Pattern of Tree Species Richness along the Elevation Gradient of Modi River Basin in Annapurna Conservation Area, Central Nepal

A Dissertation Submitted to Partial Fulfillment of the Requirements for the Master's Degree in Botany

Department of Botany

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Symbol number: 347/072

T.U. Regd no: 5-2-19-482-2010

August, 2020

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RECOMMENDATION LETTER

This is certified that the dissertation work entitled **"Pattern of Tree species richness along the elevation gradient of Modi River basin in ACA, Nepal"** submitted by "**Ram Prasad Khanal"** has been carried out under our supervision. To the best of our knowledge, this research has not been submitted for any other degree, anywhere else. We therefore, recommend this dissertation work to be accepted as a partial fulfillment of Masters' degree in Botany from Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

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I, hereby declare that the dissertation work entitled "**Pattern of Tree species richness along the elevation gradient of Modi River basin in ACA, Nepal"** is carried out by myself and has not been submitted elsewhere for any other academic degree. All the sources of information have been specifically acknowledged by reference wherever adopted from other sources.

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LETTER OF APPROVAL

The dissertation work entitled **"Pattern of Tree species richness along the elevation gradient of Modi River basin in ACA, Nepal"** submitted by **Ram Prasad Khanal** has been accepted for the examination and submitted to the Amrit Campus, Tribhuvan University for the partial fulfillment of the requirements for Masters' degree in Botany (Ecology).

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CERTIFICATE OF ACCEPTANCE

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ACKNOWLEDGEMENT

I express my gratitude to Prof. Dr. Mohan Prasad Devkota, Head of Department of Botany, Amrit Campus, Tribhuvan University for supervising this dissertation and for his kind, continuous support, inspiration and gracious words of encouragement throughout my dissertation work.

I am deeply indebted to respected Co-supervisor Dr. Shiva Devkota for his kind, continuous guidance, constructive feedback, constant encouragement and precious support in the entire dissertation work.

I am heartily thankful to Dr. Laxmi Joshi Shrestha Coordinator of Department of Botany, Amrit Campus for providing me the necessary facilities and administrative help.

I also thankful to Prof. Dr. Kanta Poudyal and Prof. Dr. Mukesh Kumar Chettri for their valuable suggestions and guidance during thesis work.

I also want to express heartful thanks to Mrs SP Devkota, friends Mr. Deepak Tamang and Mr. Nabin Kumar Darai for their constant and precious support in the entire field work.

I am thankful to my friend Mr. Keshab Acharya for his constant and precious support in the Statistical work. I am very much thankful to seniors Ms. Shanta Budhamagar, Ms. Gyanu Thapa magar, Ms. Susmita Simkhada, Ms. Rasmi Paudel, Ms. Anu Paudel and juniors Mr. Dashrath Joshi and Mr. Bishal Subedi for their constant support and also thankful to those supportive hands for their direct or indirect help during the study.

Lastly, I express my kind appreciation to my batch friends for their kind support. I am grateful to my parents, family members and relatives for their help during my study.

Ram Prasad Khanal

LIST OF ABBREVIATION

p	Level of Significance
dbh	Diameter at Breast Height
ha^{-1}	Per hectare
IVI	Importance Value Index
masl	Meter above sea level
°C	Degree Centigrade
°F	Degree Fahrenheit
MDE	Mid domain effect
DNPWC	Department of National Parks and Wildlife Conservation
KATH	National Herbarium and Plant Laboratories, Godavari, Lalitpur
ACA	Annapurna Conservation Area
ACAP	Annapurna Conservation Area Project
MBC	Machhapuchhre Base Camp
NTNC	National Trust for Natural Conservation
IUCN	International Union for Conservation of Nature
LRMP	Land Resources Mapping Project
R^2	Coefficient of determination
SPSS	Statistical Package for the Social Science
DCA	Detrended correspondence analysis
CCA	Canonical correspondence analysis
GLM	Generalized linear model

ABSTRACT

Elevational diversity gradient is an ecological pattern where biodiversity changes with elevation. Main aim of this study was to find the relationship between species richness along the elevational gradients in southern aspect of Modi River basin Annapurna Conservation Area, Central Nepal. The study was carried out in three elevational zones namely lower (1000-1800m), middle (2000-2800m) and upper elevation (3000-3800m). Starting from 1000m at Birethanti and ending to 3800m at Machhapuchhare Base camp at an interval of 200 m. Two transects having 25m × 2.5m sizes were laid at each elevation band. R- Software, SPSS- Software and Microsoft Excel were used to perform the statistical analysis. All together 30 tree species belonging to 27 genera and 21 families have been documented. Among the 21 families Fabaceae was found to be the largest family having highest number of genera and species followed by Betulaceae and Anacardiaceae. Species richness of tree species showed bimodal pattern of distribution with elevational gradients. The tree species richness significantly differs along the elevational gradients within different sites. Tree species like *Alnus nepalensis*, *Bombax ceiba* were dominant in lower elevational zone; *Rhododendron arboreum*, *Alnus nepalensis* were dominant in middle and *Betula utilis*, *Rhododendron arboreum* were observed dominant in upper elevational sites. The size class distribution diagram of overall tree species showed reverse J shaped pattern indicating a good regenerating capability of the forest. The regeneration of *Alnus nepalensis*, *Rhododendron arboreum* and *Betula utilis* were higher in comparison to other tree species which was indicated by the higher density of 0-20 size classes of them. The Canonical Correspondence Analysis (CCA) diagram shows elevational gradient strongly affected the study area sites vegetation.

Keywords: Tree species richness, elevational gradient, bimodal pattern, Annapurna Conservation Area.

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CHAPTER - ONE

INTRODUCTION

1.1 Background

The Himalayan region is known for its rich biological diversity and has always been paradise for botanists (Pande *et al*., 2002). The general mechanisms responsible for the distribution of biodiversity can be explore and understood by the influence of elevational pattern on species richness and diversity (McCain, 2007). Its diversified landforms, land relief and environmental condition support an array of forest types and vegetation patterns. Vegetation with in a forest is greatly affected by differences in the microclimate, aspect and elevation. Vegetation changes from tropical to subtropical and temperate to alpine regions of Nepal (Stainton & Schilling, 1973; Jackson, 1994). There is a great variation in the vegetation along the rainfall gradient across the country along the different elevational gradient. Thus, this study aimed at exploring the relationship between elevational gradient on tree species richness and distribution on southern aspect of ACA regions.

1.1.1 Environmental factors and Diversity

Biodiversity is essential for human survival and economic well being and for the ecosystem function and stability (Singh, 2002). Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occurs (Rosenzweig, 1995; Silvertown & Huston, 2006). Species richness is a simple and easily interpretable indicator of biological diversity (Peet, 1974). Environmental gradients related to climate, topography and vegetation are most critical environment factor influences the broad scale pattern of species richness in mountain areas (Cantlon, 1953; Moura *et al*., 2016). For the mountain areas, Land use and geographic factors such as aspect and elevation, slope degree and fluctuations are considered as the main topographic factors that affecting the vegetation diversity and distribution patterns indirectly (Sanders *et al*., 2007; Sanders & Rahbek, 2012). The light environment has a significant effect on the vegetation. The canopy covers of trees check the solar radiation which has direct influence on the diversity of ground vegetation. (Panthi *et al*., 2007) have noticed the significant correlation of moisture with canopy cover and found canopy as the main underlying environmental gradient for species richness and composition. Veetas, (1997) found that the large scale canopy disturbance will reduce the diversity and change the plant species composition. Sagar *et al*., (2008) have concluded that woody plant canopies and canopy type significantly maintains the light availability on the forest floor which control the pattern of herbaceous floral composition. Jennings, (1999) have summarized forest canopy as a chief determinants to affect plant growth, survival and nature of vegetation. The forest canopy modifies the availability of understory resources such as light, water and soil nutrients (García *et al*., 2006). Hence affect the plant growth and consequently influence s the richness and composition of understory vegetation.

High elevation ecosystems of Himalayan region are the most vulnerable geographic regions of the world and are important regions for detecting the patterns of climate change on regional scale. There is phenomenal increase in temperature as a result of global warming during the past few decades. In Nepal, between 1975 and 2005, mean annual temperature increases at a rate of 0.04°C/year with a higher rate of increase at high elevation (Baidya *et al*., 2007) which in turn has an influence in distribution and regeneration of tree-line species. The structure of tree species diversity in hill forests varies greatly from place to place due to variation of elevation, orientation of slope, nature of soil and type of intensity of disturbance (Vetaas, 2000). Intensity of major threats to forest ecosystems and biodiversity along elevational gradient is directly measure by compositional changes in forest structure. Role of habitat loss due to fragmentation, over exploitation, invasion by alien species and global climate change is premier in disruption of community structure along the elevational gradient, which can be used to assess the status of forest composition and alert for future changes. Natural disturbances such as forest fire, landslides, volcanic activity and climatic change determine forest dynamics and tree density (Burslem and Whitmore, 1999; Masaki *et al.*, 1999). Anthropogenic disturbance may regulate the regeneration dynamics structure and floristic composition of forest (Ewel *et al.*, 1981; Hong *et al*., 1995). Disturbance may increase species richness in old growth forest (Sheil, 1999) and may maintain species diversity (Huston, 2002; Petraitis *et al*., 2004). Frequent and low intensity disturbance like grazing, extraction of fire wood and fodder strongly affects forest structure and the succession of tree species in the forest (Ramírez-Marcial *et al*., 2001). 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 (Lalfakawma *et al*., 2009). Disturbance favors the growth of herbaceous species rather than the woody species (Maitima *et al*., 2009).

