia (Wall. ex Meisn.) Greene	Polygonaceae	3500	4500	BisVac	Dicot	Herb
Boehmeria macrophylla Hornem.	Urticaceae	800	2700	BoeMac	Dicot	Shrub
Boenninghausenia albiflora (Hook.) Rchb. ex Meisn.	Rutaceae	600	3300	BoeAlb	Dicot	Herb
Boschniakia himalaica Hook. & Thomson ex Hook. f.	Orobanchaceae	2900	4300	BosHim	Dicot	Herb
Bothriochloa bladhii (Retz.) S.T. Blake	Poaceae	300	2600	BotBla	Monocot	Herb
Botrychium daucifolium Wall. ex Hook. & Grev.	Ophioglossaceae	1600	2400	Bot da	Pteridophyte	Herb
Brachiaria villosa (Lam.) A. Camus	Poaceae	500	2400	BraVil	Monocot	Herb
Brachypodium pinnatum (L.) P. Beauv.	Poaceae	2200	3800	BraPin	Monocot	Herb
Brassaiopsis mitis C. B. Clarke	Araliaceae	1600	2200	BraMit	Dicot	Tree
Brassaiopsis sp.	Araliaceae	2600	NA	Bra	Dicot	Tree
Brassica oleracea L.	Brassicaceae	2200	3600	BraOle	Dicot	Herb
Brassica rapa L.	Brassicaceae	2200	3700	BraRap	Dicot	Herb
Bromus himalaicus Stapf	Poaceae	3500	3700	BroHim	Monocot	Herb
Brucea javanica (L.) Merr.	Simaroubaceae	1300	2400	BruJav	Dicot	Tree
Buddleja crispa Benth.	Scrophulariaceae	1800	4400	BudCri	Dicot	Shrub
Bulbophyllum affine Wall. ex Lindl.	Orchidaceae	1200	1500	BulAff	Monocot	Herb
Bulbophyllum reptans (Lindl.) Lindl. ex Wall.	Orchidaceae	2000	3000	BulRep	Monocot	Herb
Bulbostylis densa (Wall.) Hand.-Mazz.	Cyperaceae	1500	3500	BulDen	Monocot	Herb
Bupleurum candollei Wall. ex DC.	Apiaceae	2400	4000	BupCan	Dicot	Herb
Calamagrostis pseudophragmites (Haller) Koeler	Poaceae	1500	4600	CalPse	Monocot	Herb
Calendula officinalis L.	Asteraceae	2600	4400	CalOff	Dicot	Herb

Caltha palustris L.	Ranunculaceae	2400	4200	CalPal	Dicot	Herb
Campanula cana Wall.	Campanulaceae	1200	3400	CamCan	Dicot	Herb
Campanula pallida Wall.	Campanulaceae	1000	4500	CamPal	Dicot	Herb
Campylandra aurantiaca Baker	Asparagaceae	2300	2700	CamAur	Monocot	Herb
Campylotropis macrostyla (D. Don) Miq.	Fabaceae	1900	2200	CamMac	Dicot	Herb
Campylotropis speciosa (Schindl.) Schindl.	Fabaceae	2000	3100	CamSpe	Dicot	Herb
Cannabis sativa L.	Cannabaceae	200	2700	CanSat	Dicot	Herb
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	1800	4500	CapBur	Dicot	Herb
Caragana sukiensis C. K. Schneid.	Fabaceae	3200	4200	CarSuk	Dicot	Shrub
Cardamine yunnanensis Franch.	Brassicaceae	2000	3400	CarYun	Dicot	Herb
Carex cruciata Wahlenb.	Cyperaceae	1500	3400	CarCru	Monocot	Herb
Carex filicina Nees	Cyperaceae	1200	4000	CarFil	Monocot	Herb
Carex gracilenta Boott ex Boeckeler	Cyperaceae	3400	3800	CarGra	Monocot	Herb
Carex nubigena D. Don ex Tilloch & Taylor	Cyperaceae	1500	4000	CarNub	Monocot	Herb
Carpesium nepalense Less.	Asteraceae	1900	3900	CarNep	Dicot	Herb
Carpesium trachelifolium Less.	Asteraceae	1500	3000	CarTra	Dicot	Herb
Cassiope fastigiata (Wall.) D. Don	Ericaceae	3000	4000	CasFas	Dicot	Shrub
Castanopsis tribuloides (Sm.) A. DC.	Fagaceae	450	2300	CasTri	Dicot	Tree
Cautleya gracilis (Sm.) Dandy	Zingiberaceae	1200	3100	CauGra	Monocot	Herb
Cautleya spicata (Sm.) Baker	Zingiberaceae	1800	2800	CauSpi	Monocot	Herb
Centella asiatica (L.) Urb.	Apiaceae	500	2100	CenAsi	Dicot	Herb
Cerasus cerasoides (Buch.-Ham. ex D. Don) S.Y. Sokolov	Rosaceae	1300	2400	CerCer	Dicot	Tree
Ceropegia pubescens Wall.	Apocynaceae	900	2700	CerPub	Dicot	Climber
Chaerophyllum villosum Wall. ex DC.	Apiaceae	2100	3500	ChaVil	Dicot	Herb
Chaetoseris cyanea (D. Don) C. Shih	Asteraceae	2100	4300	ChaCya	Dicot	Climber
Chaetoseris macrantha (C. B. Clarke) C. Shih	Asteraceae	3000	4000	ChaMac	Dicot	Climber
Cheilanthes tenuifolia (Burm.f.) Sw.	Adiantaceae	2200	3800	CheTen	Pteridophyte	Herb
Chenopodium album L.	Amaranthaceae	2000	4000	CheAlb	Dicot	Herb
Chenopodium foliosum Asch.	Amaranthaceae	2600	3800	CheFol	Dicot	Herb

Chirita urticifolia Buch.-Ham. ex D. Don	Gesneriaceae	900	2300	ChiUrt	Dicot	Herb
Chloris virgata Sw.	Poaceae	2200	2900	ChlVir	Monocot	Herb
Chlorophytum nepalense (Lindl.) Baker	Asparagaceae	1400	2500	ChlNep	Monocot	Herb
Chrysopogon gryllus (L.) Trin.	Poaceae	800	2900	ChrGry	Monocot	Herb
Chrysosplenium alternifolium L.	Saxifragaceae	1900	2800	ChrAlt	Dicot	Herb
Chrysosplenium carnosum Hook. f. & Thomson	Saxifragaceae	3800	5500	ChrCar	Dicot	Herb
Cichorium intybus L.	Asteraceae	1500	2400	CicInt	Dicot	Herb
Cinnamomum glanduliferum (Wall.) Meisn.	Lauraceae	2100	2600	CinGla	Dicot	Tree
Circaea alpina L.	Onagraceae	3300	4100	CirAlp	Dicot	Herb
Circaea cordata Royle	Onagraceae	2600	3800	CirCor	Dicot	Herb
Cirsium falconeri (Hook. f.) Petr.	Asteraceae	3000	4300	CirFal	Dicot	Herb
Cirsium wallichii DC.	Asteraceae	1400	3500	CirWal	Dicot	Herb
Cissampelos pareira L.	Menispermaceae	150	2200	CisPar	Dicot	Climber
Clematis buchananiana DC.	Ranunculaceae	1800	3300	CleBuc	Dicot	Climber
Clematis montana Buch.-Ham. ex DC.	Ranunculaceae	1600	4000	CleMon	Dicot	Climber
Clematis tibetana Kuntze	Ranunculaceae	1700	4000	CleTib	Dicot	Climber
Clerodendrum chinense (Osbeck) Mabb.	Lamiaceae	200	2000	CleChi	Dicot	Climber
Clinopodium nepalense (Kitam. & Murata) Bräuchler & Heubl	Lamiaceae	1900	3600	CliNep	Dicot	Herb
Clinopodium umbrosum (M. Bieb.) C. Koch	Lamiaceae	2700	3000	CliUmb	Dicot	Herb
Clintonia udensis Trautv. & C.A. Mey.	Asparagaceae	3200	4000	CliUde	Monocot	Herb
Coccinia grandis (L.) Voigt	Cucurbitaceae	200	900	CocGra	Dicot	Climber
Codonopsis affinis Hook. f. & Thomson	Campanulaceae	2100	2800	CodAff	Monocot	Herb
Coelogyne cristata Lindl.	Orchidaceae	1000	2000	CoeCri	Dicot	Shrub
Colocasia esculenta (L.) Schott	Araceae	300	1200	ColEsc	Monocot	Herb
Colquhounia coccinea Wall.	Lamiaceae	1200	4200	ColCoc	Monocot	Herb
Commelina maculata Edgew.	Commelinaceae	1600	3000	ComMac	Dicot	Herb
Conyza canadensis (L.) Cronquist	Asteraceae	450	2500	ConCan	Dicot	Herb

Corallodiscus lanuginosus (Wall. ex DC.) B.L. Burtt	Gesneriaceae	1000	3400	CorLan	Dicot	Herb
Coriandrum sativum L.	Apiaceae	2700	3000	CorSat	Dicot	Herb
Coriaria nepalensis Wall.	Coriariaceae	1200	2400	CorNep	Dicot	Shrub
Coriaria terminalis Hemsl.	Coriariaceae	2700	3600	CorTer	Dicot	Shrub
Cornus capitata Wall.	Cornaceae	2100	3400	CorCap	Dicot	Herb
Cornus macrophylla Wall.	Cornaceae	1200	3000	CorMac	Dicot	Tree
Cortia depressa (D. Don) C. Norman	Apiaceae	3600	4900	CorDep	Dicot	Herb
Corydalis casimiriana Duthie & Prain ex Prain	Papaveraceae	2700	4500	CorCas	Dicot	Herb
Corydalis chaerophylla DC.	Papaveraceae	2100	4200	CorCha	Dicot	Herb
Corydalis govaniana Wall.	Papaveraceae	3000	4800	CorGov	Dicot	Herb
Corydalis juncea Wall.	Papaveraceae	2500	4000	CorJun	Dicot	Herb
Cotoneaster acuminatus Lindl.	Rosaceae	2500	3700	CotAcu	Dicot	Shrub
Cotoneaster affinis Lindl.	Rosaceae	2200	2800	CotAff	Dicot	Shrub
Cotoneaster frigidus Wall. ex Lindl.	Rosaceae	2200	3400	CotFri	Dicot	Shrub
Cotoneaster microphyllus var. *thymifolius* (Baker) Koehne	Rosaceae	1800	3500	CotMiv	Dicot	Shrub
Cotoneaster microphyllus Wall. ex Lindl.	Rosaceae	2000	5400	CotMic	Dicot	Shrub
Cotoneaster verruculosus Diels	Rosaceae	3000	3400	CotVer	Dicot	Shrub
Cousinia thomsonii C. B. Clarke	Asteraceae	3500	4000	CouTho	Dicot	Herb
Crassocephalum crepidioides (Benth.) S. Moore	Asteraceae	400	1900	CraCre	Dicot	Herb
Crawfurdia angustata C. B. Clarke	Gentianaceae	1800	3900	CraAng	Dicot	Climber
Crawfurdia speciosa C. B. Clarke	Gentianaceae	2600	2700	CraSpe	Dicot	Climber
Cremanthodium hookeri C. B. Clarke	Asteraceae	3800	4300	CreHoo	Dicot	Herb
Cremanthodium oblongatum C. B. Clarke	Asteraceae	2900	5000	CreObl	Dicot	Herb
Crepis flexuosa (Ledeb.) Benth. ex C. B. Clarke	Asteraceae	1500	2600	CreFle	Dicot	Herb
Crotalaria kanaii H. Ohashi	Fabaceae	2100	2900	CroKan	Dicot	Shrub
Crucihimalaya himalaica (Edgew.) Al-Shehbaz, O'Kane & R.A. Price	Brassicaceae	3000	3800	CruHim	Dicot	Herb
Cucurbita pepo L.	Cucurbitaceae	2200	2600	CucPep	Dicot	Climber
Cuscuta europaea L.	Convolvullaceae	2700	4000	CusEur	Dicot	Climber

Cuscuta reflexa Roxb.	Convolvullaceae	1100	3100	CusRef	Dicot	Climber
Cyananthus incanus Hook.f. & Thomson	Campanulaceae	2100	4500	CyaInc	Dicot	Herb
Cyananthus lobatus Wall. ex Benth.	Campanulaceae	3300	4700	CyaLob	Dicot	Herb
Cyanotis vaga (Lour.) Schult. & Schult.f.	Commelinaceae	800	2700	CyaVag	Dicot	Herb
Cyathula capitata Moq.	Amaranthaceae	1300	2900	CyaCap	Dicot	Herb
Cymbidium hookerianum Rchb. F.	Orchidaceae	2000	2500	CymHoo	Monocot	Herb
Cymbopogon stracheyi (Hook. f.) Raizada & S. K. Jain	Poaceae	900	3300	CymStr	Monocot	Herb
Cynanchum auriculatum Royle ex Wight	Apocynaceae	2000	3700	CynAur	Dicot	Climber
Cynodon dactylon (L.) Pers.	Poaceae	100	3000	CynDac	Monocot	Herb
Cynoglossum wallichii var. *glochidiatum* (Wall. ex Benth.) Kazmi	Boraginaceae	1500	4000	CynWal	Dicot	Herb
Cyperus squarrosus L.	Cyperaceae	10	3000	CypSqu	Monocot	Herb
Cypripedium himalaicum Rolfe	Orchidaceae	3000	4800	CypHim	Monocot	Herb
Cyrtomium species (Fern)	Dryopteridaceae	2200	3000	CyrSpe	Pteridophyte	Herb
Dactylis glomerata L.	Poaceae	3200	3700	DacGlo	Monocot	Herb
Dactylorhiza hatagirea (D. Don) Soo	Orchidaceae	2800	3960	DacHat	Monocot	Herb
Dahlia pinnata Cav	Asteraceae	2200	2600	DahPin	Dicot	Herb
Danthonia cumminsii Hook. f.	Poaceae	2200	4100	DanCum	Monocot	Herb
Daphne bholua Buch.-Ham. ex D. Don	Thymelaeaceae	2100	3100	DapBho	Dicot	Shrub
Daucus carota L.	Apiaceae	2	3400	DauCar	Dicot	Herb
Debregeasia saeneb (Forssk.) Hepper & J.R.I. Wood	Urticaceae	1500	2400	DebSae	Dicot	Tree
Delphinium himalayae Munz	Ranunculaceae	3000	4500	DelHim	Dicot	Herb
Delphinium incisum (Hook.f. & Thomson) Wall. ex Munz	Ranunculaceae	2200	3800	DelInc	Dicot	Herb
Delphinium vestitum Wall. ex Royle	Ranunculaceae	2700	4700	DelVes	Dicot	Herb
Dendrobium eriiflorum Griff.	Orchidaceae	1500	2100	DenEri	Monocot	Herb
Dendrobium longicornu Lindl.	Orchidaceae	1600	2500	DenLon	Monocot	Herb
Desmodium elegans DC.	Fabaceae	1200	3000	DesEle	Dicot	Tree
Desmodium microphyllum (Thunb.) DC.	Fabaceae	1800	2600	DesMic	Dicot	Herb
Desmodium williamsii H. Ohashi	Fabaceae	2400	2600	DesWil	Dicot	Herb

Deutzia compacta Craib	Hydrangeaceae	2100	3400	DeuCom	Dicot	Shrub
Deutzia staminea R. Br. ex Wall.	Hydrangeaceae	1700	3200	DeuSta	Dicot	Shrub
Dichanthium caricosum (L.) A. Camus	Poaceae	2200	3800	DicCar	Monocot	Herb
Dichrocephala benthamii C. B. Clarke	Asteraceae	600	2500	DicBen	Dicot	Herb
Dichrocephala integrifolia (L. f.) Kuntze	Asteraceae	800	3000	DicInt	Dicot	Herb
Didymocarpus aromatica D. Don	Gesneriaceae	1600	3000	DidAro	Dicot	Herb
Didymocarpus oblongus Wall. ex D. Don	Gesneriaceae	800	3000	DidObl	Dicot	Herb
Dienia cylindrostachya Lindl.	Orchidaceae	2600	3500	DieCyl	Monocot	Herb
Digitalis purpurea L.	Plantaginaceae	750	3650	DigPur	Dicot	Herb
Digitaria cruciata (Nees) A. Camus	Poaceae	1300	3500	DigCru	Monocot	Herb
Dioscorea bulbifera L.	Dioscoreaceae	150	2100	DioBul	Monocot	Climber
Dioscorea deltoidea Wall. ex Griseb.	Dioscoreaceae	450	3100	DioDel	Monocot	Climber
Dioscorea melanophyma Prain & Burkill	Dioscoreaceae	2000	2500	DioMel	Monocot	Climber
Dipsacus inermis Wall.	Caprifoliaceae	1400	4100	DipIne	Dicot	Herb
Dodecadenia grandiflora Nees	Lauraceae	2300	2900	DodGra	Dicot	Tree
Drosera peltata Thunb.	Droseraceae	2500	3600	DroPel	Dicot	Herb
Drymaria cordata (L.) Willd. ex Roem. & Schult.	Caryophyllaceae	2200	4300	DryCor	Dicot	Herb
Drynaria mollis Bedd.	Polypodiaceae	2000	3000	DryMol	Pteridophyte	Herb
Dryopteris lepidopoda Hayata	Dryopteridaceae	1600	3000	DryLep	Pteridophyte	Herb
Dryopteris sublacera H. Christ	Dryopteridaceae	2200	2700	DrySub	Pteridophyte	Herb
Dryopteris wallichiana (Spreng.) Alston & Bonner	Dryopteridaceae	1700	3000	DryWal	Pteridophyte	Herb
Dubyaea hispida DC.	Asteraceae	2700	4300	DubHis	Dicot	Herb
Duchesnea indica (Andrews) Focke	Rosaceae	1000	2500	DucInd	Dicot	Herb
Dysphania ambrosioides (L.) Mosyakin & Clemants	Amaranthaceae	300	2600	DysAmb	Dicot	Herb
Edgeworthia gardneri (Wall.) Meisn.	Thymelaeaceae	2400	3500	EdgGar	Dicot	Shrub
Elaeagnus parvifolia Wall. ex Royle	Elaeagnaceae	1300	3000	ElaPar	Dicot	Shrub
Elatostema monandrum (Buch.-Ham. ex D. Don) H. Hara	Urticaceae	1200	3100	ElaMon	Dicot	Herb
Eleusine coracana (L.) Gaertn.	Poaceae	1100	2000	EleCor	Monocot	Herb

Elsholtzia ciliata (Thunb.) Hyl.	Lamiaceae	1500	3400	ElsCil	Dicot	Herb
Elsholtzia eriostachya (Benth.) Benth.	Lamiaceae	3000	4800	ElsEri	Dicot	Herb
Elsholtzia fruticosa (D. Don) Rehder	Lamiaceae	1800	4200	ElsFru	Dicot	Shrub
Elsholtzia strobilifera (Benth.) Benth.	Lamiaceae	1900	4800	ElsStr	Dicot	Herb
Ephedra gerardiana Wall. ex Stapf	Ephadraceae	2300	5200	EphGer	Gymnosperm	Shrub
Epilobium brevifolium D. Don	Onagraceae	1500	4000	EpiBre	Dicot	Herb
Epilobium latifolium L.	Onagraceae	2700	4850	EpiLat	Dicot	Herb
Epilobium species 3 yellow fl. 19797	Onagraceae	2200	NA	EpiSpe	Dicot	Herb
Epipactis helleborine (L.) Crantz	Orchidaceae	2400	3200	EpiHel	Monocot	Herb
Epipactis royleana Lindl.	Orchidaceae	1600	3500	EpiRoy	Monocot	Herb
Equisetum arvense L.	Equisetaceae	12	3650	EquArv	Pteridophyte	Herb
Eragrostis nigra Nees ex Steud.	Poaceae	900	3000	EraNig	Monocot	Herb
Erigeron bellidioides (Buch.-Ham. ex D. Don) Benth. ex C. B. Clarke	Asteraceae	1400	4300	EriBel	Dicot	Herb
Erigeron multiradiatus (Lindl. ex DC.) Benth. ex C. B. Clarke	Asteraceae	2600	4000	EriMul	Dicot	Herb
Eriobotrya dubia (Lindl.) Decne.	Rosaceae	1500	2000	EriDub	Dicot	Tree
Eriocaulon nepalense Prescott ex Bong.	Eriocaulaceae	1500	3000	EriNep	Monocot	Herb
Erysimum benthamii Monnet	Brassicaceae	2300	4100	EryBen	Dicot	Herb
Erythrina arborescens Roxb.	Fabaceae	1500	3000	EryArb	Dicot	Tree
Eulaliopsis binata (Retz.) C. E. Hubb.	Poaceae	150	2600	EulBin	Monocot	Herb
Euonymus fimbriatus Wall.	Celastraceae	2300	3600	EuoFim	Dicot	Tree
Euonymus lucidus D. Don	Celastraceae	1800	2600	EuoLuc	Dicot	Tree
Euphorbia sikkimensis Boiss.	Euphorbiaceae	2200	3400	EupSik	Dicot	Herb
Euphorbia species	Euphorbiaceae	2200	3400	EupSpe	Dicot	Herb
Euphorbiaceae 15020	Euphorbiaceae	2200	NA	Eup150	Dicot	Herb
Euphrasia himalayica Wettst.	Orobanchaceae	3200	4200	EupHim	Dicot	Herb
Euphrasia nepalensis Pugsley	Orobanchaceae	2800	4300	EupNep	Dicot	Herb
Eurya acuminata DC.	Pentaphylacaceae	1300	2500	EurAcu	Dicot	Tree
Eurya cerasifolia (D. Don) kobuski	Pentaphylacaceae	900	2300	EurCer	Dicot	Tree
Fagopyrum dibotrys (D. Don) H. Hara	Polygonaceae	1500	3400	FagDib	Dicot	Herb
Fagopyrum esculentum Moench	Polygonaceae	1800	4100	FagEsc	Dicot	Herb
Fagopyrum tataricum (L.) Gaertn.	Polygonaceae	1400	3900	FagTat	Dicot	Herb