The distribution and diversity of plant species in forest depends on the size of the forest or habitat area also with different factors. The species area relationship truly deserves of status of a rule, and then we can confidently use it as a universal tool for understanding and conserving biological diversity. Rosenzweig, (1995) comments that "you will find more species if you sampled a larger area". The larger areas have more species due to availability of more individuals, more habitats and more biogeographically provinces (Rosenzweig, 1995, Bhattarai, 2018). Therefore, area is an important variable in explaining species richness at both broad and finer scales. The influence of area on variation in species richness along the elevational gradient and latitudinal gradient has rarely been considered (Heaney, 2001). Bhattarai & Vetaas (2006) did not observe maximum species richness at the largest area available along the elevational gradient. The areas often decrease with increasing with increasing elevation because of generally steeper terrain towards the higher peaks (Körner, 2000; Lomolino, 2001; Korner & Spehn, 2002). The drought indicating factors i.e. lengths of dry period and cumulative water deficit were more important for determining species distribution (Bongers *et al*., 2009). Along with the elevational gradient, the upper limit of species richness remains high up to a considerable elevational level (2500m) and tree richness increases with increasing moisture in the Indian Himalaya region (Rikhari *et al.*, 1991). The forest has suffered due to increased human activities, which have been the result of change in demography in different parts of the country (Eckholm, 1975). Since last few decades Nepal's forest have fallen under the axe in an unprecedented rate due to high demand for fuel wood, timber and also for agricultural expansions.

Human interferences have a prominent role in changing vegetation structure. These effects were over grazing, wood cutting for fuel and construction activities especially road and infrastructure (El-Juhany & Aref, 2012).

1.1.2 Elevation gradient and species

Elevational gradients can serve as experimental systems to investigate and test several ecological and bio-geographical hypotheses (Körner, 2000). The variations in the climate, soil and elevation are responsible for the range of natural vegetation in the country (Majupuria & Majupuria, 1999). Elevational patterns of species richness and their underlying mechanisms have been long been a controversial issue in biodiversity and biogeographically research and several hypotheses has been proposed in the past decades. Local and regional studies have suggested that area and geometric constraints are two of major factors affecting the elevational patterns of species richness. In the past decades, the most general patterns were the decreasing species richness with increasing latitude (Rapoport, 1952, Willig *et al.*, 2003, Hillebrand, 2004). However as refuse for most species and a surrogate of latitude, elevational gradients of species richness in mountainous regions have received increasing attention in recent years (Rahbek, 1995; Körner, 2000).

Mountain slopes with significant bioclimatic amplitude generally have more species at the bottom than the top (Vetaas & Grytnes, 2002). In mountainous areas, such as the Himalayas, the maximum number of endemic species is expected to occur at high elevations, due to isolation mechanisms (Shrestha & Joshi, 1996). Review of literature on species richness and elevation gradient, found that about 50% studies show a hump shaped trend in species richness with a maximum species at mid- elevation, another 25% show a monotonic decline in species in species richness from low elevation to high elevation (Rahbek, 1995) and remaining shows nearly constant from the low lands to mid-elevation and strong decline further i.e. diversity plateau at low elevations with increasing elevation have found a decreasing trend in species diversity, richness, whereas others have found a hump shaped relationship between species richness and elevation (Vetaas & Grytnes, 2002; Klimeš, 2003). More recent studies show maximum species richness at middle elevation for vascular plants, Pteridophytes however the monotonic decline in species richness as the elevation increase is also found (Vetaas & Grytnes, 2002).

Species richness changes patterns with elevation characterize the vegetation in simple but powerful way (Baniya *et al.,* 2010). General concept about the species richness with the elevation is gradual decrease in species richness as the elevation increases

(Korner & Spehn, 2002). There are three main patterns of species richness patterns a monotonic increase with elevation, a monotonic decrease with elevation and a unimodel pattern (Rahbek, 1995, 2002). The most dominant patterns of species richness along elevation are the unimodel patterns. Which is observed in almost half (C.50%) of the previous studies and is much higher than the monotonically decreasing patterns (C.25%) (Rahbek, 1995, 2005). Elevations and slopes influence the species richness and dispersion behavior of tree species (Eilu & Obua, 2005). Kharkwal *et al.,* (2005) also pointed that elevation and climatic variables like temperature and rainfall are the determinants of species richness. Along with elevation the co-factors like topography, aspects, inclination of slope, soil type, soil texture, nutrients availability, substrate stability etc further effect the forest composition (Holland & Steyn, 1975).

1.1.3 Slope, aspect and vegetation

The species richness and composition patterns 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; Northern and Northeastern slopes have low temperatures and higher soil and air moisture contents as compared to southern and other slopes at the same elevation due to less solar exposure and higher moisture content and evapotranspiration which is akin to other Himalayan areas (Baduni & Sharma, 1996). Kutiel & Lavee, (1999) studies the effect of slope aspect on vegetation and found the significantly higher vegetation cover on north facing slope than on south facing slope. Carmel & Kadmon (1999) concluded on their study of the effect of slope and aspect on vegetation changes that the slope and aspect strongly affect the rate of vegetation change on north facing slopes. Panthi *et al*., (2007) report the effect of aspect on plant species richness and composition and found to be significantly higher species richness on north aspect rather than on the south. Sharma (2012) found significantly higher species richness of vascular plants in north facing slopes compared to the south facing slopes. Aspect is found to be a less significant predictor, but it could improve explanatory ability of precipitation in describing the plant richness pattern. It indicates combined influence of topography and climate in defining plant richness pattern. Shah *et al.,* (2011) had advocated that the heterogeneity in vegetation and species distribution in the Himalayas be characterized by topography, soil, climate and its geographic location.

Several climate-based explanations have been proposed to explain broad-scale diversity patterns, e.g., the Mid-Domain Effect (Colwell & Hurtt, 1994), Productivity-Diversity hypothesis, the Physiological Tolerance Hypothesis, the Speciation Rates Hypothesis and Species-Temperature Hypotheses such as the Metabolic Theory (Sanders *et al*., 2007). However, climate-based water-energy dynamics also appears to be an essential factor that determines patterns of diversity (O'Brien, 1998).

1.2 Research question, justification and limitations, Hypothesis and Objectives

1.2.1 Research questions

- What is the tree diversity and how does it changes in Modi River basin?
- What kind of regeneration pattern of tree species observed in Modi River basin?

1.2.2 Justification of study

Understanding of tree species richness along environmental gradient and how these environmental factors influence the distribution pattern, abundance and co-existence of tree species has becomes a vital issue in ecology. Plant species have their own specific requirements of climatic and environmental condition to grow, persist and reproduce (Bhatta *et al.,* 2015). As the human population increases there is increasing demand on forest resources. Therefore, an investigation of how does utilization of forest resources influence biodiversity can be of importance in the planning of a sustainable forestry in Nepal. In small scale, environmental factors like soil fertility, topography and irradiance can play vital role in species distribution where as on a large scale climatic variables such as pattern of rainfall along with elevation can play a significant role in species distribution (Amissah *et al.,* 2014). An elevational gradient is major predictable environmental factors that change the pattern of species composition in Himalayan region. In context of Nepal; it has broad parallel zone of vegetation ranging from tropical to alpine zone within the short horizontal distance (Jackson, 1994) that provides an ideal situation to explore the plant species richness and distribution along elevational gradient as response to certain environmental condition. Changing climatic gradient is the main impacting factors within the Himalayan ecosystem (Gaire *et al.,* 2014) that affects the change of environmental conditions, availability and condition of resources (Nicotra *et al*., 2010).

Still there are large areas in Nepal yet to be explored to understand the distribution pattern of plants along the elevation gradient. Very few empirical studies have been carried out in Annapurna Conservation Area (ACA), Central Nepal, one of the largest conservation area in the country. Hence, present study has been conducted in the Modi River basin in ACA in Central Nepal to understand the Himalayan elevational gradient in Central Nepal to develop better understanding of climatic effects on tree species diversity and distribution pattern. It will be much fruitful to find out the current status and tree species composition along elevational gradient in sub-tropical to alpine forest of Modi River basin forest of ACA. This will be vital not only for the local indigenous communities of Annapurna region and other Mountainous regions around the globe because they rely heavily on forest and plant resources for their everyday livelihoods, but also for the entire global society because of the iconic value of the Himalayas and its biodiversity for the world.

1.2.3 Hypothesis

The proposed study is driven by following hypotheses:

- There is a significant relation between elevational gradient and diversity of tree species.

1.2.4 Objectives of study

The overall objective of the proposed research is to study the changes in diversity and richness of tree species along the elevational gradient in Modi River basin. The specific objectives are as follows.

- To analyze diversity of tree species and distribution pattern,
- To investigate the patterns of changes in tree species richness.

This study was carried out specifically on the southern slope of subtropical-temperate forest of Modi River basin in ACA region extending from 1000m to 3800m and could not cover additional forest area. Species richness pattern is assessed for tree species only. Due to the limitation of time and resources, analysis of herbaceous species, shrub species and soil quality could not be made. Therefore only Tree species ($\geq$ 6cm dbh) were taken into consideration.

CHAPTER - TWO

LITERATURE REVIEW

2.1 Plant diversity and elevational gradient

Sigdel, (1970) studied the elevational co-related pattern of plant community structure in the Shivapuri National Park, Nepal and found the pattern of distribution of plant species was not uniform according to elevation. He found species richness was highest in the middle range of elevation. Species diversity of tree and shrubs species was higher at 1600-1800m, but for herb species diversity was higher in 1900-2300m. All the ecological parameter of the plant species was higher in 1900-2300m. Except basal area of tree that was highest in site 2300-2732m. Bhattarai & Vetaas, (2003) evaluate the variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalaya, East Nepal. They found species richness has significant hump- shaped patterns along the elevation gradient at 600-800m.

Grytnes & Vetaas, (2002) also used compare the different null models for species rich patterns in the Nepalese Himalayans and observed maximum species richness in between 1500-2500m from 100 to 1500m, species richness increases steeply with elevation where as above 2500m, species richness decrease towards 6000m. Xu *et al.*, (2017) also observed bell-shaped pattern along the elevational gradient. Subedi *et al.*, (2015) studied the distribution pattern of vascular plant species of mountain in Nepal and their fate against global warming. They investigate in upper Manang Region between (2700-6000m) and observed that vascular plant species of Manang has a hump-shaped unimodel relationship with elevation. The species richness increased weakly at the lower elevation and increased sharply up to 3500m, then decreased with increasing elevation. Carpenter, (2005) studied the environmental control of plant species density on a Himalaya elevation gradient. He found that both understory and tree species density showed a humped unimodal response to elevation. Grau *et al.*, (2007) compare the elevational species richness patterns of bryophytes with other plant groups in Nepal, central Himalaya. They also observed clear humped shaped relationship with elevation and marked maximum species richness at the middle Elevation around 2500m.

Behera & Kushwaha, (2007) used an analysis of elevational behavior of tree species in Subansiri district, eastern Himalaya. Data on the tree species were gathered from every 200m steps between 200m to 2200m gradients. And observed tree diversity demonstrated a greater variation along the gradient. They found the alpha diversity, the total number of species per step declined along the gradients. They also observed two maxima in the alpha diversity pattern in 601-1000m; and the other in 1601m-1800m. Wang *et al.*, (2007) explore the elevational patterns of seed plant richness and quantified the effects of area and the mid domain effect (MDE) on the richness pattern in a high mountain area, Gaoligong mountain (215m to 5791m) located in south eastern Tibet, China. They observed that richness and density of seed plants at species, genus and family levels all showed hump shaped patterns along the elevational gradients. They suggested that the mid domain effect significantly influences the patterns of species richness and is likely be stronger for broad ranged species than for narrow ranged ones in the Gaoligong Mountains. Chawla *et al.*, (2008) also observed similar result at an elevation of around 1500m to 4605m.

Panthi *et al.*, (2007) studied plant species richness and composition in a Trans Himalaya inner valley of Manang District, central Nepal. They sampled 80 plots in between 3000-4000m. Their result showed a plateau in species richness at the elevation range of 3000m to 4000m. Although the species richness is significantly slope due to the moisture, Canopy and aspects are the main environmental factors influencing species composition and richness in the dry inner valley of the Trans-Himalaya.

Baniya *et al*., (2010) studied the elevation gradient of lichen species richness in Nepal. They found the total number of lichens as well as the number of endemic species (55 spp.) showed humped relationships with elevation; and their highest richness was observed between 3100–3400m and 4000–4100m, respectively. They observed a unimodal relationship of richness with elevation, with Crustose lichens having a peak at higher elevations (4100–4200m) than Fruticose and Foliose lichens. They also found that the unimodal patterns for all Algal and Cyano-bacterial lichen richness, as well as Corticolous lichen richness, however they observed slightly bimodal relationships of Saxicolous and Terricolous lichen richness along with elevation. The slightly bimodal distributions of Saxicolous and Terricolous lichens were depressed at the elevational maximum of Corticolous lichens. Kang *et al.*,

(2017) investigated a typical pine-oak mosaic mixed forest in the Qinling Mountains, China. In the sample plot, they analyzed the population structure and spatial distribution of the stems for the predominant species, to identify the mechanisms of species coexistence and succession trends of the forest. They observed the population structures of all species were bimodality distributed, with young trees (dbh <1 cm) more abundant than older trees. They also observed that population structure of *Quercus aliena* was bimodal and rather continuous. However, *Pinus tabuliformis* and *Pinus armandii* were discontinuously bimodal, with distinct size deficiencies. Similarly, Liu, (2017) also studied the spatial patterns of vegetation and different life-forms species diversity along an elevation gradient in the middle section of the southern slope of the Tianshan Mountains in Xinjiang, China. He observed diversity indices of the community as a whole presented bimodal patterns. The peak values for the species diversities were found in the transition region between mountain steppe desert and mountain desert steppe (2200–2300m), and in the alpine grassland region (2900–3100m), while maximum species diversities were in the areas of intermediate environmental gradient. He also find out the main environmental factors on the distribution patterns in plant diversity were the elevation, soil water, total nitrogen, available nitrogen, organic matter, and total salt. Acharya *et al.,* (2011) studied about the Orchid species richness along elevational gradients in the central and eastern Himalaya. They observed a humped shaped relationship between Orchid species richness and elevations in Nepal and Bhutan with maximum richness at 1600m corresponding to climate 16°C mean annual temperature. They also found richness of Orchid species that are endemic to central and eastern Himalaya showed a bimodal patterns.

Grau *et al.*, (2012) estimates the pattern of species richness of vascular plants in the south- eastern Pyrenees and nearby mountains of Catalonia. They found the distribution of individual observations along elevation followed a humped pattern, with a maximum of 28,560 at the interval between 1200- 1300m and a marked decrease towards higher and lower elevations. Xu *et al.*, (2011) observed the distribution pattern of plant species diversity in the mountainous region of Ili River valley, Xinjiang and find out that Patrick and Shannon–Wiener index of the plant communities presented a bimodality pattern along elevation on the northern slope; Simpson index and Pielou index showed a partially unimodal pattern whereas on the southern slope all the species diversity indices showed two peaks, though an unobvious bimodality pattern was observed for Patrick index's. Acharya *et al.,* (2011) examined the pattern of trees species richness, density and basal area along an elevation gradient of eastern Himalaya, India. They evaluated the roles of geometric constraints and environmental factors for the observed patterns. They used regression analysis to establish elevational pattern of trees and to relate environmental factors with tree species and density. They observed tree species richness depicted unimodel pattern with a peak at 1500m. The climatic and energy related factors; rainfall, temperature, moisture index, and actual evapotranspiration positively co-related with tree species richness.

Chhetri & Bhattarai, (2013) observed the floristic composition and diversity in upper Manaslu conservation area, Central Nepal. They also found the unimodal relationship of the species composition. Tang *et al.*, (2014) observed elevation patterns of plant richness in the Taibai Mountain, China. They showed that richness of overall plants, seed plants, bryophytes and ferns all showed hump shaped patterns peaking at 1200-1300m along the elevational gradient in between 819m to 3767m.

Bhattarai *et al.*, (2014) describes the variation in vascular plant species richness along elevation gradient of the Karnali River valley, Nepal Himalaya. The regression analysis (GLM) revealed a unimodal relationship of species richness of total vascular plants and all life forms within elevation 2800 to 4400m at local and regional scales. They observed that several factors like climate related water energy – dynamics, species area relationships and local environmental factors play vital role in concern to produce such kind of observed patterns. They also observed that topographic and habitat heterogeneity as well as soil parameters capture the patterns of species richness along elevation gradient at the local scale.

Sujakhu *et al.*, (2014) studied the forest structure and regeneration pattern of *Betula utilis* in Samagaun Valley, Manaslu Conservation area, Nepal. They observed four tree species from the forest in which *Betula utilis* was the dominant tree species with the highest important value index (173.22) in mixed *Betula* forest and 262.96 in pure *Betula* forest while *Abies spactabilis* was the co dominant species 65.95 in mixed *Betula* forest and *Rhododendron campanulatum* was the co- dominant species 37.03 in pure *Betula* forest. They also observed density of *Betula utilis* increased with increase in elevation where as density of other tree species decreased with increase in elevation. Similarly, Sinha *et al.*, (2018) observed an effort of elevation and climate in shaping the forest compositions of Singalila National park in Kangchendzonga Landscape, Eastern Himalaya, India. They encountered 70 species with in transect of 2000m to 3636m. They observed the entire forest regime reflected a negative correlation with the elevation. The climatic variables (evapotranspiration and moisture index) are the factors that drive the final shape of forest community structure. Likewise, Rai & Shrestha, (2018) studied the species richness from cropland to forest in Ghunsa Valley, Eastern Himalaya. They carried out four land types namely cropland, meadow, exploited forest and natural forest. They found species richness was significantly different in different land use types and observed highest species richness in exploited forest type. This is due to in the natural forest only the competitive dominant species can survive but in exploited forest, light demanding as well as shady plants can co-exist; where as in the meadows due to grazing of domestic animals the species richness found lower than exploited forest. However in other hand due to regular use, cleaned up vegetation and anthropogenic disturbances the cropland has lowest species richness among other land use types. Pandey *et al.*, (2016) also studied the structure, composition and diversity in relatively undisturbed forests along an elevational gradient from 2000m to 3900m of Langtang National park in central Himalaya. They studied on 20 sampling plots of two sub zones of the temperate and sub alpine zone. They observed *Tsuga dumosa* was ecologically most important species in the upper and the lower subalpine zone with high important value index (IVI= 124.31). Similarly *Quercus semecarpifolia* and *Lithocarpus elegans* were the ecologically most important species in the upper and the lower temperate zone with IVI of 66.64 and 46.39 respectively.