Fern Cat ear	Pteridaceae	2200	3000	FerCat	Pteridophyte	Herb
Fern3 species	Pteridaceae	2200	3800	FerSpe	Pteridophyte	Herb
Festuca parvigluma Steud.	Poaceae	2400	3600	FesPar	Monocot	Herb
Ficus neriifolia Sm.	Moraceae	1400	2200	FicNer	Dicot	Tree
Ficus palmata Forssk.	Moraceae	600	2300	FicPal	Dicot	Tree
Ficus semicordata Buch.-Ham. ex Sm.	Moraceae	200	1700	FicSem	Dicot	Tree
Ficus species (liana 27937)	Moraceae	2200	2600	FicSpe	Dicot	Climber
Fimbristylis complanata (Retz.) Link	Cyperaceae	900	3100	FimCom	Monocot	Herb
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	100	1800	FimDic	Monocot	Herb
Fragaria daltoniana J. Gay	Rosaceae	2000	2800	FraDal	Dicot	Herb
Fragaria nilgerrensis Schltdl. ex J. Gay	Rosaceae	2800	4200	FraNil	Dicot	Herb
Fragaria nubicola (Hook. f.) Lindl. ex Lacaita	Rosaceae	1600	4000	FraNub	Dicot	Herb
Fritillaria cirrhosa D. Don	Liliaceae	3000	4600	FriCir	Monocot	Herb
Fumaria indica (Hausskn.) Pugsley	Papaveraceae	150	2400	FumInd	Dicot	Herb
Galinsoga parviflora Cav.	Asteraceae	850	3000	GalPar	Dicot	Herb
Galium acutum Edgew.	Rubiaceae	2000	4100	GalAcu	Dicot	Herb
Galium elegans Wall. ex Roxb.	Rubiaceae	1400	3000	GalEle	Dicot	Herb
Gastrochilus distichus (Lindl.) Kuntze	Orchidaceae	2200	2800	GasDis	Monocot	Herb
Gaultheria fragrantissima Wall.	Ericaceae	1200	2600	GauFra	Dicot	Shrub
Gaultheria hookeri C. B. Clarke	Ericaceae	3200	3500	GauHoo	Dicot	Shrub
Gaultheria nummularioides D. Don	Ericaceae	2100	4100	GauNum	Dicot	Shrub
Gaultheria trichophylla Royle	Ericaceae	2700	4500	GauTri	Dicot	Herb
Gentiana capitata Buch.-Ham. ex D. Don	Gentianaceae	1500	4500	GenCap	Dicot	Herb
Gentiana depressa D. Don	Gentianaceae	2900	4300	GenDep	Dicot	Herb
Gentiana huxleyi Kusn.	Gentianaceae	3000	4000	GenHux	Dicot	Herb
Gentiana ornata (D. Don) Wall. ex Griseb.	Gentianaceae	3400	5500	GenOrn	Dicot	Herb
Gentiana paludosa Munro ex Hook. f.	Gentianaceae	2200	3800	GenPal	Dicot	Herb
Gentiana prostrata var. *karelinii* (Griseb.) Kusn.	Gentianaceae	4000	4600	GenPro	Dicot	Herb
Gentiana sykesii H.Sm.	Gentianaceae	3000	3800	GenSyk	Dicot	Herb
Geranium donianum Sweet	Geraniceae	3200	4800	GerDon	Dicot	Herb

Geranium highly dissected	Geraniceae	2200	3000	GerHig	Dicot	Herb
Geranium nakaoanum H. Hara	Geraniceae	3500	4500	GerNak	Dicot	Herb
Geranium nepalense Sweet	Geraniceae	1500	4000	GerNep	Dicot	Herb
Geranium pratense L.	Geraniceae	2200	3500	GerPra	Dicot	Herb
Geranium procurrens Yeo	Geraniceae	2100	3500	GerPro	Dicot	Herb
Geranium wallichianum D. Don ex Sweet	Geraniceae	2100	4200	GerWal	Dicot	Herb
Gerbera maxima (D. Don) Beauverd	Asteraceae	1900	2900	GerMax	Dicot	Herb
Gerbera nivea (DC.) Sch. Bip.	Asteraceae	2800	4500	GerNiv	Dicot	Herb
Geum sikkimense Prain	Rosaceae	3000	4200	GeuSik	Dicot	Herb
Girardinia diversifolia (Link) Friis	Urticaceae	1700	3000	GirDiv	Dicot	Herb
Gladiolushybridus C. Morren	Iridaceae	2200	2600	GlaHyb	Monocot	Herb
Globba clarkei Baker	Zingiberaceae	600	1900	GloCla	Monocot	Herb
Glycine max (L.) Merr.	Fabaceae	1000	1700	GlyMax	Dicot	Herb
Gnaphalium affine D. Don	Asteraceae	600	3700	GnaAff	Dicot	Herb
Gonostegia hirta (Blume ex Hassk.) Miq.	Urticaceae	500	2400	GonHir	Dicot	Herb
Goodyera biflora (Lindl.) Hook. f.	Orchidaceae	2000	3800	GooBif	Monocot	Herb
Goodyera repens (L.) R. Br.	Orchidaceae	1000	4200	GooRep	Monocot	Herb
Gynura pseudo-china (L.) DC.	Asteraceae	1400	2600	GynPse	Dicot	Herb
Habenaria arietina Hook. f.	Orchidaceae	2000	2900	HabAri	Monocot	Herb
Habenaria diphylla (Nimmo) Dalzell	Orchidaceae	1250	4150	HabDip	Monocot	Herb
Habenaria pectinata D. Don	Orchidaceae	900	3200	HabPec	Monocot	Herb
Hackelia uncinata (Benth.) C. E. C. Fisch.	Boraginaceae	3800	4350	HacUnc	Dicot	Herb
Halerpestes tricuspis (Maxim.) Hand.-Mazz	Ranunculaceae	2600	4400	HalTri	Dicot	Herb
Hedera nepalensis K. Koch	Araliaceae	2000	3200	HedNep	Dicot	Climber
Hedychium coccineum Buch.-Ham. ex Sm.	Zingiberaceae	150	2000	HedCoc	Monocot	Herb
Hedychium spicatum Sm.	Zingiberaceae	2100	2400	HedSpi	Monocot	Herb
Hedysarum kumaonense Baker	Fabaceae	2400	4600	HedKum	Dicot	Herb
Helictotrichon junghuhnii (Buse) Henrard	Poaceae	2100	4400	HelJun	Monocot	Herb
Hemiphragma heterophyllum Wall.	Plantaginaceae	1800	3500	HemHet	Dicot	Herb
Heracleum lallii C. Norman	Apiaceae	3000	4200	HerLal	Dicot	Herb

Heracleum nepalense D. Don	Apiaceae	1800	3700	HerNep	Dicot	Herb
Herminium josephi Rchb. f.	Orchidaceae	2700	4100	HerJos	Monocot	Herb
Herminium lanceum (Thunb.) Vuijk	Orchidaceae	1500	3500	HerLan	Monocot	Herb
Hieracium umbellatum L.	Asteraceae	2200	2600	HieUmb	Dicot	Herb
Himalrandia tetrasperma (Wall. ex Roxb.) T. Yamaz.	Rubiaceae	1300	2600	HimTet	Dicot	Shrub
Hippophae tibetana Schltdl.	Elaeagnaceae	3800	4500	HipTib	Dicot	Shrub
Holboellia latifolia Wall.	Lardizabalaceae	1600	3000	HolLat	Dicot	Climber
Homalium napaulense (DC.) Benth.	Salicaceae	700	1800	HomNap	Dicot	Shrub
Hordeum vulgare L.	Poaceae	2200	3800	HorVul	Monocot	Herb
Huperzia hartwegiana (Spring) Trevis.	Lycopodiaceae	50	3600	HupHar	Pteridophyte	Herb
Huperzia phlegmaria (L.) Rothm.	Lycopodiaceae	50	2200	HupPhl	Pteridophyte	Herb
Huperzia serrata (Thunb.) Rothm.	Lycopodiaceae	2300	3000	HupSer	Pteridophyte	Herb
Hydrangea anomala D. Don	Hydrangeaceae	1900	2700	HydAno	Dicot	Tree
Hydrangea aspera D. Don	Hydrangeaceae	1600	2600	HydAsp	Dicot	Tree
Hydrangea heteromalla D. Don	Hydrangeaceae	2400	3300	HydHet	Dicot	Tree
Hydrocotyle himalaica P. K. Mukh.	Apiaceae	1500	2500	HydHim	Dicot	Herb
Hymenophyllum tenellum (Jacq.) Kuhn	Hymenophyllaceae	1600	3000	HymTen	Pteridophyte	Herb
Hyoscyamus niger L.	Solanaceae	2000	3400	HyoNig	Dicot	Herb
Hypericum choisyanum Wall. ex N. Robson	Hypericaceae	800	2100	HypCho	Dicot	Shrub
Hypericum elodeoides Choisy	Hypericaceae	1200	3300	HypElo	Dicot	Herb
Hypericum japonicum Thunb.	Hypericaceae	150	2600	HypJap	Dicot	Herb
Hypericum petiolulatum Hook. f. & Thomson ex Dyer	Hypericaceae	150	2600	HypPet	Dicot	Shrub
Hypericum podocarpoides N. Robson	Hypericaceae	800	2100	HypPod	Dicot	Shrub
Hypericum uralum Buch.-Ham. ex D. Don	Hypericaceae	1200	3600	HypUra	Dicot	Shrub
Hypoxis aurea Lour.	Hypoxidaceae	1700	2900	HypAur	Monocot	Herb
Ilex dipyrena Wall.	Aquifoliaceae	2500	3000	IleDip	Dicot	Tree
Ilex excelsa (Wall.) Voigt	Aquifoliaceae	600	2100	IleExc	Dicot	Tree
Impatiens amplexicaulis Edgew.	Balsaminaceae	2700	3700	ImpAmp	Dicot	Herb
Impatiens arguta Hook. f. & Thomson	Balsaminaceae	2100	2900	ImpArg	Dicot	Herb

Impatiens edgeworthii Hook. f.	Balsaminaceae	2600	3800	ImpEdg	Dicot	Herb
Impatiens racemosa DC.	Balsaminaceae	1300	3900	ImpRac	Dicot	Herb
Impatiens scabrida DC.	Balsaminaceae	1000	3600	ImpSca	Dicot	Herb
Impatiens urticifolia Wall.	Balsaminaceae	2700	3800	ImpUrt	Dicot	Herb
Imperata cylindrica (L.) Raeusch.	Poaceae	700	2400	ImpCyl	Monocot	Herb
Incarvillea arguta Royle	Bignoniaceae	1800	3500	IncArg	Dicot	Herb
Indigofera cassioides DC.	Fabaceae	300	1700	IndCas	Dicot	Shrub
Indigofera heterantha Brandis	Fabaceae	600	3100	IndHet	Dicot	Shrub
Inula cappa (Buch.-Ham. ex D. Don) DC.	Asteraceae	150	2500	InuCap	Dicot	Shrub
Inula hookeri C. B. Clarke	Asteraceae	2600	3700	InuHoo	Dicot	Shrub
Iris clarkei Baker ex Hook. f.	Iridaceae	3000	3500	IriCla	Monocot	Herb
Iris decora Wall.	Iridaceae	1800	4000	IriDec	Monocot	Herb
Iris kemaonensis D. Don ex Royle	Iridaceae	2500	4300	IriKem	Monocot	Herb
Isachne albens Trin.	Poaceae	1800	2300	IsaAlb	Monocot	Herb
Isodon coetsa (Buch.-Ham. ex D. Don) Kudô	Lamiaceae	600	3400	IsoCoe	Dicot	Herb
Isodon repens (Wall. ex Benth.) Murata	Lamiaceae	1900	3300	IsoRep	Dicot	Herb
Ixeris polycephala Cass	Asteraceae	750	1800	IxePol	Dicot	Herb
Jasminum dispermum Wall.	Oleaceae	1500	2300	JasDis	Dicot	Climber
Jasminum humile L.	Oleaceae	1500	3000	JasHum	Dicot	Shrub
Juncus benghalensis Kunth	Juncaceae	2200	3500	JunBen	Monocot	Herb
Juncus chrysocarpus Buchenau	Juncaceae	2700	5200	JunChr	Monocot	Herb
Juncus duthiei (C. B. Clarke) Noltie	Juncaceae	2600	3000	JunDut	Monocot	Herb
Juncus grisebachii Buchenau	Juncaceae	3000	NA	JunGri	Monocot	Herb
Juncus khasiensis Buchenau	Juncaceae	2000	3800	JunKha	Monocot	Herb
Juncus wallichianus Laharpe	Juncaceae	1700	2900	JunWal	Monocot	Herb
Juniperus communis L.	Cuprassaceae	2700	3200	JunCom	Gymnosperm	Tree
Juniperus indica Bertol.	Cuprassaceae	3700	4100	JunInd	Gymnosperm	Tree
Juniperus recurva Buch.-Ham. ex D. Don	Cuprassaceae	3300	4600	JunRec	Gymnosperm	Tree
Juniperus squamata Buch.-Ham. ex D. Don	Cuprassaceae	3300	4400	JunSqu	Gymnosperm	Shrub
Jurinea dolomiaea Boiss.	Asteraceae	3200	4300	JurDol	Dicot	Herb

Justicia diffusa Willd.	Acanthaceae	1000	2300	JusDif	Dicot	Herb
Kalanchoe integra (Medik.) Kuntze	Crassulaceae	NA	3800	KalInt	Dicot	Herb
Kobresia fragilis C. B. Clarke	Cyperaceae	3700	4900	KobFra	Monocot	Herb
Kobresia gammiei C. B. Clarke	Cyperaceae	2200	3800	KobGam	Monocot	Herb
Kyllinga brevifolia Rottb.	Cyperaceae	300	2400	KylBre	Monocot	Herb
Kyllinga odorata Vahl	Cyperaceae	1100	2000	KylOdo	Monocot	Herb
Lablab purpureus (L.) Sweet	Fabaceae	1000	2500	LabPur	Dicot	Climber
Lactuca brunoniana Wall. ex C. B. Clarke	Asteraceae	2200	3400	LacBru	Dicot	Herb
Lactuca sativa L.	Asteraceae	100	3300	LacSat	Dicot	Herb
Laggera alata (D. Don) Sch. Bip. ex Oliv.	Asteraceae	800	2500	LagAla	Dicot	Herb
Lamium amplexicaule L.	Lamiaceae	1200	3700	LamAmp	Dicot	Herb
Larix griffithii Hook.f.	Pinaceae	1400	3900	LarGri	Gymnosperm	Tree
Larix potaninii var. *himalaica* (W.C. Cheng & L.K. Fu) Farjon & Silba	Pinaceae	2400	3600	LarPot	Gymnosperm	Tree
Lathyrus laevigatus (Waldst. & Kit.) Gren.	Fabaceae	2100	3100	LatLae	Dicot	Shrub
Lecanthus peduncularis (Wall. ex Royle) Wedd.	Urticaceae	1200	3200	LecPed	Dicot	Herb
Legume species 2 21395	Fabaceae	2200	3400	LegSpe	Dicot	Herb
Leibnitzia nepalensis (Kunze) Kitam.	Asteraceae	2000	4100	LeiNep	Dicot	Herb
Leontopodium himalayanum DC.	Asteraceae	3000	5500	LeoHim	Dicot	Herb
Leontopodium jacotianum Beauverd	Asteraceae	2700	4900	LeoJac	Dicot	Herb
Lepisorus mehrae Fraser-Jenk.	Polypodiaceae	2600	2660	LepMeh	Pteridophyte	Herb
Leptodermis kumaonensis Parker	Rubiaceae	2500	3800	LepKum	Dicot	Herb
Leucas cephalotes (Roth) Spreng.	Lamiaceae	150	2400	LeuCep	Dicot	Herb
Leucosceptrum canum Sm.	Lamiaceae	1000	2800	LeuCan	Dicot	Tree
Leycesteria formosa Wall.	Caprifoliaceae	2000	3200	LeyFor	Dicot	Shrub
Ligularia fischeri (Ledeb.) Turcz.	Asteraceae	2200	4600	LigFis	Dicot	Herb
Lilium nepalense D. Don	Liliaceae	2300	3400	LilNep	Monocot	Herb
Lindera neesiana (Wall. ex Nees) Kurz	Lauraceae	1800	2700	LinNee	Dicot	Tree
Lindera obtusiloba var. *heterophylla* (Meisn.) H.B. Cui	Lauraceae	2300	2900	LinObt	Dicot	Tree
Lindera pulcherrima (Nees) Hook. f.	Lauraceae	1400	2700	LinPul	Dicot	Tree

Lithocarpus pachyphyllus (Kurz) Rehder	Fagaceae	2100	2800	LitPac	Dicot	Tree
Litsea cubeba (Lour.) Pers.	Lauraceae	1000	2700	LitCub	Dicot	Tree
Lomatogonium graciliflorum H. Sm.	Gentianaceae	3000	4500	LomGra	Dicot	Herb
Lomatogonium sikkimense (Burkill) H. Sm.	Gentianaceae	3000	5000	LomSik	Dicot	Herb
Lonicera acuminata Wall.	Caprifoliaceae	2100	3200	LonAcu	Dicot	Climber
Lonicera angustifolia Wall. ex DC.	Caprifoliaceae	2600	3800	LonAng	Dicot	Shrub
Lonicera glabrata Wall.	Caprifoliaceae	1900	2300	LonGla	Dicot	Shrub
Lonicera lanceolata Wall.	Caprifoliaceae	2700	3800	LonLan	Dicot	Shrub
Lotus corniculatus subsp. *corniculatus* L.	Fabaceae	3000	3700	LotCor	Dicot	Herb
Luzula multiflora (Retz.) Lej.	Juncaceae	3200	4000	LuzMul	Monocot	Herb
Lycopersicon esculentum Mill.	Solanaceae	250	1400	LycEsc	Dicot	Herb
Lycopodium japonicum Thunb.	Lycopodiaceae	2200	3400	LycJap	Pteridophyte	Herb
Lygodium japonicum (Thunb.) Sw.	Lygodiaceae	2200	3000	LygJap	Pteridophyte	Climber
Lyonia ovalifolia (Wall.) Drude	Ericaceae	1300	3300	LyoOva	Dicot	Tree
Lyonia villosa (Wall. ex C.B. Clarke) Hand.-Mazz.	Ericaceae	2700	3800	LyoVil	Dicot	Tree
Machilus duthiei King	Lauraceae	1000	2900	MacDut	Dicot	Tree
Maesa chisia Buch.-Ham. ex D. Don	Primulaceae	1200	2600	MaeChi	Dicot	Tree
Magnolia kisopa (Buch.-Ham. ex DC.) Figlar	Magnoliaceae	1400	2000	MagKis	Dicot	Tree
Maharanga emodi (Wall.) A. DC.	Boraginaceae	2200	4500	MahEmo	Dicot	Herb
Mahonia napaulensis DC.	Berberidaceae	2000	2900	MahNap	Dicot	Shrub
Maianthemum oleraceum (Baker) LaFrankie	Asparagaceae	2500	3400	MaiOle	Monocot	Herb
Maianthemum purpureum (Wall.) LaFrankie	Asparagaceae	2600	4200	MaiPur	Monocot	Herb
Malaxis muscifera (Lindl.) Kuntze	Orchidaceae	2600	4100	MalMus	Monocot	Herb
Malus pumila Mill.	Rosaceae	2450	3000	MalPum	Dicot	Tree
Malva verticillata L.	Malvaceae	2100	3000	MalVer	Dicot	Herb
Mariscus sumatrensis (Retz.) T. Koyama	Cyperaceae	100	2400	MarSum	Monocot	Herb
Mazus surculosus D. Don	Phrymaceae	900	3000	MazSur	Dicot	Herb
Meconopsis grandis Prain	Papaveraceae	3000	5200	MecGra	Dicot	Herb

Meconopsis paniculata (D. Don) Prain	Papaveraceae	3000	4400	MecPan	Dicot	Herb
Meconopsis simplicifolia (D. Don) Walp.	Papaveraceae	3300	5300	MecSim	Dicot	Herb
Meeboldia achilleifolia (DC.) P. K. Mukh. & Constance	Apiaceae	2200	3800	MeeAch	Dicot	Herb
Meizotropis buteiformis Voigt	Fabaceae	300	2000	MeiBut	Dicot	Tree
Melica scaberrima (Steud.) Hook.f.	Poaceae	3200	4000	MelSca	Monocot	Herb
Melissa axillaris (Benth.) Bakh. f.	Lamiaceae	1000	3600	MelAxi	Dicot	Herb
Mentha longifolia (L.) L.	Lamiaceae	1600	2700	MenLon	Dicot	Herb
Micromeria biflora (Buch.-Ham. ex D. Don) Benth.	Lamiaceae	2900	4000	MicBif	Dicot	Herb
Microstegium fasciculatum (L.) Henrard	Poaceae	1300	1500	MicFas	Monocot	Herb
Microstegium nudum (Trin.) A. Camus	Poaceae	1800	3200	MicNud	Monocot	Herb
Mimulus tenellus var. *nepalensis* (Benth.) Tsoong	Phrymaceae	NA	3000	MimTen	Dicot	Herb
Miscanthus nepalensis (Trin.) Hack.	Poaceae	1100	3000	MisNep	Monocot	Herb
Momordica balsamina L.	Cucurbitaceae	600	2200	MomBal	Dicot	Climber
Momordica dioica Roxb. ex Willd.	Cucurbitaceae	1100	2200	MomDio	Dicot	Climber
Morina longifolia Wall.	Caprifoliaceae	3000	4200	MorLon	Dicot	Herb
Morina nepalensis D. Don	Caprifoliaceae	3000	4500	MorNep	Dicot	Herb
Mucuna species	Fabaceae	2600	3000	MucSpe	Dicot	Climber
Mulgedium bracteatum (Hook.f. & Thomson ex C. B. Clarke) C. Shih	Asteraceae	2200	3600	MulBra	Dicot	Herb
Myriactis nepalensis Less.	Asteraceae	1400	3900	MyrNep	Dicot	Herb
Myrica esculenta Buch.-Ham. ex D. Don	Myricaceae	1200	2300	MyrEsc	Dicot	Tree
Myricaria rosea W.W. Sm.	Tamaricaceae	3300	4500	MyrRos	Dicot	Shrub
Nardostachys jatamansi (D. Don) DC.	Caprifoliaceae	3200	5000	NarJat	Dicot	Herb
Nasturtium officinale R.Br.	Brassicaceae	1400	2100	NasOff	Dicot	Herb
Neillia rubiflora D. Don	Rosaceae	2100	3200	NeiRub	Dicot	Shrub
Neolitsea pallens (D. Don) Momiy. & H. Hara	Lauraceae	2000	3000	NeoPal	Dicot	Tree
Neottia pinetorum (Lindl.) Szlach.	Orchidaceae	3000	3800	NeoPin	Monocot	Herb
Neottianthe secundiflora (Kraenzl.) Schltr.	Orchidaceae	2500	3200	NeoSec	Monocot	Herb
Nepeta laevigata (D. Don) Hand.-Mazz.	Lamiaceae	2000	5000	NepLae	Dicot	Herb

Nephrolepis cordifolia (L.) C. Presl	Davalliaceae	2000	3400	NepCor	Pteridophyte	Herb
Notholirion bulbuliferum (Lingelsh.) Stearn	Liliaceae	3200	4100	NotBul	Monocot	Herb
Notochaete hamosa Benth.	Lamiaceae	2600	3400	NotHam	Dicot	Herb
Oenothera glazioviana Micheli	Onagraceae	1200	2300	OenGla	Dicot	Herb
Onychium dulongjiangense W.M. Chu	Adiantaceae	2600	3000	OnyDul	Pteridophyte	Herb
Onychium japonicum (Thunb.) Kunze	Adiantaceae	2400	3500	OnyJap	Pteridophyte	Herb
Ophiopogon intermedius D. Don	Asparagaceae	1200	3000	OphInt	Monocot	Herb
Oplismenus compositus (L.) P. Beauv.	Poaceae	300	2800	OplCom	Monocot	Herb
Origanum vulgare L.	Lamiaceae	600	4000	OriVul	Dicot	Herb
Orobanche cernua Loefl.	Orobanchaceae	2400	2900	OroCer	Dicot	Herb
Osbeckia stellata Buch.-Ham. ex Ker Gawl.	Melastomataceae	1300	2600	OsbSte	Dicot	Shrub
Osmundastrum claytonianum (L.) Tagawa	Osmundaceae	2200	3800	OsmCla	Dicot	Herb
Osyris lanceolata Hochst. & Steud.	Santalaceae	1100	2600	OsyLan	Dicot	Shrub
Oxalis corniculata L.	Oxalidaceae	300	2900	OxaCor	Dicot	Herb
Oxygraphis endlicheri (Walp.) Bennet & Sumer Chandra	Ranunculaceae	2200	5000	OxyEnd	Dicot	Herb
Oxyria digyna (L.) Hill	Polygonaceae	2400	5000	OxyDig	Dicot	Herb
Oxyspora paniculata (D. Don) DC.	Melastomataceae	1300	2000	OxyPan	Dicot	Shrub
Oxytropis microphylla (Pall.) DC.	Fabaceae	2700	4100	OxyMic	Dicot	Herb
Panax pseudoginseng Wall.	Araliaceae	2700	4000	PanPse	Dicot	Herb
Panicum miliaceum L.	Poaceae	2200	2400	PanMil	Monocot	Herb
Paris polyphylla Sm.	Melanthiaceae	1800	3500	ParPol	Dicot	Herb
Parnassia nubicola Wall. ex Royle	Celastraceae	2900	4200	ParNub	Dicot	Herb
Parnassia tenella Hook. f. & Thomson	Celastraceae	3000	3500	ParTen	Dicot	Herb
Parnassia wightiana Wall. ex Wight & Arn.	Celastraceae	2700	3600	ParWig	Dicot	Herb
Parochetus communis Buch.-Ham. ex D. Don	Fabaceae	900	4000	ParCom	Dicot	Herb
Parthenocissus semicordata (Wall.) Planch.	Vitaceae	2100	3200	ParSem	Dicot	Climber
Pedicularis bicornuta Klotzsch	Orobanchaceae	3000	5200	PedBic	Dicot	Herb
Pedicularis bifida (Buch.-Ham. ex D. Don) Pennell	Orobanchaceae	1300	2300	PedBif	Dicot	Herb

Pedicularis gracilis Wall. ex Benth.	Orobanchaceae	2100	3300	PedGra	Dicot	Herb
Pedicularis megalantha D. Don	Orobanchaceae	3100	4300	PedMeg	Dicot	Herb
Pedicularis mollis Wall. ex Benth.	Orobanchaceae	3000	4500	PedMol	Dicot	Herb
Pedicularis rhinanthoides Schrenk ex Fisch. & C.A. Mey.	Orobanchaceae	3600	4900	PedRhi	Dicot	Herb
Peperomia tetraphylla (G. Forst.) Hook. & Arn.	Piperaceae	1000	2500	PepTet	Dicot	Herb
Peristylus fallax Lindl.	Orchidaceae	2700	3700	PerFal	Monocot	Herb
Persea odoratissima (Nees) Kosterm.	Lauraceae	1000	2000	PerOdo	Dicot	Tree
Persicaria amplexicaulis (D. Don) Ronse Decr.	Polygonaceae	2100	4800	PerAmp	Dicot	Herb
Persicaria capitata (Buch.-Ham. ex D. Don) H. Gross	Polygonaceae	600	2400	PerCap	Dicot	Herb
Phalaris arundinacea L.	Poaceae	2100	3000	PhaAru	Monocot	Herb
Phaseolus lunatus L.	Fabaceae	1000	2100	PhaLun	Dicot	Climber
Phaseolus vulgaris L.	Fabaceae	1000	1200	PhaVul	Dicot	Climber
Phlomis macrophylla Benth.	Lamiaceae	2300	4500	PhlMac	Dicot	Herb
Phlomis rotata Benth. ex Hook. f.	Lamiaceae	3800	6100	PhlRot	Dicot	Herb
Phyllanthus species	Euphorbiaceae	760	1700	PhySpe	Dicot	Herb
Picea smithiana (Wall.) Boiss.	Pinaceae	2300	3600	PicSmi	Gymnosperm	Tree
Pieris formosa (Wall.) D. Don	Ericaceae	2000	3300	PieFor	Dicot	Tree
Pilea anisophylla (Hook. f.) Wedd.	Urticaceae	900	2000	PilAni	Dicot	Herb
Pilea scripta (Buch.-Ham. ex D. Don) Wedd.	Urticaceae	1300	2500	PilScr	Dicot	Herb
Pilea umbrosa Blume	Urticaceae	1200	2500	PilUmb	Dicot	Herb
Pinus wallichiana A. B. Jacks.	Pinaceae	1800	3300	PinWal	Gymnosperm	Tree
Piptanthus nepalensis (Hook.) D. Don	Fabaceae	2000	3800	PipNep	Dicot	Shrub
Pisum sativum L.	Fabaceae	1200	4000	PisSat	Dicot	Herb
Plagiogyria pycnophylla (Kunze) Mett.	Plagiogyriaceae	2000	3000	PlaPyc	Pteridophyte	Herb
Plantago himalaica Pilg.	Plantaginaceae	2600	3800	PlaHim	Dicot	Herb
Plantago major L.	Plantaginaceae	900	4100	PlaMaj	Dicot	Herb
Pleione humilis (Sm.) D. Don	Orchidaceae	2400`	3000	PleHum	Monocot	Herb
Pleione praecox (Sm.) D. Don	Orchidaceae	2000	2400	PlePra	Monocot	Herb
Pleurospermum benthamii (Wall. ex DC.) C.B. Clarke	Apiaceae	3500	4000	PleBen	Dicot	Herb

Pleurospermum dentatum (DC.) C. B. Clarke	Apiaceae	3600	4500	PleDen	Dicot	Herb
Poa annua L.	Poaceae	2300	3500	PoaAnn	Monocot	Herb
Poa nepalensis (Wall. ex Griseb.) Duthie	Poaceae	2300	3000	PoaNep	Monocot	Herb
Pogonatherum paniceum (Lam.) Hack.	Poaceae	900	3200	PogPan	Monocot	Herb
Polygala sibirica L.	Polygalaceae	2700	3600	PolSib	Dicot	Herb
Polygonatum cirrhifolium (Wall.) Royle	Asparagaceae	1700	4600	PolCir	Monocot	Herb
Polygonatum griffithii Baker	Asparagaceae	2200	3800	PolGri	Monocot	Herb
Polygonatum hookeri Baker	Asparagaceae	2900	5000	PolHoo	Monocot	Herb
Polygonatum oppositifolium (Wall.) Royle	Asparagaceae	1800	3800	PolOpp	Monocot	Herb
Polygonatum verticillatum (L.) All	Asparagaceae	2400	4700	PolVer	Monocot	Herb
Polygonum delicatulum Meisn.	Polygonaceae	2700	4400	PolDel	Dicot	Herb
Polygonum filicaule Wall. ex Meisn.	Polygonaceae	2800	4900	PolFil	Dicot	Herb
Polygonum runcinatum Buch.-Ham. ex D. Don	Polygonaceae	1600	3800	PolRun	Dicot	Herb
Polypodiodes amoena (Wall. ex Mett.) Ching	Polypodiaceae	1300	3800	PolAmo	Pteridophyte	Herb
Polypodium species	Polypodiaceae	2200	3400	PolSpe	Pteridophyte	Herb
Polypogon fugax Nees ex Steud.	Poaceae	1500	3600	PolFug	Monocot	Herb
Polystichum squarrosum (D. Don) Fée	Dryopteridaceae	1300	3200	PolSqu	Pteridophyte	Herb
Polystichum yunnanense H. Christ	Dryopteridaceae	2200	3400	PolYun	Pteridophyte	Herb
Populus ciliata Wall. ex Royle	Salicaceae	2000	3200	PopCil	Dicot	Shrub
Populus jacquemontiana var. *glauca* Dode	Salicaceae	NA	3400	PopJac	Dicot	Shrub
Potentilla anserina L.	Rosaceae	3600	4600	PotAns	Dicot	Herb
Potentilla argyrophylla Wall. ex Lehm.	Rosaceae	3900	4600	PotArg	Dicot	Herb
Potentilla coriandrifolia D. Don	Rosaceae	3900	5600	PotCor	Dicot	Herb
Potentilla cuneata Wall. ex Lehm.	Rosaceae	2400	4900	PotCun	Dicot	Herb
Potentilla eriocarpa Wall. ex Lehm.	Rosaceae	3500	5050	PotEri	Dicot	Herb
Potentilla fruticosa L.	Rosaceae	2700	4300	PotFru	Dicot	Herb
Potentilla griffithii Hook. f.	Rosaceae	2500	3400	PotGri	Dicot	Herb

Potentilla lineata Trevir.	Rosaceae	1600	4800	PotLin	Dicot	Herb
Potentilla microphylla D. Don	Rosaceae	3700	5100	PotMic	Dicot	Herb
Potentilla nepalensis Hook.	Rosaceae	2300	2600	PotNep	Dicot	Herb
Potentilla saundersiana Royle	Rosaceae	3100	4900	PotSau	Dicot	Herb
Primula atrodentata W. W. Sm.	Primulaceae	3500	4900	PriAtr	Dicot	Herb
Primula denticulata Sm.	Primulaceae	1500	4900	PriDen	Dicot	Herb
Primula geraniifolia Hook. f.	Primulaceae	2800	4600	PriGer	Dicot	Herb
Primula glomerata Pax	Primulaceae	3100	5200	PriGlo	Dicot	Herb
Primula gracilipes Craib	Primulaceae	3200	4100	PriGra	Dicot	Herb
Primula primulina (Spreng.) H. Hara	Primulaceae	3400	5000	PriPri	Dicot	Herb
Primula sikkimensis Hook.	Primulaceae	2900	4800	PriSik	Dicot	Herb
Prinsepia utilis Royle	Rosaceae	1500	2900	PriUti	Dicot	Shrub
Prunella vulgaris L.	Lamiaceae	1200	3800	PruVul	Dicot	Herb
Prunus persica (L.) Batsch.	Rosaceae	2200	3300	PruPer	Dicot	Tree
Pseudocaryopteris bicolor (Roxb. ex Hardw.) P.D. Cantino	Lamiaceae	300	2100	PseBic	Dicot	Shrub
Pseudocaryopteris foetida (D. Don) P.D. Cantino	Lamiaceae	1200	2200	PseFoe	Dicot	Shrub
Pteridaceae Large	Pteridaceae	2200	3800	PteLar	Pteridophyte	Herb
Pteridaceaea 22614	Pteridaceae	NA	3000	Pte 22	Pteridophyte	Herb
Pteris cretica L.	Pteridaceae	2200	3000	PteCre	Pteridophyte	Herb
Pteris species 28060	Pteridaceae	2200	3800	PteSpe	Pteridophyte	Herb
Pycreus stramineus C. B. Clarke	Cyperaceae	200	2200	PycStr	Monocot	Herb
Pyracantha crenulata (D. Don) M. Roem.	Rosaceae	1200	2500	PyrCre	Dicot	Shrub
Pyrus pashia Buch.-Ham. ex D. Don	Rosaceae	750	2600	PyrPas	Dicot	Tree
Quercus floribunda Lindl. ex A. Camus	Fagaceae	2100	2700	QueFlo	Dicot	Tree
Quercus glauca Thunb.	Fagaceae	450	3100	QueGla	Dicot	Tree
Quercus lamellosa Sm.	Fagaceae	1600	2800	QueLam	Dicot	Tree
Quercus semecarpifolia Sm.	Fagaceae	1700	3800	QueSem	Dicot	Tree
Ranunculus adoxifolius Hand.-Mazz.	Ranunculaceae	3600	4300	RanAdo	Dicot	Herb
Ranunculus brotherusii Freyn	Ranunculaceae	3000	5000	RanBro	Dicot	Herb
Ranunculus diffusus DC.	Ranunculaceae	1500	4000	RanDif	Dicot	Herb

Ranunculus ficariifolius H. Lev. & Vaniot	Ranunculaceae	3200	3800	RanFic	Dicot	Herb
Ranunculus hirtellus Royle	Ranunculaceae	2800	5500	RanHir	Dicot	Herb
Ranunculus pulchellus C. A. Mey.	Ranunculaceae	3600	4900	RanPul	Dicot	Herb
Raphanus sativus L.	Brassicaceae	15	3870	RapSat	Dicot	Herb
Rhamnus purpurea Edgew.	Rhamnaceae	2100	2900	RhaPur	Dicot	Tree
Rheum acuminatum Hook. f. & Thomson ex Hook.	Polygonaceae	3300	4200	RheAcu	Dicot	Herb
Rheum australe D. Don	Polygonaceae	3200	4200	RheAus	Dicot	Herb
Rhodiola himalensis (D. Don) S. H. Fu	Crassulaceae	3700	4600	RhoHim	Dicot	Herb
Rhododendron anthopogon D. Don	Ericaceae	3300	5100	RhoAnt	Dicot	Shrub
Rhododendron arboreum Sm.	Ericaceae	1500	3300	RhoArb	Dicot	Tree
Rhododendron barbatum Wall. ex G. Don	Ericaceae	2700	3600	RhoBar	Dicot	Tree
Rhododendron campanulatum D. Don	Ericaceae	2800	4400	RhoCam	Dicot	Tree
Rhododendron campylocarpum Hook. f.	Ericaceae	3000	3900	RhoCay	Dicot	Tree
Rhododendron cinnabarinum Hook. f.	Ericaceae	3200	3800	RhoCin	Dicot	Tree
Rhododendron cowanianum Davidian	Ericaceae	3000	3900	RhoCow	Dicot	Tree
Rhododendron grande Wight	Ericaceae	1700	2900	RhoGra	Dicot	Tree
Rhododendron griffithianum Wight	Ericaceae	2100	2500	RhoGri	Dicot	Tree
Rhododendron hodgsonii Hook. f.	Ericaceae	3000	3800	RhoHod	Dicot	Tree
Rhododendron lepidotum Wall. ex G. Don	Ericaceae	2100	4700	RhoLep	Dicot	Shrub
Rhododendron purple	Ericaceae	NA	2600	RhoPur	Dicot	Tree
Rhododendron setosum D. Don	Ericaceae	3700	5600	RhoSet	Dicot	Shrub
Rhododendron thomsonii Hook. f.	Ericaceae	2900	3800	RhoTho	Dicot	Tree
Rhododendron triflorum Hook. f.	Ericaceae	2400	3300	RhoTri	Dicot	Tree
Rhododendron white	Ericaceae	NA	2500	RhoWhi	Dicot	Tree
Rhododendron wightii Hook. f.	Ericaceae	3300	4100	RhoWig	Dicot	Tree
Rhus punjabensis J.L. Stewart ex Brandis	Anacardiaceae	2100	2300	RhuPun	Dicot	Tree
Ribes griffithii Hook. f. & Thomson	Grossulariaceae	2900	4000	RibGri	Dicot	Shrub
Ribes himalense Royle ex Decne.	Grossulariaceae	2700	3500	RibHim	Dicot	Shrub