Rao *et al.*, (1990) observed the floristic composition, diversity, dominance and distribution pattern of species and tree population structure in three stands of a sub-tropical wet hill broad-leaved forest of Meghalaya, India, along a disturbance gradient. They analyzed the effect of disturbance on tree population structure by using density-diameter curves; and found that tree species showed reverse J-shaped and/or negative exponential curves in disturbed stands, whereas they exhibited sigmoid to bimodal mound shaped curves in the undisturbed stand.

Vetaas & Grytnes, (2002) studied the distribution of vascular plant species richness and endemic richness along the Himalaya elevation gradient in Nepal. They found maximum species endemism at 3800-4200m and also found the maximum species richness at 1500-2500m.

Kumar & Ram, (2005) investigated the anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya and observed that disturbance decreased the dominance of single species and increased the plant biodiversity by mixing species of different succession status. They observed species richness and diversity for all the vegetation layers were higher in low elevation–high disturbance forests. Mean tree density decreased from high to moderate and increased in low disturbance. The shrub density decreased from high to low disturbance whereas the reverse occurred for herbs species. Similarly, Kailash *et al.*, (2017) studied about quantitative analysis of vegetation in Nagarjun Hill, Nepal. Quantitative vegetation study was undertaken on the northeast and southwest slope of Nagarjun Hills situated on the northwest border of Kathmandu Valley. They sampled 20m × 20m plots in between 1430m and 2060m Elevation on an elevational difference of 50m. They observed the index of species diversity on the northeast slope was higher at 1610m (17.51) and that on the southwest slope was at 1840m (16.42). They also observed total tree density, total basal area and tree trunk volume were higher on the southwest slope than on the northeast slope. This is presumably due to higher values of girth and height of tree. Dorji *et al.*, (2014) also studied about plant species richness, evenness and composition along environmental gradients in an Alpine meadow grazing ecosystem in central Tibet, China. They also observed that species richness increased with elevation and species evenness increase with soil moisture at lower elevation; but decrease with soil moisture at higher elevation.

2.2 Plant diversity and aspect

Slope aspect is a major topographical feature and is an important factor in mountain ecosystems because it is more stable than other variables such as climatic factors and plant communities (Carletti *et al.,* 2009). Nahidan *et al.,* (2015) established that slope aspect can significantly affect the quantity of SOC, TN, and enzyme activity by altering the rate of litter decomposition and the activity of soil microbes. Soil nutrient conditions, especially C and nitrogen N contents, are affected by slope aspect, which are among the most important factors shaping soil microbial activity. Shuai *et al.*, (2017) investigated the elevational distribution of rodent diversity (alpha and beta diversity) and its underlying mechanisms along the southern and northern slopes of Mt. Taibai, the highest mountain in the Qinling Mountains, China. They observed species richness of rodents on the two slopes showed distinct distribution patterns, with a monotonically decreasing pattern along the southern slope and a hump-shaped elevational pattern evident along the northern slope. They also observed that temperature was an important explanatory factor for the richness pattern along the southern slope, and the mid-domain effect (MDE) was important in explaining the richness pattern along the northern slope. Warren, (2008) also find out that the south facing slopes generally experience higher temperature, greater light intensity and lower moisture than north facing slopes. The plant species with different tolerance levels to these factors might determine their preference for a particular forest type.

Heydari & Mahdavi, (2009) studied the pattern of plant species diversity in related to physiographic factors in Melah Gavan Protected area, Iran. They collect the data from 67 field plots in a systematic randomized design and obtained that the biodiversity is maximum in southern aspect and minimum in eastern aspect. Moreover plant richness was found most in southern aspect while it was not significantly different in other aspects. They also found that biodiversity and richness amongst the elevational classes showed that the low elevations (1400-1500m and 1500-1600m ranges) have the most, while the upper elevations (1800-1900m and 1900-2000m ranges) have the least diversity.

Cottle, (1932) studied the vegetation on north and south slopes of mountains in south western Texas. He observed there are marked differences in the species found on the north and south slopes. He found that environmental conditions on the southern slope are much less favorable to plant growth as compared to northern slope. Water content of soil is 5 to 16 percent lower; evaporation is 24 to 44 percent higher; soil temperatures are 10° to 20° F. higher at the 2-inch level, and also much higher at a depth of 12 inches. Humidity is 5 to 11 percent lower, and wind velocity much greater. He also observed that the cover of vegetation was found to be less than one half as great and the production of dry matter only about one- twentieth of that on the north slope. Whereas several factors interact to produce these conditions, the water relation is being the controlling one.

Albaba, (2014) studied the effects of slope orientations on vegetation characteristics of Wadi Alquf Forest Reserve (WAFR) West bank Palestine. He addressed the effects of slope orientation on vegetation characteristics of WAFR flora, trees and under story layer. He observed the slope affects on the composition, structure, density of the plant communities, tree canopy and diameter at breast height (dbh). He selected two representative sites i.e. north facing slope aspect and south facing slope aspect and found that the north facing slope aspects has higher diversity in compare to south facing slope aspect. This is probably due to the fact that north facing slope aspects usually provide more suitable niche for many plant species to grow and reproduce. He also found that the slope aspect has no significant effects on the tree canopy.

Zeng *et al.*, (2014) studied the effects of slope aspect and slope position on plant diversity and spatial distribution in the hilly region of Mountain Taihang, North China. They collect samples along 32 quadrats at different slope position (upper, medium and lower) of southern and northern slopes. And found shrubs were better distributed in southern slopes while herbs were better distributed in northern slopes. Måren *et al.*, (2015) studied about how does slope aspect impact forest stand characteristics and soil properties in a semi arid trans-Himalayan valley. Here they analyzed the forest stand characteristics, carbon stock and soil properties of north and south facing slopes. They found that *Pinus wallichiana* as dominant and *Juniperus indica* as co-dominant species in both aspects. However *Betula utilis* and *Abis spectabilis* were only recorded in north facing aspects. They found that there is a not vast difference of carbon stock and soil properties (except for potassium highest in south facing slope) in between both aspects.