Ribes takare D. Don	Grossulariaceae	2200	3300	RibTak	Dicot	Shrub
Rosa brunonii Lindl.	Rosaceae	1500	2400	RosBru	Dicot	Shrub
Rosa macrophylla Lindl.	Rosaceae	2100	3800	RosMac	Dicot	Shrub
Rosa sericea Lindl.	Rosaceae	2200	4600	RosSer	Dicot	Shrub
Roscoea alpina Royle	Zingiberaceae	2400	3100	RosAlp	Monocot	Herb
Roscoea capitata Sm.	Zingiberaceae	1200	2600	RosCap	Monocot	Herb
Roscoea purpurea Sm.	Zingiberaceae	1800	2900	RosPur	Monocot	Herb
Rubia species	Rubiaceae	2200	3000	RubSpi	Dicot	Shrub
Rubus biflorus Buch.-Ham. ex Sm.	Rosaceae	2100	3300	RubBif	Dicot	Shrub
Rubus calycinus Wall. ex D. Don	Rosaceae	2200	2800	RubCal	Dicot	Shrub
Rubus ellipticus Sm.	Rosaceae	1700	2300	RubEll	Dicot	Shrub
Rubus nepalensis (Hook. f.) Kuntze	Rosaceae	2100	3200	RubNep	Dicot	Herb
Rubus niveus Thunb.	Rosaceae	2000	2900	RubNiv	Dicot	Shrub
Rubus paniculatus Sm.	Rosaceae	2100	2900	RubPan	Dicot	Shrub
Rubus species 5 lvs	Rosaceae	2200	3800	RubSpe	Dicot	Herb
Rubus splendidissimus H. Hara	Rosaceae	2400	3000	RubSpl	Dicot	Shrub
Rumex acetosa L.	Polygonaceae	2100	4100	RumAce	Dicot	Herb
Rumex nepalensis Spreng.	Polygonaceae	1200	4200	RumNep	Dicot	Herb
Saccharum rufipilum Steud.	Poaceae	2200	2600	SacRuf	Monocot	Herb
Sagina japonica (Sw.) Ohwi	Caryophyllaceae	1600	3400	SagJap	Dicot	Herb
Sagina saginoides (L.) H. Karst.	Caryophyllaceae	2000	3600	SagSag	Dicot	Herb
Salix bistyla Hand.-Mazz.	Salicaceae	2200	3800	SalBis	Dicot	Shrub
Salix calyculata Hook. f. ex Andersson	Salicaceae	3600	4500	SalCal	Dicot	Shrub
Salix denticulata Andersson	Salicaceae	2400	3000	SalDen	Dicot	Shrub
Salix hylematica C. K. Schneid.	Salicaceae	2600	4500	SalHyl	Dicot	Shrub
Salix myrtillacea Andersson	Salicaceae	2900	4000	SalMyr	Dicot	Shrub
Salix serpyllum Andersson	Salicaceae	3000	4700	SalSer	Dicot	Shrub
Salix sikkimensis Andersson	Salicaceae	3800	4400	SalSik	Dicot	Shrub
Salvia campanulata Wall. ex Benth.	Lamiaceae	2400	3800	SalCam	Dicot	Herb
Salvia hians Royle ex Benth.	Lamiaceae	2600	4100	SalHia	Dicot	Herb
Salvia mukerjeei Bennet & Raizada	Lamiaceae	1500	3000	SalMuk	Dicot	Herb
Sambucus adnata Wall. ex DC.	Adoxaceae	2000	3700	SamAdn	Dicot	Shrub

Sanguisorba diandra (Hook. f.) Nordborg	Rosaceae	3000	4400	SanDia	Dicot	Herb
Sanicula elata Buch.-Ham. ex D. Don	Apiaceae	1600	3500	SanEla	Dicot	Herb
Sarcococca pruniformis Lindl.	Buxaceae	1900	2300	SarPru	Dicot	Shrub
Satyrium nepalense D. Don	Orchidaceae	600	4600	SatNep	Monocot	Herb
Saurauia napaulensis DC.	Actinidiaceae	750	2100	SauNap	Dicot	Tree
Saussurea alpina (L.) DC.	Asteraceae	1800	2630	SauAlp	Dicot	Herb
Saussurea deltoidea (DC.) Sch. Bip.	Asteraceae	2600	3400	SauDel	Dicot	Herb
Saussurea fastuosa (Decne.) Sch. Bip.	Asteraceae	2900	3800	SauFas	Dicot	Herb
Saxifraga aspera L.	Saxifragaceae	2600	3800	SaxAsp	Dicot	Herb
Saxifraga brunonis Wall. ex Ser.	Saxifragaceae	2400	5600	SaxBru	Dicot	Herb
Saxifraga diversifolia Wall. ex Ser.	Saxifragaceae	2400	4800	SaxDiv	Dicot	Herb
Saxifraga filicaulis Wall. ex Ser.	Saxifragaceae	2700	3800	SaxFil	Dicot	Herb
Saxifraga hispidula D. Don	Saxifragaceae	3300	4500	SaxHis	Dicot	Herb
Saxifraga mucronulata Royle	Saxifragaceae	3800	4800	SaxMuc	Dicot	Herb
Saxifraga parnassifolia D. Don	Saxifragaceae	1900	4900	SaxPar	Dicot	Herb
Saxifraga stenophylla Royle	Saxifragaceae	4500	5700	SaxSte	Dicot	Herb
Saxifraga strigosa Wall. ex Ser.	Saxifragaceae	2100	4200	SaxStr	Dicot	Herb
Schisandra grandiflora (Wall.) Hook. f. & Thomson	Schisandraceae	2100	3300	SchGra	Dicot	Climber
Scleria terrestris (L.) Fassett	Cyperaceae	150	1500	SclTer	Monocot	Herb
Scorzonera bupleuroides D. Don	Asteraceae	2600	NA	ScoBup	Dicot	Herb
Scurrula elata (Edgew.) Danser	Loranthaceae	1600	2700	ScuEla	Dicot	Shrub
Scutellaria prostrata Jacq. ex Benth.	Lamiaceae	2400	4500	ScuPro	Dicot	Herb
Sedum majus (Hemsley) Migo	Crassulaceae	1300	4300	SedMaj	Dicot	Herb
Selaginella chrysocaulos (Hook. & Grev.) Spring	Selaginellaceae	1400	2700	SelChr	Pteridophyte	Herb
Selaginella species 2 upright	Selaginellaceae	2600	3800	SelSpe	Pteridophyte	Herb
Selaginella spp. 3	Selaginellaceae	3000	3400	SelSpp	Pteridophyte	Herb
Selinum wallichianum (DC.) Raizada & Saxena	Apiaceae	2700	4800	SelWal	Dicot	Herb
Selliguea oxyloba (Wall. ex Kunze) Fraser-Jenk.	Polypodiaceae	2600	NA	SelOxy	Pteridophyte	Herb
Senecio cappa Buch.-Ham. ex D. Don	Asteraceae	1300	2900	SenCap	Dicot	Shrub
Senecio kumaonensis Duthie ex C.	Asteraceae	2800	4500	SenKum	Dicot	Shrub

Jeffrey & Y.L. Chen						
Senecio laetus Edgew.	Asteraceae	1400	4000	SenLae	Dicot	Shrub
Senecio raphanifolius Wall. ex DC.	Asteraceae	2300	4000	SenRap	Dicot	Shrub
Senecio scandens Buch.-Ham. ex D. Don	Asteraceae	2100	2800	SenSca	Dicot	Shrub
Senecio species (white)	Asteraceae	2600	3400	SenSpe	Dicot	Shrub
Setaria italica (L.) P. Beauv.	Poaceae	1100	1800	SetIta	Monocot	Herb
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	900	2300	SetPum	Monocot	Herb
Setaria viridis (L.) P. Beauv.	Poaceae	2300	3800	SetVir	Monocot	Herb
Sibbaldia cuneata Hornem. ex Kuntze	Rosaceae	3400	4500	SibCun	Dicot	Herb
Sibbaldia purpurea Royle	Rosaceae	3900	5600	SibPur	Dicot	Herb
Sigesbeckia orientalis L.	Asteraceae	400	2700	SigOri	Dicot	Herb
Silene gonosperma (Rupr.) Bocquet	Caryophyllaceae	3000	5500	SilGon	Dicot	Herb
Silene indica Roxb. ex Otth	Caryophyllaceae	2000	4500	SilInd	Dicot	Herb
Smilax aspera L.	Smilacaceae	1200	2600	SmiAsp	Monocot	Climber
Smilax elegans Wall. ex Kunth	Smilacaceae	1800	3100	SmiEle	Monocot	Climber
Smilax myrtillus A.DC.	Smilacaceae	1800	2600	SmiMyr	Monocot	Climber
Solanum americanum Mill.	Solanaceae	900	2900	SolAme	Dicot	Herb
Solanum tuberosum L.	Solanaceae	2100	2600	SolTub	Dicot	Herb
Solanum virginianum L.	Solanaceae	300	900	SolVig	Dicot	Herb
Solidago virga-aurea L.	Asteraceae	2300	3400	SolVir	Dicot	Herb
Sonchus wightianus DC.	Asteraceae	600	2500	SonWig	Dicot	Herb
Sophora species	Fabaceae	2200	NA	SopSpe	Dicot	Shrub
Sorbaria tomentosa (Lindl.) Rehder	Rosaceae	2100	2900	SorTom	Dicot	Tree
Sorbus cuspidata (Spach) Hedl.	Rosaceae	2700	3700	SorCus	Dicot	Tree
Sorbus microphylla (Wall. ex Hook. f.) Wenz.	Rosaceae	3000	4500	SorMic	Dicot	Tree
Sorghum bicolor (L.) Moench	Poaceae	NA	3800	SorBic	Monocot	Herb
Spinacia oleracea L.	Amaranthaceae	2200	NA	SpiOle	Dicot	Herb
Spiraea arcuata Hook. f.	Rosaceae	3500	4900	SpiArc	Dicot	Shrub
Spiraea bella Sims	Rosaceae	1900	4200	SpiBel	Dicot	Shrub
Spiranthes sinensis (Pers.) Ames	Orchidaceae	100	4600	SpiSin	Monocot	Herb
Spirea species (2 24896)	Rosaceae	2200	3800	SpiSpe	Dicot	Shrub

Spongiocarpella nubigena (D. Don) Yakovlev	Fabaceae	3600	5200	SpoNub	Dicot	Herb
Sporobolus fertilis (Steud.) Clayton	Poaceae	1000	2400	SpoFer	Monocot	Herb
Sporobolus piliferus (Trin.) Kunth	Poaceae	900	2700	SpoPil	Monocot	Herb
Stachys melissifolia Benth.	Lamiaceae	2100	4000	StaMel	Dicot	Herb
Stellaria himalayensis Majumdar	Caryophyllaceae	2600	3400	SteHim	Dicot	Herb
Stellaria media (L.) Vill.	Caryophyllaceae	1800	2700	SteMed	Dicot	Herb
Stellaria monosperma Buch.-Ham. ex D. Don	Caryophyllaceae	2600	3200	SteMon	Dicot	Herb
Stellera chamaejasme L.	Thymelaeaceae	2700	4200	SteCha	Dicot	Herb
Stephania gracilenta Miers	Menispermaceae	2100	2400	SteGra	Dicot	Climber
Streptopus simplex D. Don	Asparagaceae	2400	4000	StrSim	Monocot	Herb
Strobilanthes urticifolia Wall. ex Kuntze	Acanthaceae	2200	3800	StrUrt	Dicot	Herb
Swertia angustifolia Buch.-Ham. ex D. Don	Gentianaceae	600	2600	SweAng	Dicot	Herb
Swertia arisanensis Hayata	Gentianaceae	2000	3600	SweAri	Dicot	Herb
Swertia chirayita (Roxb. ex Fleming) Karsten	Gentianaceae	1500	2500	SweChi	Dicot	Herb
Swertia nervosa (Wall. ex G. Don) C. B. Clarke	Gentianaceae	700	3000	SweNer	Dicot	Herb
Swertia paniculata Wall.	Gentianaceae	1800	4000	SwePan	Dicot	Herb
Swertia pedicellata Banerji	Gentianaceae	NA	3800	SwePed	Dicot	Herb
Symplocos dryophila C. B. Clarke	Symplocaceae	2000	2600	SymDry	Dicot	Tree
Symplocos glomerata King ex C. B. Clarke	Symplocaceae	2000	2500	SymGlo	Dicot	Tree
Symplocos lucida (Thunb.) Siebold & Zucc.	Symplocaceae	1500	3000	SymLuc	Dicot	Tree
Synotis alata (Wall. ex Wall.) C.Jeffrey & Y.L. Chen	Asteraceae	2500	3800	SynAla	Dicot	Herb
Synotis wallichii (DC.) C.Jeffrey & Y.L. Chen	Asteraceae	2400	3300	SynWal	Dicot	Herb
Syringa emodi Wall. ex Royle	Oleaceae	2500	3600	SyrEmo	Dicot	Tree
Tagetes patula L.	Asteraceae	900	2000	TagPat	Dicot	Herb
Tanacetum atkinsonii (C. B. Clarke) Kitam.	Asteraceae	2200	3800	TanAtk	Dicot	Herb
Tanacetum dolichophyllum (Kitam.) Kitam. ex Kitam. & Gould	Asteraceae	3000	4400	TanDol	Dicot	Herb

Taraxacum eriopodum (D. Don) DC.	Asteraceae	3300	4600	TarEri	Dicot	Herb
Taraxacum officinale Webb	Asteraceae	2600	3800	TarOff	Dicot	Herb
Taxus wallichiana Zucc.	Taxaceae	2300	3400	TaxWal	Gymnosperm	Tree
Tetrastigma serrulatum (Roxb.) Planch.	Vitaceae	500	2400	TetSer	Dicot	Climber
Tetrastigma species (hairy)	Vitaceae	2200	NA	TetSpe	Dicot	Climber
Thalictrum cultratum Wall.	Ranunculaceae	2400	4200	ThaCul	Dicot	Climber
Thalictrum dalzellii Hook.	Ranunculaceae	2600	NA	ThaDal	Dicot	Climber
Thalictrum foetidum L.	Ranunculaceae	2300	4700	ThaFoe	Dicot	Climber
Thalictrum foliolosum DC.	Ranunculaceae	1300	3400	ThaFol	Dicot	Climber
Thalictrum montanum K.F. Schimp. & Spenn.	Ranunculaceae	3400	3800	ThaMon	Dicot	Climber
Thalictrum reniforme Wall.	Ranunculaceae	2800	3300	ThaRen	Dicot	Climber
Thalictrum virgatum Hook. f. & Thomson	Ranunculaceae	2400	4500	ThaVir	Dicot	Herb
Thamnocalamus spathiflorus (Trin.) Munro	Poaceae	2500	3000	ThaSpa	Monocot	Herb
Thermopsis barbata Benth.	Fabaceae	2700	4600	TheBar	Dicot	Herb
Thermopsis lanceolata R. Br.	Fabaceae	3600	4300	TheLan	Dicot	Herb
Theropogon pallidus (Wall. ex Kunth) Maxim.	Asparagaceae	1800	2700	ThePal	Monocot	Herb
Thlaspi arvense L.	Brassicaceae	2100	4500	ThlArv	Dicot	Herb
Thymus linearis Benth.	Lamiaceae	2400	4500	ThyLin	Dicot	Herb
Tibetia himalaica (Baker) H.P. Tsui	Fabaceae	3300	4600	TibHim	Dicot	Herb
Tordyliopsis brunonis DC.	Apiaceae	3300	4600	TorBru	Dicot	Herb
Torilis japonica (Houtt.) DC.	Apiaceae	500	3000	TorJap	Dicot	Herb
Toxicodendron wallichii (Hook. F.) Kuntze	Anacardiaceae	300	2800	ToxWal	Dicot	Tree
Trevesia palmata (Roxb. ex Lindl.) Vis.	Araliaceae	250	2500	TrePal	Dicot	Tree
Tricholepis species	Asteraceae	2200	NA	TriSpe	Dicot	Herb
Trifolium repens L.	Fabaceae	1500	2500	TriRep	Dicot	Herb
Trigonella emodi Benth.	Fabaceae	1300	4900	TriEmo	Dicot	Herb
Trillium govanianum Wall. ex D. Don	Melanthiaceae	2700	4000	TriGov	Dicot	Herb
Triplostegia glandulifera Wall. ex DC.	Caprifoliaceae	1800	3800	TriGla	Dicot	Herb

Tripogon trifidus Munro ex Stapf	Poaceae	200	1800	TriTri	Monocot	Herb
Triticum aestivum L.	Poaceae	50	3650	TriAes	Monocot	Herb
Tsuga dumosa (D. Don) Eichler	Pinaceae	2100	3600	TsuDum	Gymnosperm	Tree
Typhonium diversifolium Wall. ex Schott	Araceae	2400	4300	TypDiv	Monocot	Herb
Ulmus wallichiana Planch.	Ulmaceae	2000	3000	UlmWal	Dicot	Tree
UN Asteraceae	Unidentified	2600	NA	UN co	Dicot	Herb
UN 39fern	Unidentified	2600	NA	UN 39f	Dicot	Herb
UN Lonicera like 24842/21947	Unidentified	2200	2600	UN Lon	Dicot	Herb
UN Shrub 18188	Unidentified	2600	NA	UN Shr	Dicot	Herb
UN Tree like Rhus	Unidentified	2200	NA	UN Tre	Dicot	Herb
Urtica dioica L.	Urticaceae	3000	4500	UrtDio	Dicot	Herb
Vaccinium vacciniaceum (Roxb.) Sleumer	Ericaceae	1600	2800	VacVac	Dicot	Shrub
Valeriana hardwickii Wall.	Caprifoliaceae	1200	4000	ValHar	Dicot	Herb
Valeriana jatamansi Jones	Caprifoliaceae	1500	3300	ValJat	Dicot	Herb
Verbascum thapsus L.	Scrophulariaceae	1800	4000	VerTha	Dicot	Herb
Veronica himalensis D. Don	Plantaginaceae	3000	5000	VerHim	Dicot	Herb
Viburnum cotinifolium D. Don	Adoxaceae	2100	3600	VibCot	Dicot	Shrub
Viburnum cylindricum Buch.-Ham. ex D. Don	Adoxaceae	1200	2500	VibCyl	Dicot	Shrub
Viburnum erubescens Wall. ex DC.	Adoxaceae	1500	3000	VibEru	Dicot	Shrub
Viburnum grandiflorum Wall. ex DC.	Adoxaceae	3000	3700	VibGra	Dicot	Shrub
Viburnum mullaha Buch.-Ham. ex D. Don	Adoxaceae	2500	4000	VibMul	Dicot	Shrub
Viburnum nervosum D. Don	Adoxaceae	2600	3500	VibNer	Dicot	Tree
Vicia bakeri Ali	Fabaceae	2700	3200	VicBak	Dicot	Herb
Vicia faba L.	Fabaceae	1350	3900	VicFab	Dicot	Herb
Vigna angularis (Willd.) Ohwi & Ohashi	Fabaceae	1500	2600	VigAng	Dicot	Climber
Vincetoxicum hirundinaria Medik.	Apocynaceae	2300	3600	VinHir	Dicot	Herb
Viola betonicifolia Sm.	Violaceae	1600	3900	VioBet	Dicot	Herb
Viola biflora L.	Violaceae	2100	4500	VioBif	Dicot	Herb
Viola canescens Wall.	Violaceae	150	2400	VioCan	Dicot	Herb

Viola pilosa Blume	Violaceae	1200	3000	VioPil	Dicot	Herb
Vitis species	Vitaceae	2200	3000	VitSpe	Dicot	Climber
Wikstroemia canescens Wall. ex Meisn.	Thymelaeaceae	1800	3200	WikCan	Dicot	Shrub
Woodfordia fruticosa (L.) Kurz	Lythraceae	200	1800	WooFru	Dicot	Shrub
Wulfeniopsis amherstiana (Benth.) D.Y. Hong	Plantaginaceae	1500	3000	WulAmh	Dicot	Herb
Youngia japonica (L.) DC.	Asteraceae	230	2900	YouJap	Dicot	Herb
Zanthoxylum armatum DC.	Rutaceae	1100	2500	ZanArm	Dicot	Tree
Zanthoxylum nepalense Babu	Rutaceae	2700	3100	ZanNep	Dicot	Tree
Zanthoxylum oxyphyllum Edgew.	Rutaceae	2100	2800	ZanOxy	Dicot	Tree
Zea mays L.	Poaceae	NA	3000	ZeaMay	Monocot	Herb

Annex III: Correlation Matrices of three sets of variables taken (nominal variables not included here)

(For details and full form of the abbreviation see Table 3.1.)