CHAPTER - THREE

MATERIALS & METHODS

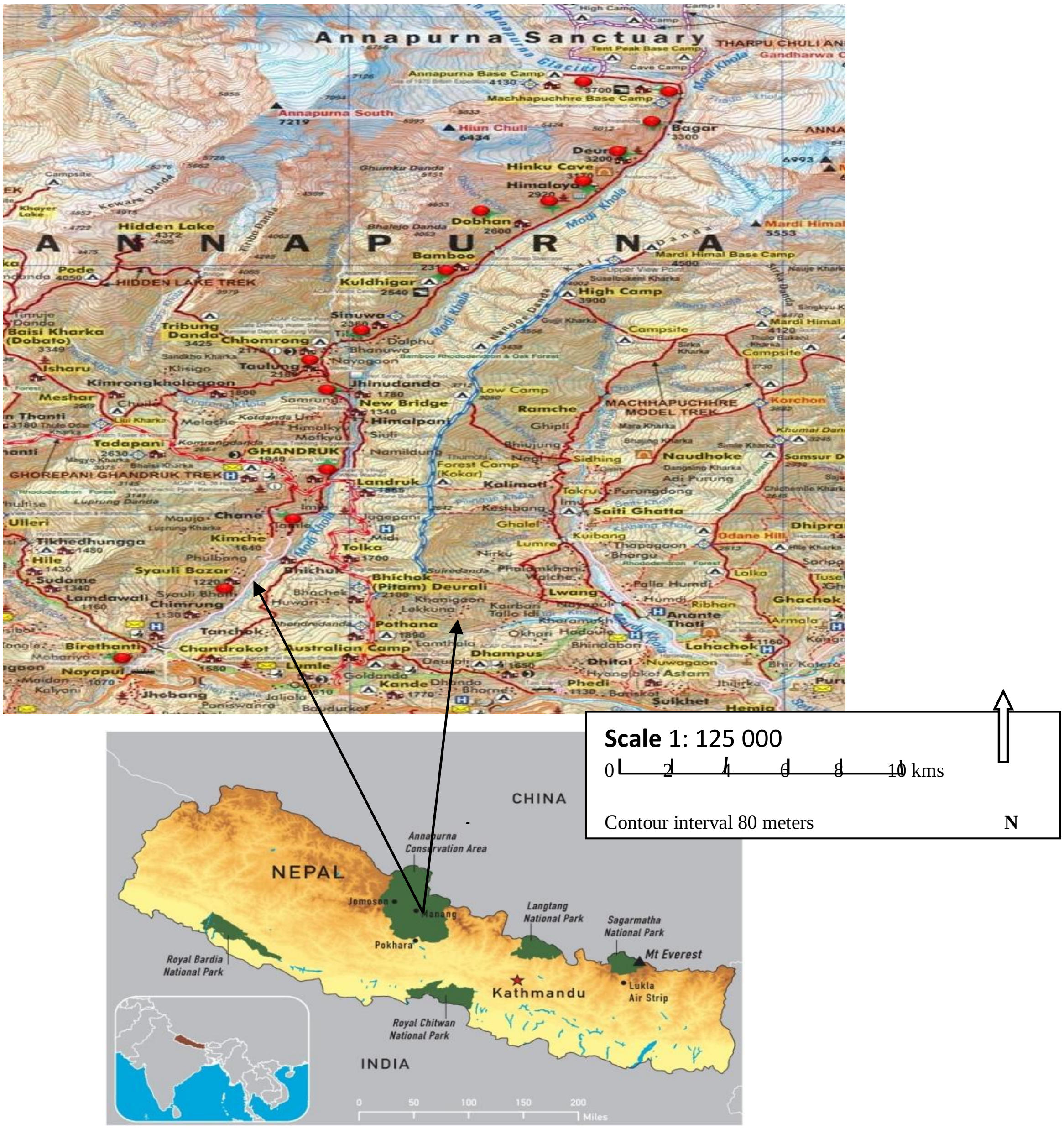
3.1 Study area

3.1.1 Annapurna Conservation Area

Annapurna Conservation Area (ACA) located in Nepal's western region (28° 13'48" - 29° 19' 48"N latitude and 83° 28'48" - 84° 26'24" E longitude) covers 7629 sq.km and is the largest protected area of the country (NTNC 2013; DNPWC 2016). It was officially gazette in conservation 1992 and covers 7629 km^2. Within this conservation area, elevation varies from less than 1000m to 8091m, the height of Mt. Annapurna-I the 10^{th} highest peak in the world. Due to the unique geographical features and various climatic conditions (from sub-tropical and temperate to arid desert type) the area is endowed with excellent habitats for diverse flora and fauna. Being located at the central part of Nepal it occupies an area of great Phyto-geographical significance in the sense of being the "platform", where eastern and western Himalayan floristic elements merge together. It contains over 1352 species of flowering plants, 128 species of wild mammals, 514 species of birds, 40 species of reptiles and 23 species of amphibian (Baral *et al*., 2019). The Annapurna region, where lies some of the highest peaks in the world is one of the most popular trekking destination for the visitors in Nepal.

3.1.2 Modi River Basin en route to Annapurna Base Camp

The proposed study covered the area from Birethanti to Annapurna Base Camp or up to tree line along the Modi River basin. Modi Khola valley lies in the south-western part of the ACA (Fig1). Modi Khola is a tributary of the river Kali Gandhaki, one of the main Himalayan antecedent rivers entering Nepal from the high Tibetan plateau of the China. Modi Khola originates from the northern part of Annapurna Sanctuary Area. The study area is spread over Annapurna Rural municipalities of Kaski District of Gandaki Provience. Phytogeographically study area represents sub-topical to alpine regions of Nepal Himalayas varying from 1000m to 3740m (tree line). Lumle, being the wettest area with 5550mm of annual rainfall in the country has a great climatic significance. This valley is also important in the sense that a west Himalayan element like *Aesculus indica* terminates its eastward distribution here (Shakya *et al*., 2002).



Source: Nepal Map Publisher Pvt. Ltd. 2018.

Fig. 1: Map of Study Area (Modi Khola Valley)

3.1.3 Climate

Climate varies from subtropical monsoon and humid at the lower elevations to cold wet winter in the alpine region (Shrestha & Ghimire, 1996). The most influencing factors of central Nepal are two great mountain ranges; the great Himalayan and the Siwalik range. Great variation in Elevation of Kaski District causes the variation in climate as well. Generally the climate of Kaski District ranges from Sub tropical to cold Alpine type. The climate of the study site Modi River basin is Subtropical to Temperate in nature which lies in south-western part of the ACA.

The meteorological data were taken from nearby Pokhara Airport station. The climatic data from Ghandruk station and Lumle station were unavailable; due to internal issues of Department of Hydrology and Meteorology. High rainfall and considerably humid atmosphere generally characterized the climate of ACA. Climatic data from 2007 to 2017 showed the monthly average maximum and minimum temperature of Pokhara Station to be 31.25˚C and 7.25˚C in the month of June and January, respectively (Fig2). ACA receives a good amount of mean annual rainfall 3621.73mm at Pokhara. This receives a good amount of rainfall from June/July to August/September with an average annual rainfall of 2934.97mm in Pokhara station. The highest monthly rainfall occurs in July (893.64mm) and the lowest in December (3.95mm) within Pokhara station (Fig.2). It also represents that the monthly average maximum and minimum relative humidity of Pokhara station to be 82.42 and 59.86 percent in the month of August and April respectively. (Source: Department of Hydrology and Meteorology, Babarmahal, Kathmandu).

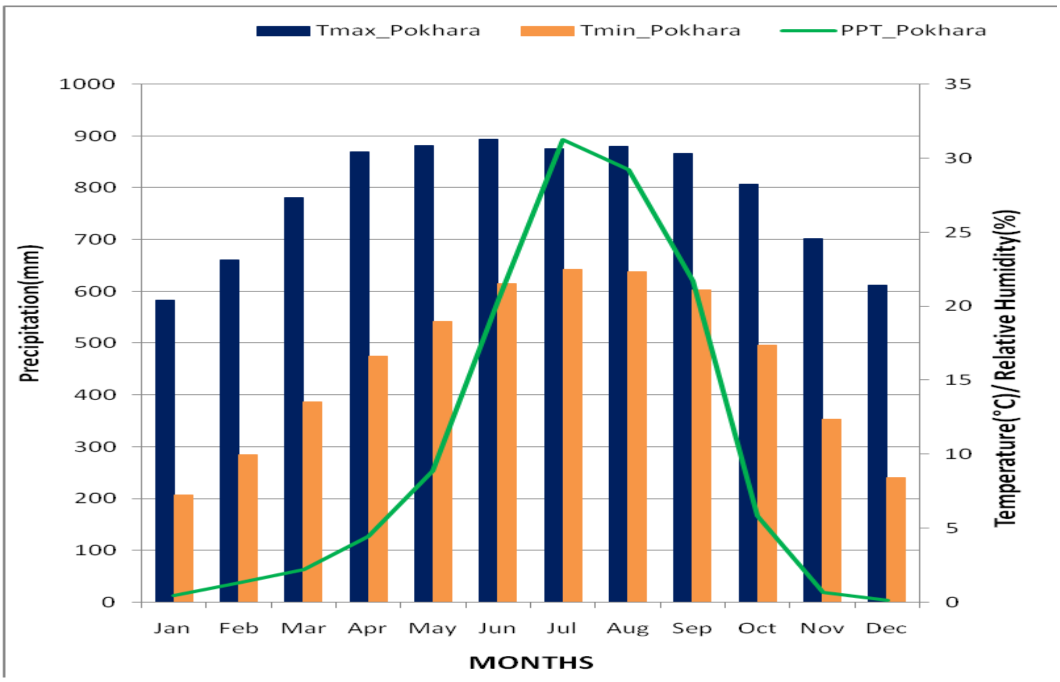


Fig. 2: Eleven years (2007-2017) average monthly minimum and maximum temperature, precipitation and relative humidity recorded at Pokhara weather station (nearest station from Modi River basin). (Source: Department of Hydrology and Meteorology, Babarmahal, Kathmandu. 2019)

3.2 Biodiversity of ACA

3.2.1 Flora

ACA is considered as the wide variation in elevation and topography, which consist of higher number of biodiversity. A total of 1352 plant species have been recorded in the Annapurna Conservation Area (Baral *et al*., 2019). In a route of less than 50 km, tropical hardwood trees (such as *Shorea robusta, Terminalia tomentosa, Eugenia jambolana,* and *Bombax ceiba*), Pine clad hills and Oak forests at medium elevations then Rhododendrons and Firs that give way to Birches and Junipers before the vegetation changes to alpine scrub lands, grasslands, meadows and finally a tree less zone can also be found (Christensen & Clausen, 2009).

The subtropical zone west of Modi is heavily disturbed by human settlement and encroachment; south facing slopes of the temperate zone are dominated by pure Rhododendrons forests. Species distribution in this region are: *Schima wallichii, Castanopsis indica, Alnus nepalensis, Bombax malabericum, Viburnum erubescens, Daphniphyllum himalayense, Rhododendron arboreum, Prunus cerasoides, Quercus semecarpifolia, Acer pectinatum, Phyllanthus emblica, Ficus glaberrima, Ficus roxburghii Potentilla* species and shrubs species above (Adhikari & Fischer, 2010).

Quick looks at the vegetation found in the valley reveals that much of the original vegetation types have been heavily exploited by the local communities along the basin.

Table1: Dominant tree species in Modi Khola Valley within Annapurna Conservation Area.

Bioclimatic Zone	Elevation (m)	Dominant tree species
Lower Sub-Tropical	1001-1500	*Shorea robusta, Bombax ceiba, Phyllanthus emblica, Lyonia ovalifolia, Macaranga indica*
Upper Sub-tropical	1501-2000	*Alnus nepalensis, Daphniphyllum himalayense, Engelhardtia spicata, Castanopsis indica etc*
Lower Temperate	2001-2500	*Schima wallichii, Prunus cerasoides,*

		Rhododendron arboreum, Ilex excelsa etc
Upper Temperate	2501-3000	*Engelhardtia spicata, Castanopsis indica* *Acer pectinatum, Acer acuminatum etc.*
Lower Sub-Alpine	3001-3500	*Tsuga dumosa, Aesculus indica, Rhododendron arboreum, Quercus semecarpifolia., Quercus glauca, Quercus lamellose, Laurel spp.* etc.
Upper Sub-Alpine	3501-4000	*Rhododendron lepidotum, Betula utilis, Juniper sps.*

Sources: Dobremez, 1972; LRMP, 1986

3.2.2 Fauna

The variation in elevation and topography along with the existing forest cover provides a wide range of habitats. It harbors 128 species of wild mammals, 514 birds, 20 fish, 23 amphibians, 40 reptiles and 348 butterflies (Baral *et al*., 2019). It is well known that it provides habitat for Himalayan Musk deer (*Moschus leucogaster*), red panda (*Ailurus fulgens*), snow leopard (*Panthera uncia*), lynx (*Felis lynx*), Himalayan brown bear (*Ursus arctos*), blue sheep (*Pseudois nayaur*), Tibetan argali (*Ovis ammon*), grey wolf (*Canis lupus*), leopard cat (*Prionailurus bengalensis*), Himalayan Monal (*Lophophorus impejanus*), Satyr tragopan (*Tragopan satyra*) and Cheer pheasant (*Catreus wallichii*) among other species (Adhikari & Fischer, 2010). Among these animals, the Musk deer, the Red panda, and the Snow leopard are on the world list of endangered species (IUCN 2019). The Annapurna region also provides excellent habitats for various types of spring and autumn birds migrating from India and China as well as from other regions.

3.2.3 Culture & Ethnicity

The conservation area has lots of ethnic diversity and culture. Gurung and Magar are the dominant ethnic group present at Annapurna conservation area. The major settlements in ACA are Ghandruk the largest Gurung village. The settlements above 3000m are of temporary nature. The Major tourist destinations are Birethati, Ghandruk, Jhinu, Chomrong, Himalaya, Deurali, MBC and ABC. Most of the people living in the ACA are subsistence farmers and livestock owners. Few households are involved in tourism business. The lower reaches of Modi between 1000m elevation to 2000m are primarily used for cultivation of agricultural products. A great number of the male members from Gurung and Magar community serve in the Nepalese army, British army and Indian Gurkha army. The Lama and Thakali communities are concentrated at higher elevation. They all have their own distinct culture and traditions. Rai, Chettri, Tamang and Brahimins are other inhabitants of this region. Hence many temples and monasteries can be found in this area (Baral *et al.*, 2008).

3.3 Study design

Study sites in the ACA were selected at fifteen different elevational bands from Birethati 1000m to Machapuchre base camp 3800m with an interval of 200m. Sites were selected along the Modi River basin on southern aspect.

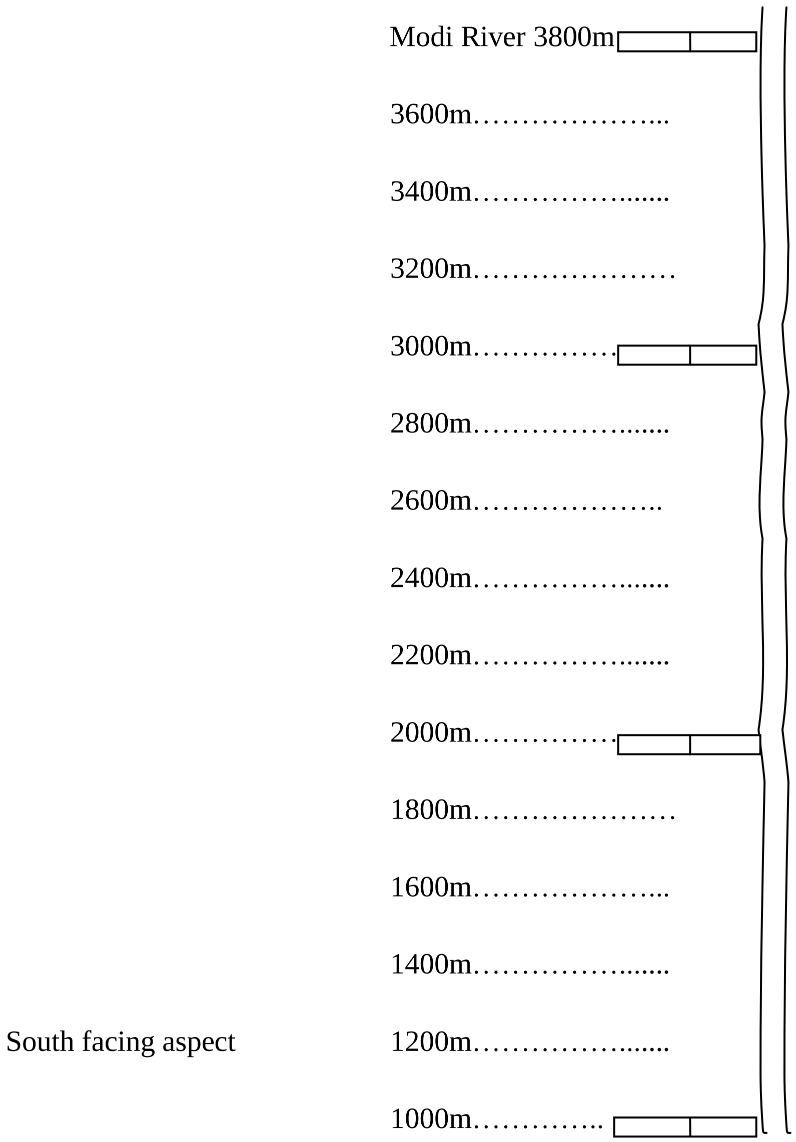
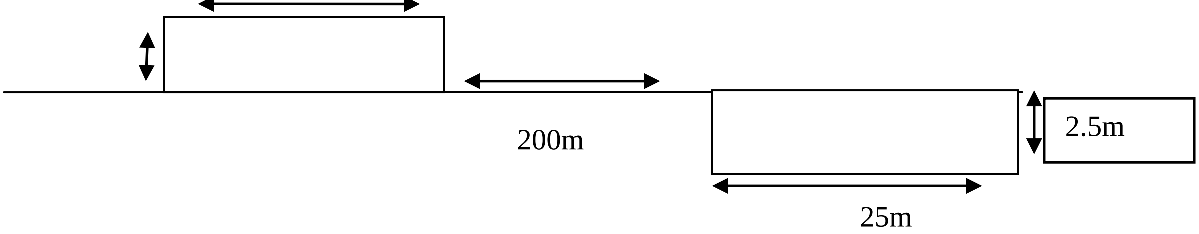


Fig. 3: Elevation



(Scheidegger *et al.*, 2010)

Fig. 4: Quadrats layout for tree sampling

3.3.1 Quadrats.

The research quadrats were laid out from 1000m (Birethanti) up to 3800m (in between Machhapuchre and Annapurna Base Camp) in every 200m elevational level. Two quadrats having 25m × 2.5m size were laid at each elevation gradients within an interval of 50m horizontal distance on southern aspect along the main trail (Scheidegger *et al.*, 2010) with the help of measuring tape (Cai Hong company). Ten quadrats were laid on each elevational site, and total 30 quadrats were laid to complete the entire field work.

3.3.2 Field work

The study area was visited twice (first in monsoon, 19th August- 25th August, 2018 and second in pre-winter season, 22nd November- 24th November, 2018) for data collection. Quadrats were laid down with help of Global Positioning System (GPS) coordinates and nylon rope. Tree species occurring inside each transect were recorded. Associated plant species were noted down inside the each quadrats. Tree species along the main trail was noted down by general observation. Latitude, Longitude and elevation of each sample quadrats were recorded by Global Positioning System (GPS, Garmin 60csx). To determine the floristic composition of forest i.e. tree species having DBH 1.37 m ≥ 6cm were recorded using Diameter tape (20m × 5m Yammayo Company). Canopy coverage was estimated with the help of densiometer (Spherical densitometer model- A, Robert E. Lemmon, forest densiometer) and tree height (Angel) was determined by Clinometers (Germany).

3.3.3 Plant collection and identification

Most of the plant species were identified in the field with the help of 'Flowers of the Himalaya' (Polunin & Stainton, 1984) and its supplement (Stainton 1988), (Storrs & Storrs, 1998). Species that could not be identified in the field were collected, tagged, dried along with their local names and brought to the Amrit Campus, Lainchaur; KATH for further identification. Digital photographs of live plant species were taken in the field and the photo-number and tag were noted. The unidentified specimens were compared with relevant specimens deposited at Amrit Campus and further confirmed with those deposited at KATH Herbaria. For nomenclature of species, APG III system (Chase & Reveal, 2009) and Press *et al*. (2000) were adopted. The latest taxonomic literature (www.floraofnepal.org or www.efloras.org) were also visited for unresolved species.