Bioclimatic Set

	BIO 1	BIO 2	BIO 3	BIO 4	BIO 5	BIO 6	BIO 7	BIO 8	BIO 9	BIO 10	BIO 11	BIO 12	BIO 13	BIO 14	BIO 15	BIO 16	BIO 17	BIO 18	BIO 19
BIO1																			
BIO2	-0.81																		
BIO3	-0.23	0.49																	
BIO4	-0.8	0.91	0.14																
BIO5	0.97	-0.67	-0.16	-0.68															
BIO6	0.99	-0.86	-0.23	-0.86	0.95														
BIO7	-0.84	0.97	0.28	0.97	-0.71	-0.89													
BIO8	1	-0.78	-0.24	-0.76	0.97	0.98	-0.81												
BIO9	1	-0.84	-0.22	-0.84	0.96	1	-0.87	0.99											
BIO10	1	-0.77	-0.24	-0.75	0.98	0.98	-0.8	1	0.99										
BIO11	1	-0.84	-0.23	-0.84	0.96	1	-0.87	0.99	1	0.99									
BIO12	0.75	-0.86	-0.44	-0.74	0.61	0.76	-0.84	0.76	0.79	0.74	0.77								
BIO13	0.74	-0.84	-0.47	-0.72	0.6	0.74	-0.81	0.74	0.77	0.72	0.75	0.99							
BIO14	0.38	-0.61	-0.06	-0.58	0.24	0.44	-0.64	0.38	0.44	0.36	0.42	0.62	0.54						
BIO15	0.36	-0.38	-0.33	-0.32	0.28	0.32	-0.33	0.37	0.36	0.34	0.36	0.61	0.68	-0.08					
BIO16	0.74	-0.84	-0.46	-0.72	0.6	0.74	-0.81	0.75	0.77	0.73	0.76	0.99	1	0.54	0.68				
BIO17	0.43	-0.67	-0.16	-0.6	0.3	0.49	-0.69	0.42	0.48	0.41	0.46	0.63	0.54	0.94	-0.17	0.54			
BIO18	0.74	-0.84	-0.46	-0.72	0.61	0.74	-0.81	0.75	0.77	0.73	0.76	0.99	1	0.54	0.68	1	0.54		
BIO19	0.35	-0.64	-0.15	-0.59	0.22	0.43	-0.65	0.34	0.41	0.33	0.39	0.54	0.46	0.93	-0.24	0.46	0.98	0.46	

Microclimatic Set

	maxT.H	MeanT.H	minT.H	maxT.iB	MeanT.iB	minT.iB	maxH.H	meanH.H	minH.H
maxT.H									
MeanT.H	0.84								
minT.H	0.7	0.95							
maxT.iB	0.64	0.68	0.63						
MeanT.iB	0.64	0.74	0.7	0.98					
minT.iB	0.62	0.76	0.75	0.93	0.98				
maxH.H	0.1	0.31	0.37	0.2	0.26	0.3			
meanH.H	0.02	0.33	0.42	0.17	0.25	0.31	0.94		
minH.H	-0.14	0.28	0.41	0.1	0.19	0.25	0.78	0.93	

Topographical Set

	BIOALT	REG	VAL	ALTL	ALTD	ALTG	LAT	LONG	ASP	SLOP
BIOALT										
REG	-0.19									
VAL	0.04	0.5								
ALTL	0.8	0.01	0							
ALTD	0.8	0.01	0	1						
ALTG	0.82	0.07	0.07	0.98	0.98					
LAT	0.33	-0.87	-0.53	0.11	0.11	0.06				
LONG	-0.17	0.99	0.53	0.01	0.01	0.08	-0.91			
ASP	-0.06	-0.06	-0.08	-0.01	-0.01	-0.01	0.09	-0.08		
SLOP	-0.07	0.05	0.07	-0.05	-0.05	-0.04	-0.06	0.05	0.01	

Annex IV : Publications

Published

1. Tamang, R., **Rai, S. K.,** Scheidegger, C., & Shrestha, K. K. (2018). Species richness from cropland to forest in Ghunsa valley, eastern Himalaya. *International Journal of Indigenous Herbs and Drugs.* 3(2):1-4.

2. **Rai, S. K.,** Tamang, R., Gajurel, J. P., Devkota, S., Shrestha, K. K., Nobis, M. P., & Scheidegger, C. (2017). Environmental covariates of species richness and composition of vascular plants of Olangchung Gola and Ghunsa valleys of eastern Nepal. *Asian Journal of Conservation Biology.* 6(2): 94-104.

3. **Rai, S. K.,** Sharma, S., Shrestha, K. K., Gajurel, J. P., Devkota, D., Nobis, M. P. & Scheidegger, C. (2016). Effects of the environment on species richness and composition of vascular plants in Manaslu Conservation Area and Sagarmatha region of Nepal Himalaya. *Banko Janakari.*26(1):1-16

4. **Rai, S. K.,** Gajurel, J. P., Shrestha, K. K., Scheidegger, C., & Shakya, L. R. (2014). *Risleya (Orchidaceae),* a new Record for Flora of Nepal. *The Journal of Japanese Botany,* Vol. 89(6): 409-412.

5. **Rai, S. K.,** Gajurel, J., Shrestha, K. K., Scheidegger, C., & Shakya, L. R. (2013). *Peristylus manii* (H.G. Reichenbach) Mukerjee (Orchidaceae) – a new record for Nepal. *Pleione*, 7, 250-252.

6. Gajurel, J., **Rai, S. K.,** Shrestha, K. K., Scheidegger, C., & Shakya, L.R. (2013). *Bulbophyllum griffithii* (Lindley) Reichenbach f. and *Platanthera cumminsiana* (King & Pantling) J. Renz – two new records of orchids from Nepal. *Pleione*, 7, 253-257.

Manuscript under preparation

a. **Rai, S. K.,** Gajurel, J. P., Devkota, S., Shrestha, K. K., Scheidegger, C., & Nobis, M. (....). *Distribution modelling of vascular plants of Nepal Himalaya: Present and Future scenarios under climate change*.

b. **Rai, S. K.,** Chongbang, T. B., Gajurel, J. P., Devkota, S., Shrestha, K. K., Nobis, M., & Scheidegger, C. (....). *Light indicators of different land use types and the species distribution pattern according to the energy input*.

c. **Rai, S. K.,** Gajurel, J. P., Devkota, S., Shrestha, K. K., Scheidegger, C., & Nobis, M. (....). *Data recording, variable selection, and transformation for the Ecological Modelling studies in Nepal Himalaya* (A methodological paper).

d. **Rai, S. K.,** Gajurel, J. P., Devkota, S., Shrestha, K. K., Nobis, M., & Scheidegger, C. (....). *Effect of environmental variables and land use types on the species richness and composition in Nepal Himalaya (Synthesis paper)*

Conferences/Seminar/Workshops

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2. Rai, S. K., & Shrestha, K. K. (2016). *Traditional Use and Management Practice of Tree Species in Manaslu Conservation Area, Nepal* in the World Wood Day 2016, 21-26 March, Kathmandu, Nepal.

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Species richness from cropland to forest in Ghunsa valley, eastern Himalaya

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Abstract

Objective: Species richness is the number of total species present in an ecological community which is widely used to measure biodiversity. The main aim of this study was to study variation in species richness along land use types, from cropland to forest.

Methods: This study was carried out in Ghunsa valley, Kanchenjungha Conservation Area of Eastern Himalaya during 2012. Four land use types, namely cropland, meadow, exploited forest and natural forest were selected at each of five elevational bands starting from 2,200 m above sea level at Sekathum to 3,800 m asl at Rambuk kharka, Taplejung. A total of 70 transects, having 25 m × 2.5 m size, were laid and the vascular plant species found within each transect were recorded twice.

Results: Altogether 360 species of vascular plants belonging to 257 genera and 95 families have been documented. Among them, 25 species belongs to pteridophytes, 7 species of gymnosperms and 328 species of angiosperms. One-way ANOVA showed the total species richness (including all groups) was significantly different ($F_{3, 66}$= 7.494, p=0.000) in different land use types.

Conclusion: Species richness was significantly different in different land use types. Species richness was found highest in exploited forest.

Keywords: ANOVA, Biodiversity, Kangchenjungha, Land use types

Introduction

Species richness is the number of total species present in an ecological community. It is the widely used measure of biodiversity, which is assumed to be a simple and easily interpretable indicator of biological diversity. Species richness varies along elevation, latitude as well as change in land use types [1]. Among them light, temperature, rainfall, canopy cover, snow cover and topography are major factors. Human disturbance is the main cause of change in land use type, which severely threatens the biodiversity. People harvest plants for timber, fodder, firewood, and so on. At high level of disturbance, due to human impacts like deforestation, many species are at risk of extinction. Disturbance favors the growth of herbaceous species rather than woody species [2]. Herbaceous species was found higher in openland than forest whereas tree species found more in undisturbed natural forest. The main objective of this study was to study variation in species richness along land use types, from cropland to forest.

Materials and methods

The study was carried in Ghunsa valley, Kanchenjunga Conservation Area (27°24'- 27°57' N latitude and 87°39'-88°12' E longitude) in eastern Himalaya during 2012. This area falls on the temperate and subalpine zone. KCA harbors 844 species of plants, 279 species of birds, 83 species of insects and 23 species of mammals [3].

Study design

Study sites were selected at five different elevational bands from Sekathum (2,200 m asl) to Rambukkharka (3,800 m asl) at an interval of 400 m. At each elevational band, four different land use types (cropland, meadow, exploited forest and natural forest) were selected. Two transects having size 25 m ×2.5 m were laid on each land use type at an interval of 50 m horizontal distance by employing quasi-experimental sampling design [4]. The study area was visited twice in the year of 2012, to collect data from the field. One-way analysis of variance (ANOVA) and Kruskal Wallis test were used to significant test.

Results

A total of 360 species belongs to 257 genera and 95 families were recorded from the study area. Among them, 25 species were pteridophytes, 7 were gymnosperms and 328 species were angiosperms. Herbs with 242 species dominate over woody species, which comprise 118 species (shrub 82, tree 36 species). One-way ANOVA showed the total species richness (including all groups) was significantly different ($F_{3, 66}$=7.494, p=0.000) in different land use types. Tukey HSD test showed that the species richness in cropland was

Tamang R, Rai SK, Scheidegger C, Shrestha KK. Species richness from cropland to forest in Ghunsa valley, eastern Himalaya. Int J Ind Herbs Drugs 2018; 3(2): 1-4.

significantly different from rest of the land use types (meadow, exploited forest and natural forest) (Figure 1). But the species richness is similar among meadow, exploited and natural forest. Similarly, among the selected four land use types, exploited forest had highest α-diversity (i.e. mean±s.d., 33.72 ±11.034 species per transect) followed by meadow (31.67±10.318), natural forest (29.35±8.713) and least species in cropland (18.43±7.988).

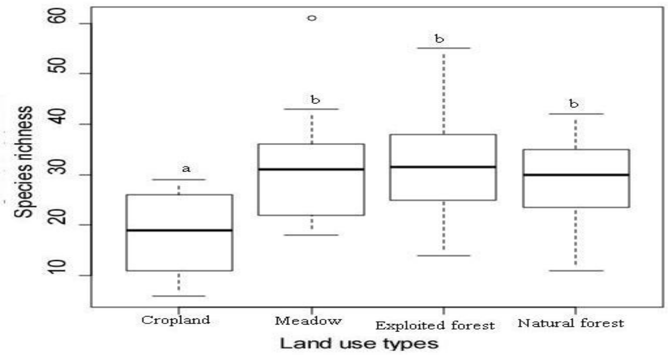

Figure 1: Boxplot showing relationship between total species richness and land use types. The boxes sharing same letters on top are not significantly different (Tukey HSD test)

Similarly, the Kruskal-Wallis test showed the species richness for all functional groups, pteridophytes (p=000), gymnosperms (p=0.033) and angiosperms (p=005) and life forms, herbs (p=0.023), shrubs (p= 0.000) and trees (0.000) also found significantly different among selected four land use types. Among the three functional groups, pteridophytes richness was found maximum (3.8±2.238) in natural forest (Figure 2). Similarly, gymnosperms and angiosperms were found maximum in exploited forest with value 1.22±1.478 and 29.39±10.393 respectively (Figure 2).

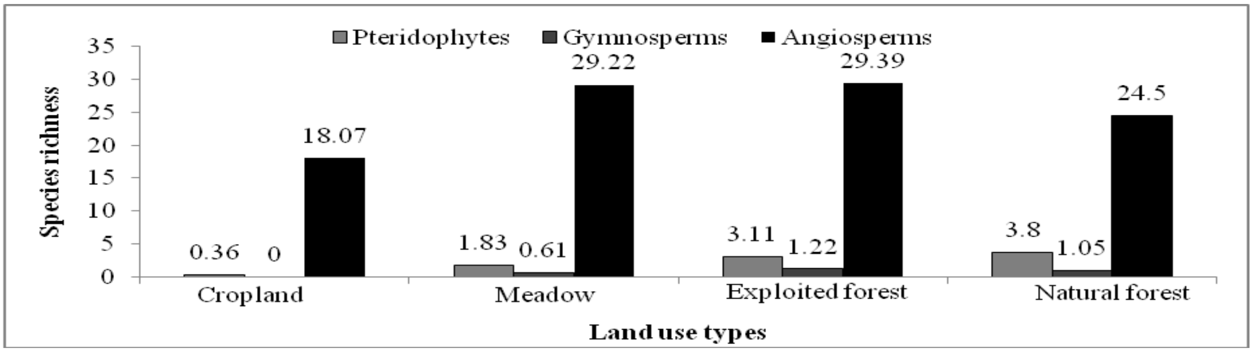

Figure 2: Relationship of mean species richness for different functional groups with land use types

Similarly, the species richness among different life forms, the herbaceous species richness was found maximum (25.72±7.85) at meadow (Figure 3), whereas shrub species (8.78±2.605) at exploited forest and tree species (3.75±2.918) found maximum at natural forest (Figure 3).

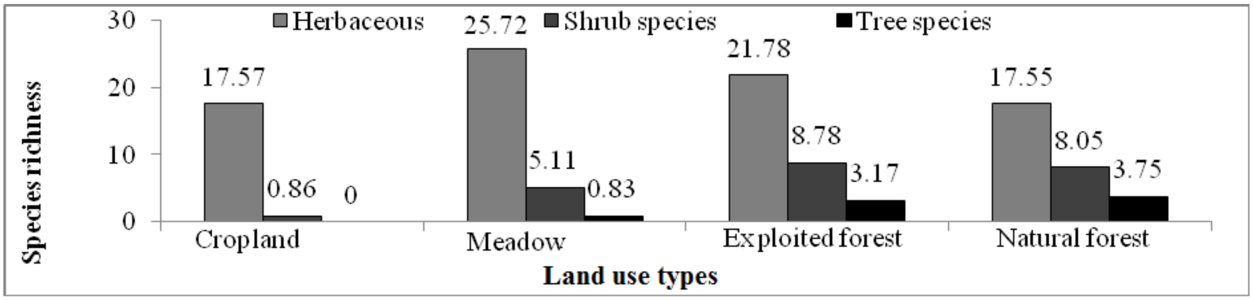

Figure 3: Relationship of mean species richness for different life forms with land use types

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Discussion

Total species richness found to be highest in exploited forest also revealed the same result of Sharma (2012). In the natural forest only the competitive dominant species can survive but in exploited forest, light demanding as well as shady plants can coexist there. Whereas in the meadows due to the grazing of domestic animals, the species richness found lower than exploited forest [5]. While due to the presence of grasses as well as shrubs in medows, speceis richness was found higher than in natural forest and cropland. On the other hand due to the regular use, cleaned up vegetation and other anthropogenic disturbances the cropland has lowest species richness.

Pteridophytes species richness found highest in natural forest because they are shady plant and grow on moist places. Natural forest has high canopy cover due to presence of old as well as big trees [5] and moisture is positively correlated with canopy cover. So, due to high moisture, pteridophytes species was found highest in natural forest than other remaining land uses. Tree species richness decreased as the level of disturbance increased from natural forest to cropland [6]. On decreasing tree species, epiphytic pteridophytic species also decreases. The maximum gymnosperms species richness was found in exploited forest in mean comparison of overall data. But among the 7 total species of gymnosperms, namely *Abies spectabilis, Ephedra gerardiana, Juniperus communis, Juniperus indica, Juniperus recurva, Juniperus squamata* and *Larix griffithiana* found in this study, 6 species were found in natural forest except *Ephedra gerardiana.* Similarly, exploited forest and medow comprises 5 species excluding *Juniperus recurva, Juniperus squamata*. The higher number of gymnosperms found in natural forest.

Angiosperms species richness follows the usual pattern of total species richness along the different land use types. The angiospermic species richness nearly equal in exploited forest and meadow. In medow, herbaceous as well as shrub species found high due to high canopy openness [1]. On the other hand species richness low in natural forest may be due to presence of old trees with high canopy cover and lowest in cropland due to regular cleaned vegetation [6].

In this study, herbaceous species richness was found to be highest in meadow. It may be due to high canopy openness than forest. Herb species richness was higher in open canopy than close canopy. But due to the regular cleaned vegetation by digging, ploughing and other anthropogenic disturbances the cropland has lower species richness than meadow [6].

Shrub species richness was found higher in exploited forest. It also followed the usual result of total species richness because shrubs are understory vegetation of forest. The shrub species was found lower in undisturbed natural forest as well as highly disturbed land use types because shrub species found higher in moderate canopy [8]. In the meadow spineless plants browse by regular grazing of animals and mostly spiny species remains there. So, shrub species was found to be lower in meadow. The tree species richness was found higher in natural forest and highest tree species richness found in the primary forest of Central Sulawesi, Indonesia. The nearly equal tree species richness found in exploited and natural forest. But it is found lower in meadow and absent in cropland may be due to higher disturbances [12].

The other cause of change in species richness in different land use types may be due to the changes in different environmental factors. These environmental factors are temperature, moisture, soil pH, soil nutrients, and soil organic matter, canopy cover [2, 8]. The natural forest has high canopy coverage due to which low intensity of light reaches to ground, so it has high moisture content in soil. But in cropland, due to high openness maximum light reaches to ground and has low moisture content. So species richness decreases from forest to cropland [13].

Conclusion

This study analysed the species richness along the land use types in Ghunsa valley of Kanchenjunga Conservation Area, eastern Himalaya on the basis of two broad categories, functional group and life forms. From this study, it can be concluded that the species richness is significantly different in different land use types for all categories. Species richness found highest species richness in exploited forest.

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Environmental Covariates of Species Richness and Composition of Vascular Plants of Olangchung Gola and Ghunsa Valleys of Eastern Nepal

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ABSTRACT

Vascular plant diversity of any region is strongly affected by the environment. This study was done to understand the effects of climate, topography and land use on species richness and composition in two valleys in Eastern Nepal namely Olangchung Gola and Ghunsa. The study covered elevational gradients between 2200 and 3800 m a.s.l. along the two river valleys and included five elevation bands on both aspects of each valley. Four main land-use types, namely natural forest, exploited forest, meadow and crop land were studied in order to test the effects of human influence in a land-use gradient. In total, 515 species belonging to 104 families were recorded. Angiosperms included 477 species, followed by 30 pteridophyte species and 8 gymnosperms. Dicotyledonous plants were more species-rich (378 species) compared to monocotyledonous plants (99 species). Species composition on the plots was analyzed by Canonical Correspondence Analysis (CCA), and Generalized Linear Model (GLM) regression was carried out to test relative effects of environmental variables on the species richness of vascular plants. Species richness and composition were significantly affected by the combined effect of climatic and topographic variables. Species richness and composition also differed between land-use types. Species richness was particularly high in exploited forests where disturbance was at an intermediate level, i.e. less intensive than in the crop fields and meadows but higher than in the natural forests. The results confirm the intermediate disturbance hypothesis and indicate that the local, multifunctional forest management maintained a high species richness of vascular plants.

Keywords: Species Composition, Species Richness, Elevation Gradient, CCA, Climate, Land Use, Biodiversity, Himalaya

INTRODUCTION

Species richness and composition are widely used biodiversity metrics for understanding ecological processes, and various studies have demonstrated the impact of the environment on these biodiversity measures (Lomolino, 2001; Rahbek, 1995). At macroecological scales abiotic environmental factors have been widely studied to explain patterns of species distributions and species richness. Climatic factors have been found to act mainly at regional scales (Currie & Paquin, 1987), whereas land use, slope, aspect, or soil moisture are common factors at local scales (Sherman *et al*., 2007). Such drivers of species diversity are particularly evident along elevational gradients (Korner, 2003; Vetaas & Grytnes, 2002).

The analyses of elevational gradients with respect to species richness and composition have often revealed strong biodiversity patterns. Besides monotonic decrease of species richness, many studies have confirmed a mid-elevation peak along the elevational gradients (Colwell *et al*., 2004; McCain, 2004). Also in the Himalaya in Nepal species richness of various taxa showed a pronounced mid elevation peak; e.g. for vascular plants (Bhattarai & Vetaas, 2003), ferns (Bhattarai *et al*., 2004), lichens (Baniya *et al*., 2010) and medicinal plants (Rokaya *et al*., 2012). Rapoport's rule which states larger species ranges at higher latitudes has been extended to altitudinal gradients (Stevens, 1992). However, the Rapoport's rule was questioned by Colwell & Hurtt (1994), and Rohde (1996) considered such effect as a local phenomenon which applies to the northern temperate zone but failed in the tropics. Instead he argued that gradients in species richness could be explained by an evolutionary approach rather than by environmental gradients. Even though the debate still remains unresolved (Lomolino, 2001), a considerable number of studies showed that species richness and composition can be explained by taking environmental gradients as predictors Sanders & Rahbek (2012) found that there are numerous factors behind that elevational gradient to explain the mechanism of the species diversity pattern. Some of the causes cited therein include climate and productivity (Rahbek, 1995), source sink dynamics (Kessler *et al*., 2011), area (Rahbek, 1995), disturbance (Escobar *et al*., 2007), geometric constraints (Sanders, 2002) and evolutionary history (Machac *et al*., 2011). The effect of other factors such as land-use

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pattern and types were also assessed. Moeslund *et al.* (2013) have shown that micro-topography also explained local plant diversity as did fertilizer and moisture gradients (Hettenbergerova *et al*., 2013). Land use types and topography also affect species composition (Paudel & Vetaas, 2014; Rodríguez-estrella, 2007). The change in species richness differs along elevation and according to the land use types in Nepal Himalaya (Rai *et al*., 2016).

In this study, we aimed to test which environmental variable influence species richness and composition in a remote mountain area in Taplejung district, Eastern Nepal. Our main research questions were: (1) How does climate affect the distribution of vascular plants in the study area? (2) How vascular plant species are associated with different land-use types?

MATERIALS AND METHODS

The eastern Himalayan region of Nepal was selected as the study site where the plant species records were used to regress against the bioclimatic variables from the worldclim and the recorded data within the plots. Further analyses were done using R software with various packages.

Figure 1a : Nepal

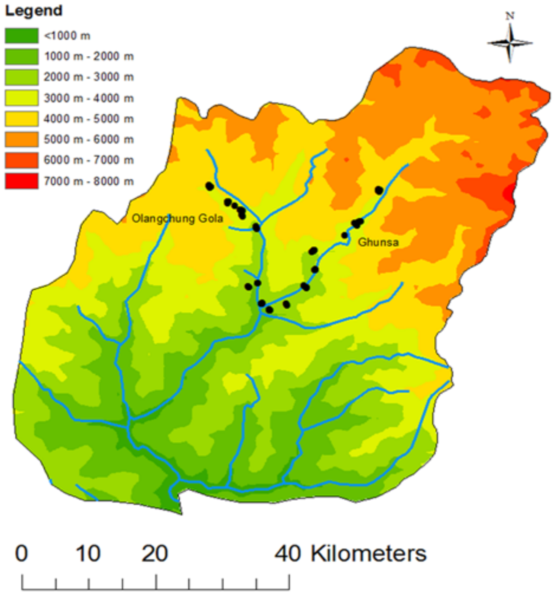

Figure 1b : Taplejung

Figure 1. Location of the study region and study sites. 1a. Map of Nepal showing the Taplejung district as shaded and 1b. Plots along the Tamor river in Olangchung Gola valley and along the Ghunsa river in Ghunsa valley.

Study area and study design

The study was conducted in the Olangchung Gola and Ghunsa river valleys of Taplejung district of Eastern Nepal from 2011 to 3013 (Fig. 1a. & 1b.).

The study covered elevational gradients between 2200 and 3800 m a.s.l. along the two river valleys and included five elevation levels on both aspects of each valley (at c. 2200, 2600, 3000, 3400, and 3800 m). Four land-use types were selected at each level, namely (a) natural forest, (b) exploited forest, (c) meadow, and (d) crop fields (Scheidegger *et al*., 2010). The land-use types were classified on site based on visual inspections according to the methods proposed by (Gregorio & Jansen, 2000). The natural forests were far from the human settlements and trees were not used for the collection of fuelwoods and timber. The exploited forests had more than 20% of tree cover which were used by people of the nearby settlement to collect fodder, fuelwood, timber and other resources. These forests were affected by people of the nearby settlement for their daily needs. The meadows consisted of grasslands, with less than 20 % tree cover. The meadows were also affected by human activities such as livestock grazing and grass collection but not intensely managed by people. The crop fields included those sites where the vegetation cover was manipulated and created by anthropogenic activities. The vegetation cover fluctuated from nearly 100% cover during plantation season and was minimal after the harvesting season.

Crop fields were absent in the highest elevation level (3800 m) except at one site in Ghunsa valley. In each land-use type two sample plots were investigated. The plot size was 25 m x 2.5 m, which was further divided into five subplots (5 m x 2.5 m). The same numbers of plots were investigated on the other side of the river at each elevation level. Thus, 16 plots characterizing four land-use types were investigated at each elevation level. Plots were selected up to 50 meters above and below each elevation level if the land-use types were not available at the exact elevation. A total of 69 plots were investigated. All vascular plant species within each subplot were recorded. Each plot was visited twice, during different seasons, in order to record as many species as possible. Tree and shrub species remained the same however the grasses and herbaceous plants species changed in the plots with change in the seasons.

This would record plants which would grow in one season and absent in next season. To reduce the sampling bias caused by spatial autocorrelation, the replicates of each plot were established at least 50m away from the first plot (Magurran, 2004).

Species identification

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

For nomenclature of the species follows the Angiospermic Phylogenetic Group (APG III; Chase & Reveal, 2009). In the case of the unresolved names (according to APG III), the nomenclature of Press *et al.* (2000) was applied. For pteridophytes we used the nomenclature of (Iwatsuki, 1998) and Fraser-Jenkins (2008, 2011). The individual species' presence/absence data of the merged plot were used as the response variable in the current study.

Environmental predictors

The following sets of environmental variables were used as predictors of analyses of species richness and composition (Table 1):

a. Microclimatic variables

This set of data was recorded on each plot during 2011 to 2013. HOBO data loggers U23-001 (Onset Computer Corporation, Bourne, MA 02532, USA) were used to record air humidity and air temperature two meters above the ground on each plot every 30 minutes. Soil temperatures were recorded at 10cm below the ground level using iButton (Maxim Integrated, San Jose, CA 95134, USA) on each plot. Soil temperature data were recorded at three-hours intervals. The mean, minimum and maximum values of the year-round data were derived using these data (Table 1). The non-available (NA) values of the data were interpolated from the mean of the corresponding records.

b. Bioclimatic variables

The bioclimatic variables were taken from the Worldclim-Global climate data (Hijmans *et al*., 2005). The data were present in 30 arc seconds (0.93km ´ 0.93km = 0.86 km^2) resolution. The values contain monthly data from 1960 to 1990 for the period of 30 years (http://www.worldclim.org/). The average values of the bioclimatic variables for each plot were interpolated with DIVA GIS ver. 7.5.0 (Hijmans *et al*., 2012). The latitude and longitude of each plot were recorded with Garmin 60S GPS set. Out of the 19 bioclimatic variables as defined by the USGS Data Series 691 (O'Donnell & Ignizio, 2012), those with high Pearson correlation coefficient (r ³ 0.7) were removed and only those less than 0.7 were selected for analysis (Booth *et al*., 1994; Dormann *et al*., 2013) (Table 1). The Hmisc (Harrell *et al*., 2015) package was used to check the collinearity among the variables.

c. Topographical Set

The third set of data contained the topographic plot information directly recorded in the field. Garmin GPS 60S was used to record the elevation of each plot. Brunton Compass was used to record the aspect in degree angle while a Clinometer was used to record the slope angle of the sample plots. The land-use types and the valleys were considered as the categorical variables and all the others were taken as quantitative variables (Table 1).

Data analyses

Initial data entry and management was done using MS Excel and MS Access. All subsequent analyses were performed with R ver. 3.1.2 (R Core Team, 2015).Package vegan (Oksanen *et al*., 2015) was used for the multivariate ordination analyses. Detrended Correspondence Analysis (DCA) was performed for the species data (Hill & Gauch, 1980) showing the gradient length of the first ordination axis higher than 3.5 standard units. Therefore, we used as constrained ordination method the unimodal model of the Canonical Correspondence Analysis (CCA) (Ter Braak, 1986). The best model was selected by the option "stepwise" of CCA.

Table 1. List of environmental predictors selected from three sets

Variables Code	Contained information
Microclimatic variables	
MeanT.H	mean air temperature
MeanT.iB	mean soil temperature
minT.iB	minimum value of soil temperature
minH.H	minimum value of air humidity
Bioclimatic variables	
BIO2	annual mean diurnal range
BIO3	isothermality
BIO4	temperature seasonality
BIO6	minimum temperature of coldest month
BIO8	mean temperature of wettest quarter
BIO14	precipitation of driest month
BIO15	precipitation seasonality
BIO16	precipitation of wettest quarter
BIO17	precipitation of driest quarter
BIO19	precipitation of coldest quarter
Topographical variables	
HABI*	land-use types (*C=crop, *M= meadow, *E= exploited forest, *F=forest)
ALTG	measured elevation
LAT	latitude
LONG	longitude
SLOP	slope angle (Sine transformed)
ASP	aspect (Cosine transformed)

Species richness was regressed against the environmental variables using generalized linear models (GLM) (McCullagh & Nelder, 1989). The models having the high deviance (D^2) were selected as the best model.

RESULTS

Species composition

The study revealed a total of 515 species of vascular plants belonging to 104 plant families. Angiosperms were represented by 477 species followed by 30 pteridophytes and 8 gymnosperms. The most dominant family was Asteraceae with 44 species followed by Poaceae (35 spp.), Rosaceae (31 spp.) and Ericaceae (25 spp.). 378 species belonged to dicots and 99 species were monocots. The herbaceous plants dominated the study area when grouped according to life forms. They included 364 species followed by 87 shrub species and 64 tree species.

The analyses of species composition by CCA were constrained using three sets of variables, namely microclimatic variables, bioclimatic variables and topographical

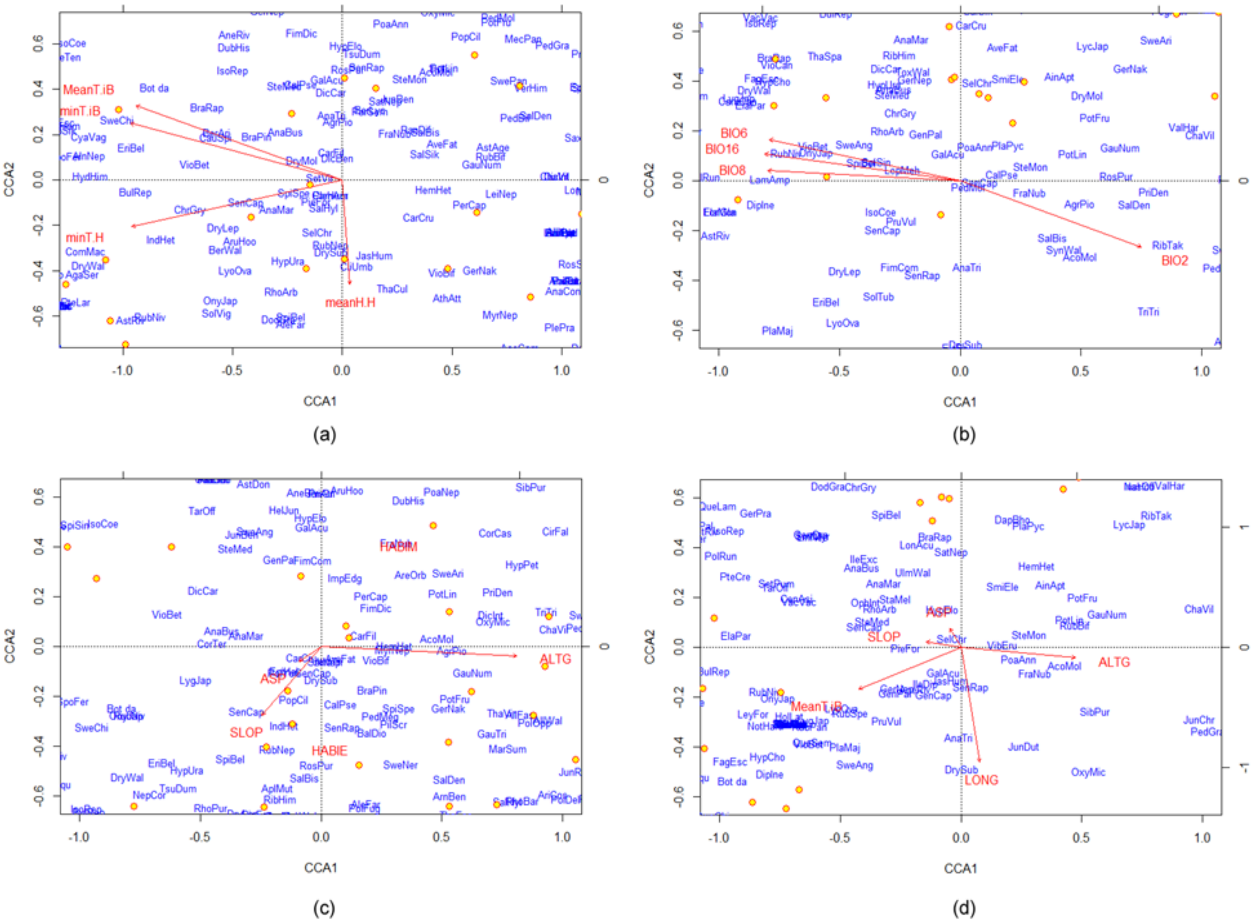

Figure 2. CCA biplots showing the effects of environmental variables on species composition. 2a. constrained by microclimate, 2b. by bioclimatic predictors, 2c. by topographical predictors, and 3d. by the combined set of all predictors (for abbreviation of predictors see Table 1)

Table 2. ANOVA testing for CCA the "marginal effect" of predictors on species composition, i.e. testing the effect of a single predictor in a model with all other predictors.

Variable Set	Code	Df	Chi Square	F	Pr(>F)	Significance Code
Loggers	minT.H	1	0.1851	1.3943	0.009	**
	meanH.H	1	0.1617	1.2185	0.156	
	MeanT.iB	1	0.1535	1.1561	0.144	
	minT.iB	1	0.1445	1.0888	0.248	
	Residual	64	8.4948			
Bioclim	BIO8	1	0.2753	2.1107	0.001	***
	BIO6	1	0.2629	2.0155	0.001	***
	BIO16	1	0.2493	1.9116	0.001	***
	BIO2	1	0.2486	1.9061	0.001	***
	Residual	64	8.3465			
Spatial	ALTG	1	0.4093	3.1705	0.001	***
	HABI	3	0.6474	1.6718	0.001	***
	ASP	1	0.157	1.2163	0.043	*
	SLOP	1	0.1526	1.182	0.082	.
	Residual	62	8.0031			
AllVar	LONG	1	0.2751	2.1436	0.001	***
	ALTG	1	0.2459	1.9159	0.001	***
	MeanT.iB	1	0.2297	1.7901	0.001	***
	SLOP	1	0.1894	1.4763	0.001	***
	ASP	1	0.1672	1.3033	0.014	*
	Residual	63	8.0843			

Table 3. The percentage of constrained variation in species composition explained by Canonical Correspondence Analysis.

Data Set	Total Inertia	Constrained Inertia	Axes	Eigenvalues	Percentage constrained variation explained	Cumulative Variation %
Microclimatic	9.499	1.004	CCA1	0.4735	47.16	
			CCA2	0.2418	24.08	71
			CCA3	0.1568	15.62	87
			CCA4	0.1323	13.18	100
Bioclimatic		1.153	CCA1	0.4854	42.10	
			CCA2	0.2962	25.69	68
			CCA3	0.2212	19.18	87
			CCA4	0.1498	12.99	100
Topographical		1.893	CCA1	0.5011	26.47	
			CCA2	0.362	19.12	46
			CCA3	0.3453	18.24	64
			CCA4	0.2138	11.29	75
			CCA5	0.2048	10.82	86
			CCA6	0.1597	8.44	94
			CCA7	0.1064	5.62	100
Combined		1.415	CCA1	0.4936	34.88	
			CCA2	0.3462	24.47	59
			CCA3	0.2395	16.93	76
			CCA4	0.1883	13.31	90
			CCA5	0.1471	10.40	100

Table 4. Summary statistics of generalized linear models with Poisson distribution of species richness regressed against predictors.

Name of variables	AIC	Residual deviance	D^2	Percentage change in D^2
Microclimate Model				
MeanT.H	710.04	298.09	0.07	
MeanT.H+MeanT.iB	695.16	281.22	0.12	79.88
MeanT.H+MeanT.iB+minH.H	691.73	275.78	0.14	14.32
Backward Elimination	691.73	275.78	0.14	0.00
Full model (all variables)	643.39	215.44	0.33	
Bioclimatic model				
BIO3	685.28	273.33	0.14	
BIO3+BIO4	673.07	259.12	0.19	30.97
BIO3+BIO4+BIO14	675.07	259.12	0.19	0.00
BIO3+BIO4+BIO14+BIO15	662.4	244.46	0.23	24.40
BIO3+BIO4+BIO14+BIO15+BIO17	651.35	231.41	0.28	17.46
BIO3+BIO4+BIO14+BIO15+BIO17+BIO19	638.15	216.21	0.32	17.31
Backward Elimination	638.15	216.21	0.32	
Stepwise regression (backward elimination & forward selection)	598.12	166.18	0.48	48.57
Full model (all variables)	606.54	164.6	0.48	
Topographic model				
ALTG	706.54	294.6	0.08	
ALTG+LAT	708.09	294.15	0.08	1.83
ALTG+LAT+LONG	694.83	278.89	0.13	60.89
ALTG+LAT+LONG+ASP	694.28	276.34	0.13	6.32
ALTG+LAT+LONG+ASP+SLOP	692.52	272.57	0.15	8.79
LAT+LONG+ASP+SLOP	690.59	272.65	0.15	
Backward Elimination	702.65	286.71	0.10	-30.20
Stepwise regression (backward & forward)	650.94	231	0.28	171.42
Full model (all variables)	661.57	227.63	0.29	
Combined model				
ALTG	706.54	294.6	0.08	
ALTG+BIO1	698.1	284.15	0.11	42.46
ALTG+BIO1+BIO12	674.19	258.25	0.19	73.87
MeanT.H+MeanT.iB+BIO3+BIO14+BIO17+BIO19+LONG+ASP	615.88	189.94	0.40	112.06
Stepwise regression (backward & forward)	609.43	179.49	0.44	8.08
Full model (all variables)	539.12	55.176	0.83	

variables. In case of microclimate set, minimum air temperature (minT.H) was the only significant predictor ($F=1.39$, $p<0.01$) in ANOVA. The mean soil temperature (MeanT.iB), minimum soil temperature (minT.iB) and minimum air temperature (minT.H) are oriented along the first CCA axis and mean air humidity (meanH.H) is placed along the second axis (Fig. 2a). In case of bioclimatic variables (Fig. 2b), annual mean diurnal range (BIO2), minimum temperature of the coldest month (BIO6), mean temperature of the wettest quarter (BIO8) and precipitation of the wettest quarter (BIO16) were found to be significant ($F_{all}>1.9$ at $p<0.001$). The topographical variables, land-use types ($F=1.67$, $p<0.001$), elevation ($F=3.17$, $p<0.01$), slope ($F=1.182$, $p>0.001$), aspect ($F=1.22$, $p<0.001$) affected the species composition significantly (Table 2 and Fig. 2c). The combined constrained effects of all variable remaining after controlling for collinearity. Among them, soil temperature and topographical variables showed significant effects on composition (Table 2 and Fig. 2d). The variation explained by the first CCA axis was 47.16% for the model using microclimate variables alone and 42.1%, 26.47% and 34.88 % for the bioclimatic, topographical and combined variable set respectively (Table 3).

Species Richness Models

Different GLM models with species richness as response and Poisson distribution for count variables were built using the same three sets of predictor variables and the combined set (Table 4). For the microclimatic model, the linear combination of mean air temperature (MeanT.H) and mean soil temperature (MeanT.iB) along with the minimum air humidity (minH.H) showed the lowest values of AIC (691.73) based on forward selection with an explained deviance $D^2 = 0.14$. Backward elimination starting with all variables did not improve the model (Table 4). The model with the bioclimatic predictors and built by forward selection consisted of six variables, i.e. isothermality (BIO3), temperature seasonality (BIO4), precipitation of driest month (BIO14), precipitation seasonality (BIO15), precipitation of driest quarter (BIO17) and precipitation of coldest quarter (BIO19). It performed better than the previous model ($AIC=638.15$, $D^2=0.32$). Backward elimination of all predictor variables did not improve the model, however, stepwise backward elimination and forward selection improved the model further ($AIC=598.12$ & $D^2=0.48$). In the topography set, linear combination of latitude (LAT), longitude (LONG), aspect (ASP) and slope angle (SLOP) of the plots had more effect than other models while doing the forward selection ($AIC=690.59$ & $D^2=0.15$). Backward elimination did not improve the model, however, stepwise backward elimination and forward selection method produced better results ($AIC=650.94$, $D^2=0.28$). Inclusion of all variables and elevation was not effective for the topographic model (Table 4).

In case of combined model, significant variables from each set were selected to initially reduce the number of predictors (similar to, Wohlgemuth *et al*., 2008). Among them, mean air temperature and mean soil temperature of the plot, isothermality, precipitation of driest month, precipitation of driest quarter, precipitation of coldest quarter along with longitude and aspect have shown a stronger effect on the species richness ($AIC=615.88$ & $D^2=0.40$) than other models. Stepwise regression with backward elimination and forward selection further improved the model ($AIC=609.43$ & $D^2=0.44$).