3.4 Data analysis

3.4.1 Numerical Analysis

Quantitative data were collected with the help of field data sheet and analyzed for coverage, density, frequency, basal area and Importance value index (IVI) according to Zobel *et al*., (1987). The diversity index (H') was calculated by using Shannon-Wiener's index. For the calculation of Evenness of species, the Pielou's Evenness index (Ep) was used (Pielou, 1966). Simpson's index (D) and Shannon-Wiener's index (H') were calculated following (Shannon & Weaver, 1949). Basal area of tree was calculated. The formulae used for the calculation of these attributes are given below:

Density represents the numerical strength of the species in a community. Density is the number of individuals per unit area. It represents the numerical strength of the species in the community. It is usually expressed as number per hectare.

Density (D) (P/ha) = $\frac{\text{Total no. of Plants of any species}}{\text{Total no. of Quadrats studied} \times \text{Area of quadrats}} \times 10000$

(Zobel *et al*., 1987)

Relative density is a proportion of density of a species with respect to total density of all species.

Relative density (RD) (%) = $\frac{\text{Density of individual species}}{\text{Total density of the all species.}} \times 100$

Frequency is defined as the number of sampling units in which the particular species occur, thus it shows degree of dispersion of a species in terms of percentage occurrence. The frequency and relative frequency was calculated using following formulas.

Frequency (F) (%) = $\frac{\text{Number of Quadrats in which species occurred}}{\text{Total number of Quadrats samples}} \times 100$

(Zobel *et al*., 1987)

Relative frequency is frequency of a species in relation to all the species.

$$\text{Relative frequency (RF) (\%)} = \frac{\text{Frequency of a species}}{\text{Total frequency of the all species}} \times 100$$

Basal area refers to the ground, actually penetrated by the stems in the soil. It is expressed in square meters. Basal area is regarded as an index of dominance of a species. Higher the basal area, greater is the dominance. Basal area of a tree species was determined by measuring either the diameter or circumference of the average tree at the breast height (1.37m) and was calculated using the following formula of

Basal Area (BA) (m^2) = $\pi D^2/4$

(Zobel *et al*., 1987)

Where,

π = 3.14

D = Diameter at breast height

Basal area in each plot was obtained by the summation of Basal Area of all trees in the quadrat and is given as m^2/ha.

The Relative Basal Area was calculated as follows:

$$\text{Relative Basal Area (RBA) (\%)} = \frac{\text{BA of a species}}{\text{Total BA of all species}} \times 100$$

Importance value index (IVI) gives the overall importance of each species in the community. It was calculated as the sum of relative values of density, frequency and basal area for trees. Relative values were obtained by the following relation.

Importance Value Index (IVI) = RD+ RF+ RBA

(Zobel *et al*., 1987)

Where,

RD = Relative Density

RF = Relative Frequency

RBA = Relative Basal Area

Species diversity is the combination of species richness and species evenness. Species richness is the number of species per sampling unit. Species evenness is the distribution of individuals among the species. Evenness is a maximum when all the species have same or nearly equal number of individuals. Species diversity can be expressed in single index number. Among the several indices most commonly used two indices are Simpson's index (Simpson, 1949) and Shannon-Wiener's index (Shannon & Weaver, 1949). Simpson's index (D) reflects the dominance because it is more sensitive to the most abundant species than the rare species.

Following relations were used to calculate Simpson's (D) and Shannon- Wiener (H') indices.

$H' = -\sum pi \times lnpi$

Where,

H' = Shannon's diversity index,

Pi = species proportion (based on species count)

ln = natural logarithm.

Simpson's Index (D) = $\sum$n (n-1) / N

(N-1)

Where,

n = the total number of organisms of a particular species

N = the total number of organisms of all species

Species richness is simply the total number of species (S) in a given ecosystem. It includes Margalef's equation and Menhinick's equation and is based on the assumptions that a relationship between S and N, total number of individuals, exists.

Menhinick's index (MeI): Menhinick's index is expressed as

$MeI = S / \sqrt{N}$,

(Whittaker, 1977)

Where,

N= Number of individuals in the sample,

S= Number of species.

Margalef's index (MI): Margalef's index was used as a simple measure of species richness

(Margalef, 1958)

Margalef's index (MI) = (S – 1) / ln N

Where,
S = total number of species
N= total number of individuals in the sample
ln = natural logarithm.

Evenness Index (Ep): For calculating the evenness of species, the Pielou's Evenness Index (Ep) was used (Pielou, 1966).

Ep = H' / ln S

Where,
H' = Shannon – Wiener diversity index.
S = total number of species in the sample.
ln = natural logarithm.

Size class distribution diagram was used to predict regeneration behavior of trees. All the trees were divided into DBH classes of 20 cm interval and density of trees in each diameter class was calculated. Size class distribution diagram was prepared by plotting diameter class on x-axis and density on y-axis (Barbour *et al*., 1999).

3.4.2 Statistical Analysis

Statistical test were done in SPSS (IBM Statistics version 21) Packages. All the data of studied area were gathered and entered as a data matrix. The dataset of sample by species matrix with 30 quadrats and 30 species was used for analyzing species composition. The effect of environmental variables and Species parameters were evaluated by linear regression. Canonical Correspondence Analysis (CCA) is a direct gradient analysis (ter Braak 2002). The gradient length obtained from DCA greater than 2.5 SD units are allowed to use Canonical Correspondence Analysis (CCA) to relate the species composition to the elevation. CCA displays three pieces of information simultaneously samples as plots, species as symbols and environmental variable as arrows or points (Palmer 2007). The change in species number through each of the site and quadrat was analyzed through an application of R Studio by R Console version 3.5.1 (R Development Core Team, 2012). Vegan package in R was used for Detrended Correspondence Analysis. The SPSS (IBM Statistics version 21) software was also used for regression graphics while bar plots were drawn using Microsoft Excel (Microsoft Office 2008).

CHAPTER - FOUR

RESULTS

4.1 Family and Genera composition

A total of 30 tree species were documented from study area, belonging to 27 genera and 21 families. Among 21 families, Fabaceae was the largest family that contains four genera and four species, followed by Betulaceae and Anacardiaceae both containing three species belonging to two genera. Many families like Rosaceae, Moraceae and Meliaceae contained only single genera and species. However, Betulaceae family contained higher number of individuals (86) followed by Ericaceae (58) and Myrsinaceae (21).

Table2. Family, genera and species enumerated in the three elevational zones

S.N.	Families	No of genera	No. of Species	No. of individual
1	Fabaceae	4	4	6
2	Betulaceae	2	3	86
3	Anacardiaceae	2	3	12
4	Juglandaceae	2	2	10
5	Ericaceae	1	1	58
6	Myrsinaceae	1	1	21
7	Sapindaceae	1	2	10
8	Lauraceae	1	1	8
9	Salicaceae	1	1	8
10	Malvaceae	1	1	7
11	Theaceae	1	1	6
12	Fagaceae	1	1	4
13	Araliaceae	1	1	3
14	Euphorbiaceae	1	1	3
15	Hypericaceae	1	1	2

16	Adoxaceae	1	1	1
17	Apocynaceae	1	1	1
18	Daphniphyllaceae	1	1	1
19	Moraceae	1	1	1
20	Meliaceae	1	1	1
21	Rosaceae	1	1	1
	Grand total	**27**	**30**	**250**

4.2 Distribution of tree species across elevational gradient

A total of 30 tree species were found along the study trail (Appendix 4). *Rhododendron arboreum* had wider distribution appearing in five elevational gradients from 1000m to 3800m followed by *Alnus nepalensis* and *Schima wallichii* with appearances in four elevational gradients respectively. *Betula utilis, Macaranga indica, Rhus javanica, Rhus succedanea* and *Persea odoratissima* have appearances in three elevational gradients. Whereas eight species have appearances in two elevational gradients and fourteen species have appearances in one elevation gradients only (Appendix 3).

4.3 Community structure of tree species

Lower Elevational Zone (1000-1800 m)

In this range *Schima wallichii* was the highest frequency was achieved as 80% and relative frequency 13.79%. The lowest frequency and relative frequency were 20% and 3.45%, respectively. Likewise, the density of individual tree species ranged from 448 stem/ha to 16 stem/ha. The total density of all tree species was 1184 stem/ha. The dominance of the individual tree species ranged from 50.24 m^2/ha – 0.0314 m^2/ha. Similarly, the important value index was found to be highest for *Alnus nepalensis* (98.77) and followed by *Bombax ceiba* (39.41) and *Engelhardtia spicata* (33.22), while the other species like *Bauhinia purpurea, Daphniphyllum himalayense, Erythrina arborescens, Prunus cerasoides* and *Adenanthera pavonina* showed least IVI (4.83). In this range canopy was dominated by *Alnus nepalensis, Bombax ceiba, Choerospondias axillaris* and *Schima wallichii* but sub canopy was well dominated by *Macaranga indica* and *Daphniphyllum himalayense*. Altogether 18 tree species were recorded from this zone. Table 3 shows the quantitative vegetation analysis of lower elevational zone.

Table3. Frequency (F%), Relative Frequency (RF), Density (D), Relative Density (RD), Basal area (BA), Relative Basal Area (RBA) and Importance Value Index (IVI) of Tree species in lower elevational zone.