The significance of each variable on the model performance was also calculated (Table 5). Mean air temperature was the most significant variable ($p<0.001$) followed by soil temperature and minimum humidity of the plots in microclimate set. In case of the bioclimatic set, all variables were significant ($p<0.001$) except precipitation seasonality. In the topography set, the latitude had a higher significance ($p<0.001$) followed by longitude ($p<0.01$). Slope and aspect were also significant at $p<0.05$. While combining all variables in the synthetic model, their effect was also changed. Slope and aspect were no longer significant in that model.

The relative effect of those predictor variables on the species richness in different land-use types are also fitted with the generalized linear models (Figure 3a-d).

DISCUSSION

Species composition

From the bioclimatic set the most informative variables for species composition were minimum temperature of the coldest month, mean temperature of the wettest quarter and precipitation of the wettest quarter. The wettest quarter in the study area is during summer months when the monsoon cloud from the Bay of Bengal reaches its peak in July (Kansakar *et al*., 2004). The higher precipitation delivers water for the growing vegetation and the ambient temperature is also favorable during the summer monsoon. Similar results were found for annual plants in Mongolia (Yan *et al*., 2015) and primates (Wang *et al*., 2013) in South East Asia.

For the topographical variables, elevation, aspect, slope and land use types show significant effect on the plant composition and richness. Moeslund *et al*. (2013) had similar results where local plant diversity patterns were controlled by soil moisture and local hydrology which were in turn affected by topography. The slope and aspect are also responsible for heterogeneity of habitats where the solar radiation also varies. The radiation has direct effects on light availability, soil and air temperature and soil moisture. In our study, species composition was significantly affected by minimum and mean soil and air temperatures (Figure 2a, Table 2).

In the Figure 2c meadows (HABIM) and exploited forest (HABIE) have been displayed. While increasing the scale of the figure, the crop fields are place far away from the meadow and the natural forest is placed near to the exploited forest. The species composition of the crop fields changes according to the season and during crop plantation, harvest and ploughing. The highly different species composition of crop fields was expected because of its intensive management by the people. Moura *et al*. (2016) also asserted that species richness and thus compositions are affected synergistically by various variables, even though, the climate itself was also a good explanatory variable. The competition regimes are

Table 5. The test statistics of the predictor variables obtained after performing the ANOVA of the chosen GLMs of species richness.

Variable Set	Variables	Estimate	S.E	p	
Microclimate	(Intercept)	3.71E+00	1.55E-01	2.00E-16	***
	MeanT.H	5.09E-02	1.04E-02	8.94E-07	***
	MeanT.iB	-3.54E-02	1.08E-02	1.06E-03	**
	minH.H	4.34E-03	1.87E-03	2.04E-02	*
Bioclimatic	(Intercept)	1.73E+01	2.41E+00	7.21E-13	***
	BIO3	-1.62E-01	2.30E-02	2.03E-12	***
	BIO4	-1.11E-03	3.28E-04	6.73E-04	***
	BIO14	-1.63E-01	3.18E-02	2.65E-07	***
	BIO15	2.20E-03	1.44E-02	8.78E-01	n.s.
	BIO17	-1.06E-01	2.46E-02	1.82E-05	***
	BIO19	1.04E-01	1.79E-02	6.38E-09	***
Topographic	(Intercept)	9.71E+01	2.23E+01	1.41E-05	***
	LAT	-9.64E-01	2.57E-01	1.74E-04	***
	LONG	-7.56E-01	2.34E-01	1.27E-03	**
	ASP	5.62E-02	2.54E-02	2.69E-02	*
	SLOP	2.03E-01	9.63E-02	3.51E-02	*
Combined	(Intercept)	1.17E+02	2.50E+01	3.08E-06	***
	MeanT.H	5.52E-02	1.33E-02	3.21E-05	***
	MeanT.iB	-3.22E-02	1.08E-02	2.78E-03	**
	BIO3	-1.36E-01	2.23E-02	1.15E-09	***
	BIO14	-1.04E-01	3.28E-02	1.46E-03	**
	BIO17	-6.82E-02	1.64E-02	3.32E-05	***
	BIO19	8.16E-02	1.42E-02	8.76E-09	***
	LONG	-1.22E+00	2.85E-01	2.03E-05	***
	ASP	4.70E-02	2.59E-02	6.93E-02	.

different for species occurring at crop fields and those at forests. Kouba *et al*. (2015) assessed the species composition in different landscape with different land use history in the Mediterranean basin and found that the composition pattern differed significantly according to successional stage. Baniya *et al*. (2009) have also assessed the species diversity in different land use types taking temporal gradient as an explanatory variable in trans-Himalayan region of Nepal. They found the hump shape of species diversity along the gradient which agrees with the intermediate species richness hypothesis (Connell, 1978). The forest and exploited forest share common species and crop fields share very less species with the forests in this study. Some species of the meadow also occur in the exploited forest. The partial clearing of the forest will create the suitable space and environment for the species occurring in the meadows. Current study does not match the results of Sharma & Vetaas (2015) who have revealed difference in the species composition of forest land and farmland, even if they shared some common species of trees in the mid-hills of Nepal. In our study, the tree species which are commonly planted on the corners of the fields were not recorded.

Species richness

Species richness was low in crop fields and higher in the exploited followed by that in meadows and natural forest. The low species richness of crop field was expected because of intensive management by the farmers that included yearly ploughing the fields in spring. Species richness is high in the crop field during plantation and most of the weeds are uprooted in the next cropping season. The high species richness in the exploited forest agrees with the intermediate disturbance hypothesis (Connell, 1978). Sharma *et al*. (2013) have found the high species richness at the grassland center and less at the forest interior. They have attributed that observation as the asymmetric mass effect due to habitat heterogeneity.

The models of different predictor variable sets performed differently in explaining species richness and composition. The microclimatic model and topographical model have less deviance than the bioclimatic model. The microclimate data and topographical data were recorded from the plots. The predictive power of those variables might be limited for plant species richness at local scale instead of their high spatial resolution. The microclimate data was recorded only for two years. This short period

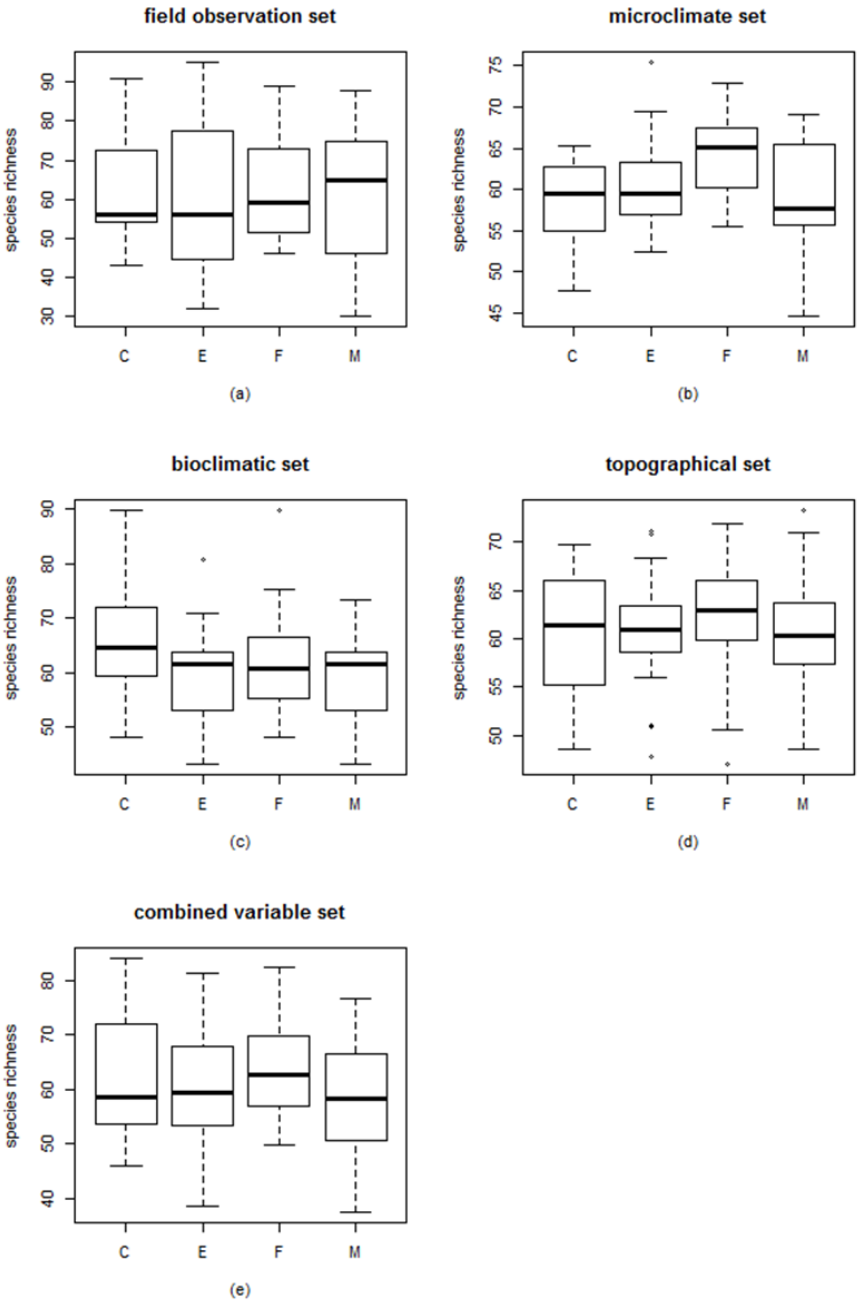

Figure 3. Observed (a) and predicted (b-d) species richness of the different land-use types. Predictions are based on the microclimate model (a), bioclimate model (b) topography model (d) and combined model (e).

may limit the performance of these data as a predictor of species richness and composition. The bioclimatic data were interpolated from the 30 arc second resolution which is (0.93*0.93) =0.86 sq. km at the equator. The bioclimatic data and the synthetic model were more robust than the previous two models. The importance of climatic factors in other taxa have also been established for example the synergistic association between climate and vegetation has a significant effect on vertebrates (Moura *et al*., 2016).

Predicted species richness changed for the different richness models (Fig. 3). In the microclimate model, the minimum humidity was also found to be significantly affecting the species richness. Hettenbergerova *et al.* (2013) have also similar results in bryophytes where the richness decreased from high moisture index to the dry plots. The dryness of the plots enhances the transpiration rate and soil moisture is depleted in faster rate. The species richness in the crop field is seen higher than the natural and exploited forest in the fitted GLMs. Since, the local conditions of crop field including vegetation cover can be changed by humans the effect of variables seem justified. Land use types are also considered as biotic factor influencing the species diversity (Moura *et al*., 2016). Moeslund *et al*. (2013) showed that local plant diversity is controlled by the topographical factors which in turn affect the soil moisture and microclimate hydrology. The soil moisture is essential for the growth of plants. Aranda *et al*. (2014) found that the geographical factors had limited influence on the species diversity of bryophytes whereas climate and habitat showed strong effect on it. In our study, the topographical s*et al*one was not good enough to explain the species richness however when combined with bioclimatic and microclimatic variables, the synergistic effect produced a good model. Similar phenomena were obtained by Stein *et al*.(2014) when doing the meta-analysis of 1148 points of 192 studies worldwide. They found that species richness was explained by land cover, vegetation, climate, soil and topography.

CONCLUSION

The microclimatic variables did not show significant effect on species composition except minimum air temperature. The percentage of variation of plant species composition explained by the first and second axis are high, but total constrained inertia is low (1.004) out of total inertia (9.499). The topographical variables elevation, aspect and slope showed significant effect on the species composition. Species compositions also differ with different land-use types. In case of bioclimatic variables, the seasonal and diurnal fluctuations such as mean diurnal range, minimum temperature of the coldest month, mean temperature and precipitation of the wettest quarter were significantly affecting species composition. The mean annual temperature and mean annual precipitation did not show significant effects. We conclude that the seasonal effect of climatic variables is more pronounced than the annual mean of such variables. This phenomenon of seasonal effect agrees with the limiting factor hypothesis. The variability of such temperature and precipitation are crucial not during the optimal growth condition but when there are extreme high or low condition reaching to physiological tolerance level (Zimmermann *et al*., 2009).

Species richness is higher in the exploited forests and meadows than intensively managed crop fields and relatively less disturbed natural forests. The results of our study support the intermediate disturbance hypothesis. The species richness decreases as the elevation increases. The previous studies have shown the mid elevational peaks, but our study area does not fall within that range. Instead, we have observed the effects of microclimate, bioclimate, topography and land use types on the species richness within the elevational range from 2200 m to 3800 m. Different generalized linear models were compared for their strength to shape the species richness after regressed with three sets of predictors and one synthetic set incorporating all predictors at one place. Mean soil and air temperature and minimum humidity of the plots significantly affected the species richness in microclimate set. In case of bioclimatic set, the isothermality, temperature seasonality, precipitation of driest month, precipitation seasonality, that of driest and coldest quarter affected the species richness significantly. The elevation, aspect and slope of the plots also showed significant effects. The species richness and composition according to different land use types.

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

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

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

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

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

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

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

Materials and methods

Study area

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

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

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

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

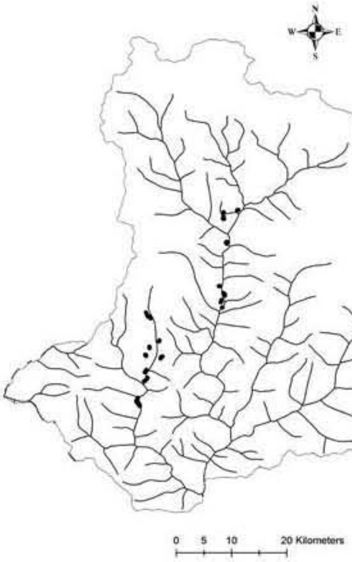

Fig. 2b: Map of Solukhumbu district with plots overlaid on Dudhkunda river valley on the left and Dudhkoshi river valley on the right

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

Study design

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

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

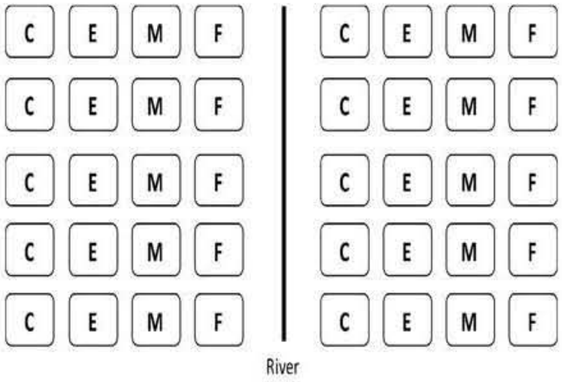

Fig. 3: Schematic diagram of sampling plot design of the study per land use type in all elevation (C= crop field, E = exploited forest, M = meadow, F = forest and the straight line at the center represents the river)

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

Data source

Plant species records as response variable

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

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

Environmental variables as predictor variables

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

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

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

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

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

Data analysis

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

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

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

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

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

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

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

Results and discussion

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

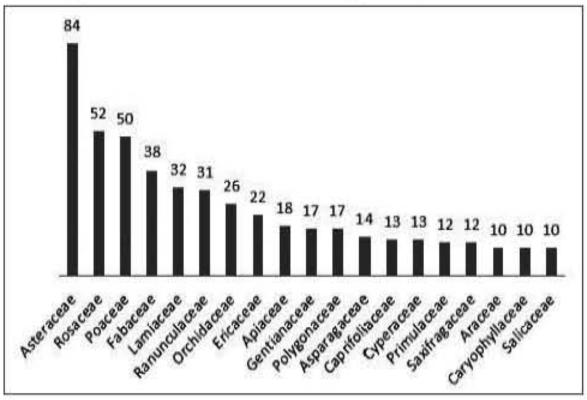

Fig. 4: Bar diagram showing the representative families, number of species on the Y-axis and families on the X-axis (families representing more than 10 spp. are included)

Species composition

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

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

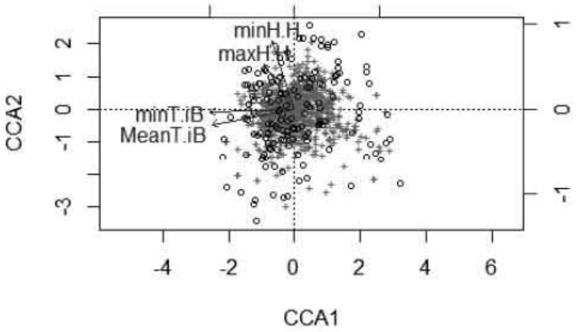

Fig. 5: CCA plot showing the species composition constrained by humidity and soil temperature; the crosses indicating the species, the circles indicating the plots and the arrows showing the predictors

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

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

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

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

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

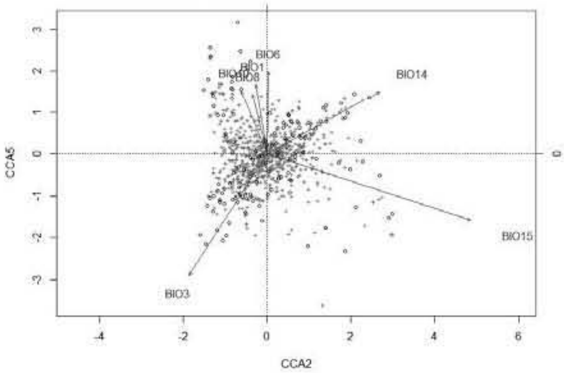

Fig. 6: CCA plot showing the species composition constrained by the bioclimatic variables; the crosses indicating the species, the circles indicating the plots and the arrows showing the predictors

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

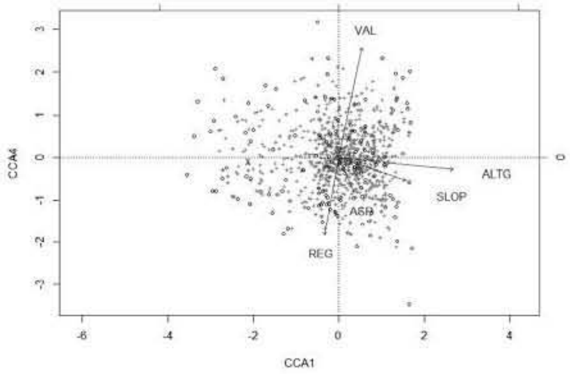

Fig. 7: CCA plot showing the species composition as shaped by the topographical variables; the crosses indicating the species, the circles indicating the plots and the arrows showing the predictors

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

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

Species richness

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

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

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

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

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

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

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

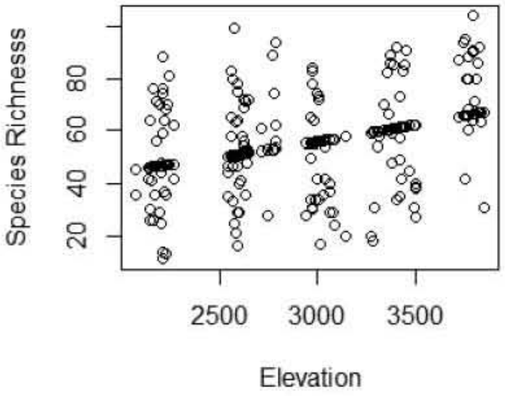

Fig. 8a: Species richness versus elevation of the plots

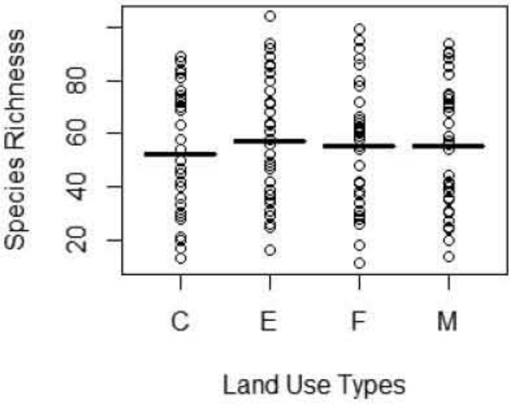

Fig. 8b: Species richness versus land use types

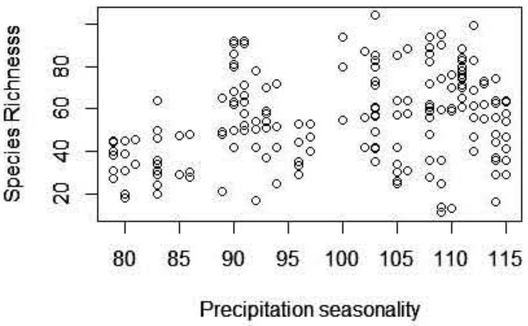

Fig. 8c: Species richness versus precipitation seasonality

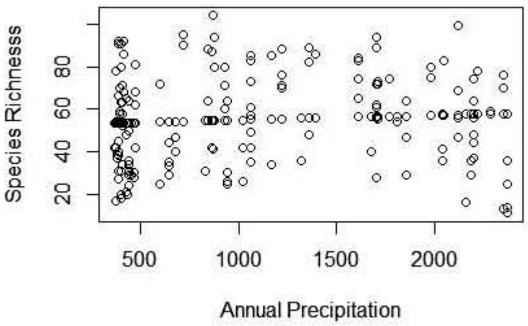

Fig. 8d: Species richness versus annual precipitation

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

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

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

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

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

Conclusion

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

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Sanjeev Kumal RAI[a,b,c], Jyoti Prasad GAJUREL[b,c], Krishna Kumar SHRESTHA[b], Christoph SCHEIDEGGER[c] and Lokesh Ratna SHAKYA[d,*]: *Risleya* (*Orchidaceae*), a New Record for Flora of Nepal

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Summary: *Risleya* King & Pantling is reported for the Flora of Nepal as a new record of the genus in *Orchidaceae*.

The genus *Risleya* King & Pantling is a monotypic genus described from Sikkim (King and Pantling 1898). *Risleya atropurpurea* King & Pantling is recorded from Sikkim, China, and Myanmar (Pearce and Cribb 2002), but the genus has not been recorded from Nepal (Hara et al. 1978, Banerji and Pradhan 1984, Press et al. 2000, Rajbhandari and Dahal 2004, 2010, Rokaya et al. 2013). It is distributed from 2900–3700 m from SW Sichuan, SE Xizang, NW Yunnan and at 3500 to 4500 m from Bhutan and India (Sikkim) (Chen et al. 2009, Pearce et al. 2002).

During our study of species diversity in forests (Scheidegger et al. 2010), a mycotrophic orchid species was recorded from a locality nearby Sarkaripati, Solukhumbu district at an altitude of 3400 m. The orchid was found on the ground covered with moss and litter. The dominant tree species of the forest were *Rhododendron arboreum* and *Abies spectabilis.* Other associated species were *Rubus nepalensis, Pleione praecox, Dichrocephala integrifolia, Gaultheria nummularioides*, etc. The ground was humus rich and moist at the time of collection of the specimen.

On critical examination, it is identified as *Risleya atropurpurea* King & Pantling. The species can readily be identified from its mycotrophic habit and deep blackish-purple flowers. This is a new record for Nepal, not only for the species, but also for the genus.

Risleya atropurpurea King & Pantling in Ann. Roy. Bot. Gard. (Calcutta) **8**: 247, t. 328 (1898); Pearce & Cribb, Orchids of Bhutan: 235 (2002); Chen, Gale & Cribb in Wu & Raven, Fl. China **25**: 245 (2009); Zang in Wu & Raven, Fl. China Illust. **25**: t. 320 f. 1 & 2 (2010). Type: INDIA. Sikkim Himalaya, 13,000 ft., 1896, R. Pantling 451 (CAL, GH). [Fig. 1]

Plants 6–22 cm tall; rhizome pubescent. Stem glabrous, dark purple, with basal sheaths; sheaths 2, tubular. Inflorescence rachis 4–7 cm, densely flowered; floral bracts lanceolate, 1 mm. Flowers 1–2 mm across, blackish-purple; pedicel and ovary 1–1.5 mm, twisted. Sepals spreading, oblong, obtuse, 1.5 × 0.5 mm. Petals lanceolate, 0.8 × 0.4 mm. Lip adnate to column at base, broadly ovate, concave, slightly crenulate at base, 1.4–1.6 × 1.2 mm. Column 0.4 mm. Fruit ovoid, 3 × 2 mm.

Distribution: E. Nepal, India (Sikkim), Bhutan, China, Myanmar.

Flowering: June.

Altitude: 3400 m.

Specimens examined: E NEPAL. Sagarmatha zone, Solukhumbu district, Taksindu to Sarkaripati, 3400 m, 27 June 2012, S. K. Rai, J. P. Gajurel, S. Devkota, Bibas Rai & Bhim Rai

Fig. 1. Type specimen of *Risleya atropurpurea* King & Pantling (INDIA. Sikkim Himalaya, 13,000 ft., 1896, R. Pantling 451, GH; from Harvard University Herbaria Database).

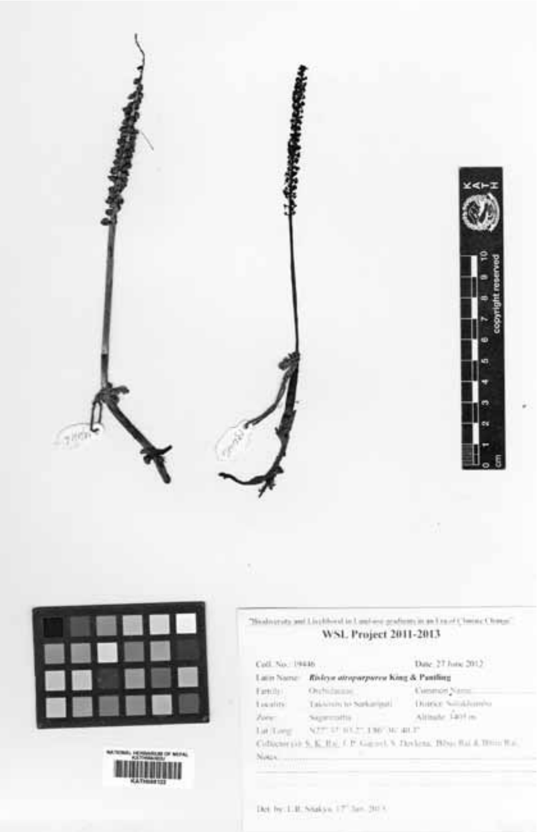

Fig. 2. *Risleya atropurpurea* King & Pantling (E NEPAL. Sagarmatha zone, Solukhumbu district, Taksindu to Sarkaripati, 27 June 2012, S. K. Rai & al. 19446, KATH005122).

19446 (KATH005122, TUCH; Figs. 2–3).

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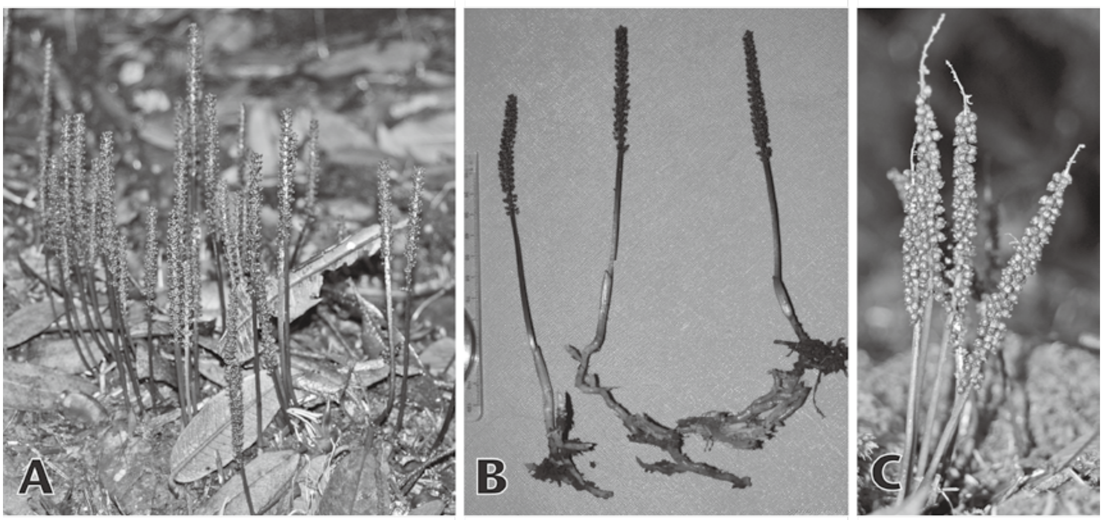

Fig. 3. *Risleya atropurpurea* King & Pantling. A. Habit. B. Close-up view. C. Fruiting stage.

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S. K. Rai[a,b,c], J. P. Gajurel[b,c], K. K. Shrestha[b], C. Scheidegger[c], L. R. Shakya[d]：**ネパール新産の *Risleya* 属（ラン科）**

ネパールからラン科の *Risleya atropurpurea* King & Pantling を初めて報告した．これは属としても初めての報告となる．本種はこれまでシッキム，ブータン，中国，ミャンマーに知られていたが，今回，ネパール東部の Sagarmatha zone, Solukhumbu district の 3400 m の地点で確認された．生育地はコケと落ち葉に被われた地表であった．

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Snow and Landscape Research,
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Peristylus manii (H.G. Reichenbach) Mukerjee [Orchidaceae] - a new record for Nepal

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Abstract

Peristylus manii (H.G. Reichenbach) Mukerjee [Orchidaceae] is reported from Nepal for the first time. A morphological description, illustration and relevant notes are provided.

Key words: Peristylus manii, New record, Nepal

Peristylus manii (H.G. Reichenbach) Mukerjee is recorded from India (Khasia Hills & Manipur) and China (S. Sichuan & C. and W. Yunnan) (Hooker *f.* 1888 – 1890; Chen *et al* 2009) but the species has not been recorded from Nepal (Hara *et al.* 1978; Banerji & Pradhan 1984; Press *et al.* 2000; Rajbhandari & Dahal 2004, 2010) so far.

During an intensive survey of species diversity in forests (Scheidegger*et al.* 2010), an orchid species was recorded from Shyo, Lho Village Development Committee (VDC), Gorkha District, Central Nepal which resembled *Herminium*in in gross morphological characters. The orchid was found on an open meadow adjacent to a *Pinus-Rhododendron* forest.

On critical examination the specimen was identified as *Peristylus manii* (H.G. Reichenbach) Mukerjee. The genus *Peristylus* is characterized by the presence of a short, pendulous, scrotiform spur. The species *Peristylus manii* was confirmed by the presence of 1 or 2 linear leaves 0.4 – 0.5 cm wide and a labellum that is 3-lobed near the middle with lateral lobes as long as the middle lobe. The specimen was also compared with the specimen of *P. manii* (Kingdon Ward 18706 deposited at AMES) collected from Khasia Hills in August 1949.

Peristylus manii (H.G. Reichenbach) Mukerjee in Notes Roy. Bot. Gard. Edinburgh 21: 153, 1953; Chen, Gale & Cribb in Wu & Raveen, Fl. China 25: 141. 2009; Zang in Wu & Raven, Fl. China Illust. 25: t. 184 f. 7 & 8. 2010.

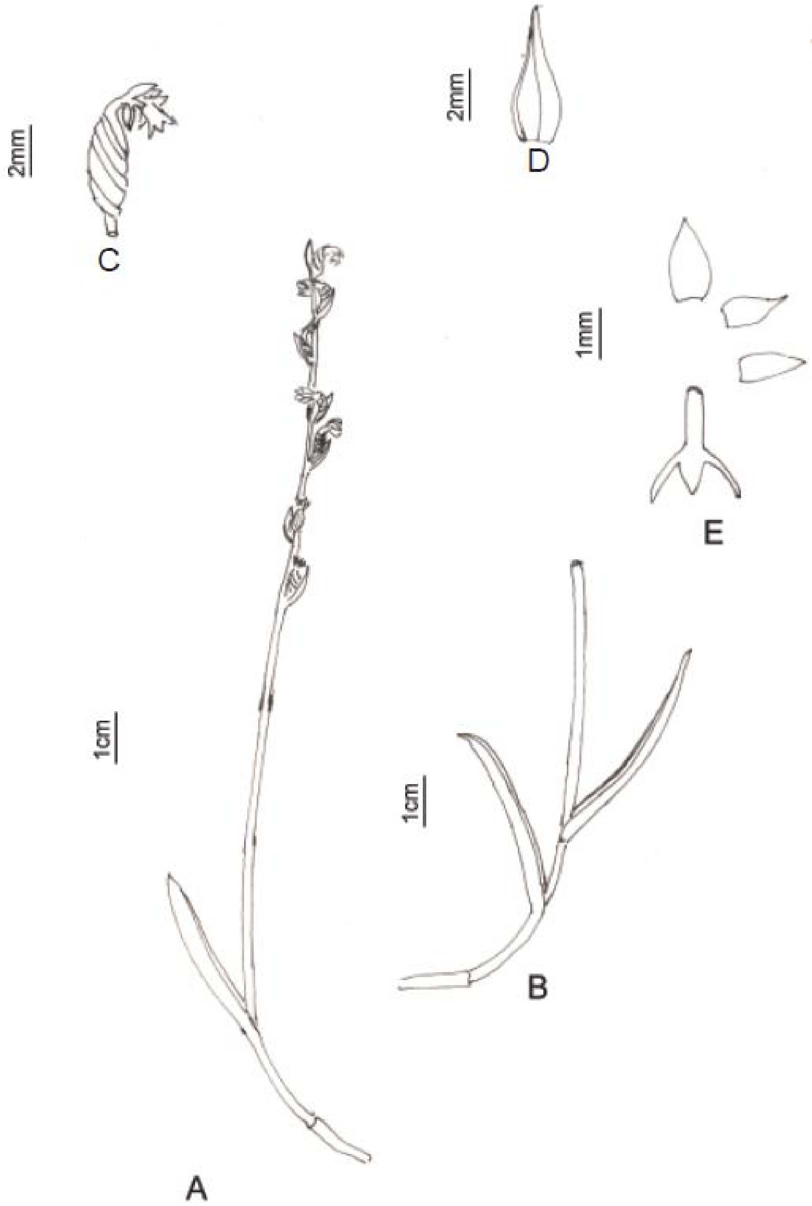

Fig. 1. ***Peristylus mannii*****: A.** Habit with inflorescence; **B.** Habit without inflorescence; **C.** Flower; **D.** Bract; **E.** Dorsal sepal, petal, lateral sepal and the lip spread out

Coeloglossum mannii H.G. Reichenbach, Linnaea 41: 54. 1877; *Habenaria gracillima* J.D. Hooker, Fl. Brit. India **6:** 163. 1890. [Fig. 1]

Plant 14 - 16 cm tall. Stem thin, with one tubular sheath at base. Leaves 1 or 2, 3 – 4 x 0.4 – 0.5 cm, linear, acuminate, base extended to long tubular sheath. Inflorescence 8 - 10 cm, flowers distant, laxly 8 – 10 flowered; flowers ca. 10 mm apart, spirally arranged, green; floral bracts ovate-lanceolate, 4.5 – 5 x 2 mm, as long as or slightly shorter than ovary, acuminate. Ovary 5 – 5.5 mm including pedicel. Dorsal sepal 1.5 x 0.8 mm, oblong-ovate, concave, subacute; lateral sepals 1.5 x 0.5 mm, oblong, acute. Petals 1.25 x 0.25 – 0.5 mm, ovate acuminate to oblong acuminate. Labellum ca. 1.6 – 2.0 mm long, spreading, narrowly oblong, ecallose, 3-lobed near middle; lateral lobes diverging 1 x 0.2 mm, as long as mid-lobe, narrowly oblong; mid-lobe 1 x 0.5 mm, oblong to triangular; spur pendulous, scrotiform, ca. 1 mm, obtuse.

Distribution: Nepal (Shyo Lho), India (Meghalaya), China (Sichuan & Yunnan).

Flowering: October

Specimen Examined: Central Nepal, Gandaki Zone, Gorkha District, Shyo Lho VDC, 3000 m, 10 October 2012, *S. K.Rai, J. P. Gajurel, S. Devkota, Bibas Rai & Bhim Rai,* 25624, KATH.

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Bulbophyllum griffithii (Lindley) Reichenbach *f.* and ***Platanthera cumminsiana*** (King &Pantling) J. Renz – two new records of orchids from Nepal

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Abstract

Platanthera cumminsiana (King & Pantling) J. Renz [Orchidaceae] so far recorded from Arunanchal Pradesh, NE India and Lachung in North Sikkim and *Bulbophyllum griffithii* (Lindley) Reichenbach *f.* [Orchidaceae] recorded from NE India, Bhutan and Lachung, North Sikkim is reported for East Nepal. Short morphological descriptions, figures and relevant notes are provided.

Key words: *Platanthera cumminsiana, Bulbophyllum griffithii,* New record, Nepal.

The genus *Platanthera* Richard comprises about 100 species distributed widely in the temperate regions of both the hemispheres (Pearce & Cribb 2002). In Nepal the genus is represented by 10 species (Rajbhandari & Dahal 2004). *Platanthera cumminsiana* (King & Pantling) J. Renz is rare and so far recorded from Arunanchal Pradesh and Lachung, Sikkim. *Platanthera cumminsiana* is so far not recorded from Nepal (Hara *et al.*1978; Banerji & Pradhan 1984; Press *et al.* 2000; Rajbhandari & Dahal 2004). Recently a species of *Platanthera* was collected from a trail between Surke to Lukla, Solukhumbu district of Nepal at the altitude of 2400 m a.m.s.l. that was identified as *Platanthera cumminsiana* (King & Pantling) J. Renz. This is an addition to the orchid flora of Nepal.

The genus *Bulbophyllum* Thouars comprises about 1000 species widely distributed in the tropical Americas, Africa, Madagascar, the Mascarene Islands, SE Asia to Australia (Pearce & Cribb 2002). This is the largest genus of higher plants in Nepal represented by 34 species (Rajbhandari & Dahal 2004). *Bulbophyllum griffithii* (Lindley) Reichenbach *f.* is rare and so far recorded from NE India, Bhutan and Lachung in Sikkim. This species is so far not recorded from Nepal (Hara *et al.*1978; Banerji & Pradhan 1984; Press *et al.* 2000; Rajbhandari & Dahal 2004). Recently this species was recorded from Sengma, Solukhumbu district of Nepal, at the altitude of 2580 m.a.s.l. This is a new addition to the orchid flora of Nepal.

"Biodiversity and Livelihood in Land-use gradients in an Era of Climate Change"

WSL Project 2011-2013

Coll. No.: 9201 Date: 16 Sept 2011

Latin Name: ***Bulbophyllum griffithii* (Lindl.) Rchb. f.**

Family: Orchidaceae Common Name:................

Locality: Sengma .... District: ....Sagarmatha

Zone: Sagarmatha Altitude: ......2580 m

Lat./Long: N27⁰ 42' 20.0", E86⁰ 42' 36.5"

Collector (s): S. K. Rai, J. P. Gajurel, S. Devkota, S. Shah & B. Rai

Notes: ....

Det. by: L.R. Shakya, 17th Jan, 2013.

Fig. 1: Photograph of the voucher specimen of *Bulbophyllum griffithii* (Lindley) Reichenbach *f.*

WSL Project 2011-2013

Coll. No.: X116
Date: 12 Sept 201
Latin Name: *Platanthera cumminsiana* (King & Pantling) Renz
Family: Orchidaceae
Zone: Sagarmatha
Altitude: 2400m

Fig. 2: Photograph of the voucher specimen of *Platanthera cumminsiana* (King & Pantling) J. Renz

Bulbophyllum griffithii (Lindley) Reichenbach *f.* in Walpers, Ann. Bot. Syst. 6: 247. 1861.

Sarcopodium griffithii Lindley, Fol. Orchid. Sarcopodium 2: 6, no. 15. 1853.

Epiphytic. Pseudobulbs 1 – 2 cm long, ovoid, compressed, cespitose. Leaf 1, ca. 4 cm long, narrowly elliptic-oblong, obtuse. Inflorescence 1-flowered, peduncle 1.5 cm long, tubular sheath at base. Flowers ca 1.5 cm across, yellow with red-brown spots. Sepals sub-equal, spreading. Petals ovate, acute, margins erose. Lip ca. 5 mm long, oblong, subacute, fleshy. Column 3 mm long.

Flowering: September

Altitude: 2580 m

Specimen examined: East Nepal, Sagarmatha zone, Solukhumbu district, Sengma, 2580 m, 16 September 2011, *S.K. Rai, J. P. Gajurel, S. Devkota, S. Shah & B. Rai*, 9201, KATH. **[Fig. 1]**

Platanthera cumminsiana (King & Pantling) J. Renz in Edinb. J. Bot. 58(1): 117. 2001.

Habenaria cumminsiana King & Pantling in J. Asiat. Soc. Bengal 64(3): 343. 1896.

Plant 12 – 18 cm tall. Tuber cylindric, oblong. Stem erect, glabrous, covered with tubular sheath at base. Leaves 3 or 4, 2 – 5 x 0.5 – 2 cm, broadly elliptic to lanceolate, margins slightly undulate, sessile. Inflorescence ca. 6 cm long, many flowered. Floral bracts lanceolate. Flowers 4 – 7 mm across, green. Sepals sub-equal, lanceolate, externally glandular pubescent. Petals triangular, obtuse, weakly falcate, inner margin crenulate. Lip simple, spurred, fleshy, oblong, deflexed at base; spur ca. 1cm long, slender, curved. Column ca. 3 mm long.

Flowering: September

Altitude: ± 2400 m

Specimen examined: East Nepal, Sagarmatha zone, Solukhumbu district, Surke to Lukla, 2400 m, 12 September 2011, *S. K. Rai, J. P. Gajurel, S. Devkota, M. Nobis, S. Shah & B. Rai,*: X116, KATH. **[Fig. 2]**

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