Species name	**D/ha**	**RD (%)**	**BA (m^2/ha)**	**RBA (%)**	**F (%)**	**RF (%)**	**IVI**
Alnus nepalensis	448	37.84	50.240	50.59	60	10.34	98.77
Bombax ceiba	112	9.46	22.891	23.05	40	6.90	39.41
Engelhardtia spicata	96	8.11	18.086	18.21	40	6.90	33.22
Schima wallichii	96	8.11	2.985	3.01	80	13.79	24.91
Persea odoratissima	112	9.46	1.286	1.30	40	6.90	17.65
Macaranga indica	48	4.05	0.246	0.25	60	10.34	14.65
Brassaiopsis hainla	48	4.05	0.407	0.41	40	6.90	11.36
Quercus semecarpifolia	64	5.41	2.269	2.28	20	3.45	11.14
Holarrhena pubescens	16	1.35	0.283	0.28	20	3.45	5.08
Juglans regia	16	1.35	0.196	0.20	20	3.45	5.00
Choerospondias axillaris	16	1.35	0.126	0.13	20	3.45	4.93
Ficus oligodon	16	1.35	0.071	0.07	20	3.45	4.87
Toona ciliata	16	1.35	0.071	0.07	20	3.45	4.87
Bauhinia purpurea	16	1.35	0.0314	0.03	20	3.45	4.83
Daphniphyllum	16	1.35	0.0314	0.03	20	3.45	4.83
Erythrina arborescens	16	1.35	0.0314	0.03	20	3.45	4.83
Prunus cerasoides	16	1.35	0.0314	0.03	20	3.45	4.83
Adenanthera pavonina	16	1.35	0.0314	0.03	20	3.45	4.83

Middle Elevational Zone (2000 – 2800 m)

Rhus succedanea and *Rhododendron arboreum* showed the highest frequency (60%) and relative frequency 16.67%. Similarly, the least frequency and relative frequency achieved as 20% and 5.56% respectively. Forest of middle elevational zone is dominated by *Rhododendron arboreum* with its highest IVI value 123.12 and co-dominated by *Myrsine capitellata* (49.2) and the species such as *Persea* and *Hypericum* showed very scanty presence with least IVI values. In this site the density of individual tree species ranged from 752 stem/ha – 16 stem/ha. While total density of all tree was found to be 1760 stem/ha. Likewise the dominance of tree species ranged from 76.53 m²/ha – 0.073 m²/ha. In this zone *Juglans* and *Acer* formed the very well canopy up to 22 ft. Consequently *Rhus* sps, *Rhododendron arboreum* made the sub canopy. Altogether 11 tree species were recorded from this site. Table 3 shows quantitative vegetative analysis of middle elevational zones.

Table4. Frequency (F%), Relative Frequency (RF), Density (D), Relative Density (RD), Basal area (BA), Relative Basal Area (RBA) and Importance Value Index (IVI) of Tree species in middle elevational zone.

Species name	**D/ha**	**RD (%)**	**BA (m²/ha)**	**RBA (%)**	**F (%)**	**RF (%)**	**IVI**
Rhododendron arboreum	752	42.73	76.534	63.73	60	16.67	123.12
Myrsine capitellata	336	19.09	22.814	19.00	40	11.11	49.20
Alnus nepalensis	256	14.55	7.495	6.24	20	5.56	26.34
Acer acuminatum	112	6.36	8.394	6.99	40	11.11	24.46
Rhus succedanea	80	4.55	1.710	1.42	60	16.67	22.64
Albizia julibrissin	48	2.73	1.327	1.10	40	11.11	14.94
Rhus javanica	48	2.73	0.636	0.53	20	5.56	8.81
Juglans regia	48	2.73	0.567	0.47	20	5.56	8.76
Acer pectinatum	32	1.82	0.385	0.32	20	5.56	7.69
Hypericum sps.	32	1.82	0.159	0.13	20	5.56	7.51
Persea odoratissima	16	0.91	0.073	0.06	20	5.56	6.53

Upper Elevational Zone (3000 – 3800 m)

Betula utilis showed the highest frequency and relative frequency achieved as 60% and 27.27%. Likewise, the lowest frequency and relative frequency achieved as 20% and 9.09% respectively. *Betula utilis* was well dominating species in this range with maximum IVI 159.72 and co-dominated by *Rhododendron arboreum* with IVI value

50.25 and *Rhus javanica* (Table 5). Other species like *Viburnum erubescens* and *Acer pectinatum* showed scanty in distribution. The density of individual tree species ranged from 576 stem/ha – 16 stem/ha, while total tree density for all tree species was found to be 1056 stem/ha. Consequently, the dominance ranged from 23.83 m²/ha – 0.005 m²/ha for individual tree species. In this site *Betula utilis* was mono-dominant canopy forming plant up to 16 ft. Altogether 7 tree species were recorded from this site. Table 4 shows quantitative vegetation analysis of upper temperate zone.

Table5. Frequency (F%), Relative Frequency (RF), Density (D), Relative Density (RD), Basal area (BA), Relative Basal Area (RBA) and Importance Value Index (IVI) of tree species in upper elevational zone.

Species name	**D/ha**	**RD (%)**	**BA (m²/ha)**	**RBA (%)**	**F (%)**	**RF (%)**	**IVI**
Acer pectinatum	16	1.52	0.005	0.02	20	9.09	10.62
Betula alnoids	96	9.09	0.608	1.99	20	9.09	20.17
Betula utilis	576	54.55	23.833	77.90	60	27.27	159.72
Rhododendron arboreum	176	16.67	4.712	15.40	40	18.18	50.25
Rhus javanica	48	4.55	0.785	2.57	40	18.18	25.29
Salix himalayensis	128	12.12	0.636	2.08	20	9.09	23.29
Viburnum erubescens	16	1.52	0.015	0.05	20	9.09	10.66

4.4 Size class distribution

The size-class distribution of stems for combined data of the park showed a right skewed and reverse J shaped distribution with continuous declining frequency in succeeding higher size class (Fig. 6). The low size class of 0- 20 cm dbh was more abundant and formed 1461.33 stem/ha. Similarly, tree density of dbh class 21-40 cm was found (853.33 stem/ha). Only 42.67 stem/ha of tree density was observed for old matured tree species above dbh size class 81-100 cm (Fig. 6). Decreasing pattern of tree density was observed consistently with increasing size class of tree from < 20 cm to > 80 cm dbh (Fig. 6). The regeneration of *Alnus nepalensis*, *Rhododendron arboreum* and *Betula utilis* were recorded higher as compared to other tree species which was indicated by the size class distribution of them (Fig. 7). The size class pattern of dominating species like *Rhododendron arboreum* and *Betula utilis* shows almost reverse J shaped distribution but for *Alnus nepalensis* size class 21-40 cm found higher than size class 0-20 cm (Fig. 7).

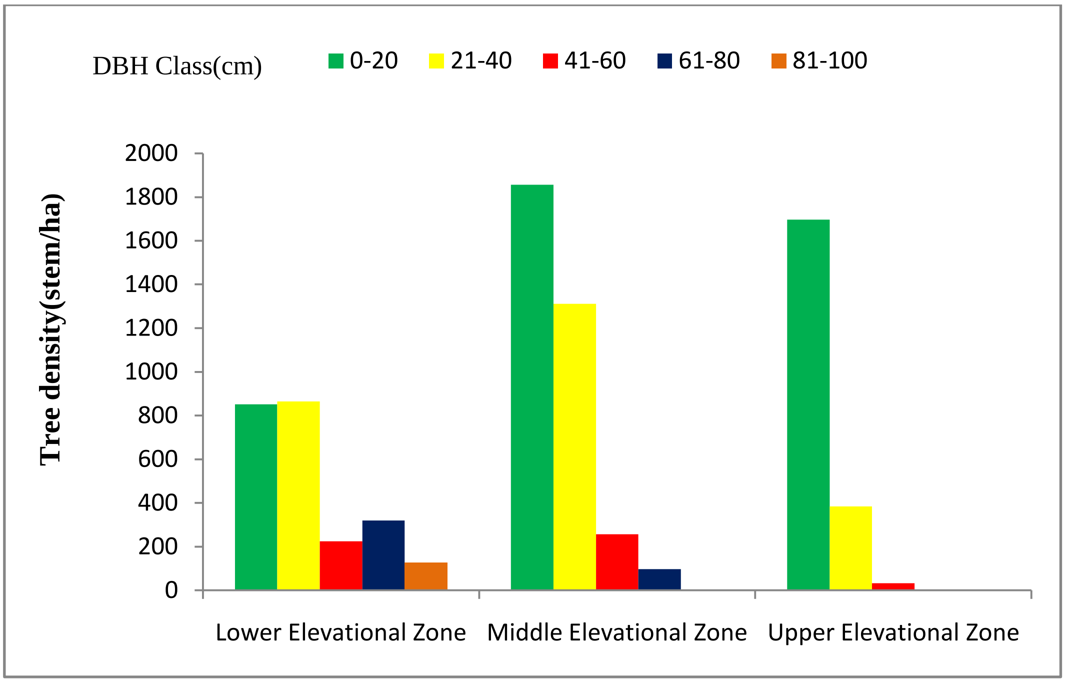


Fig. 5: Density-diameter distribution of trees with in different elevational level.

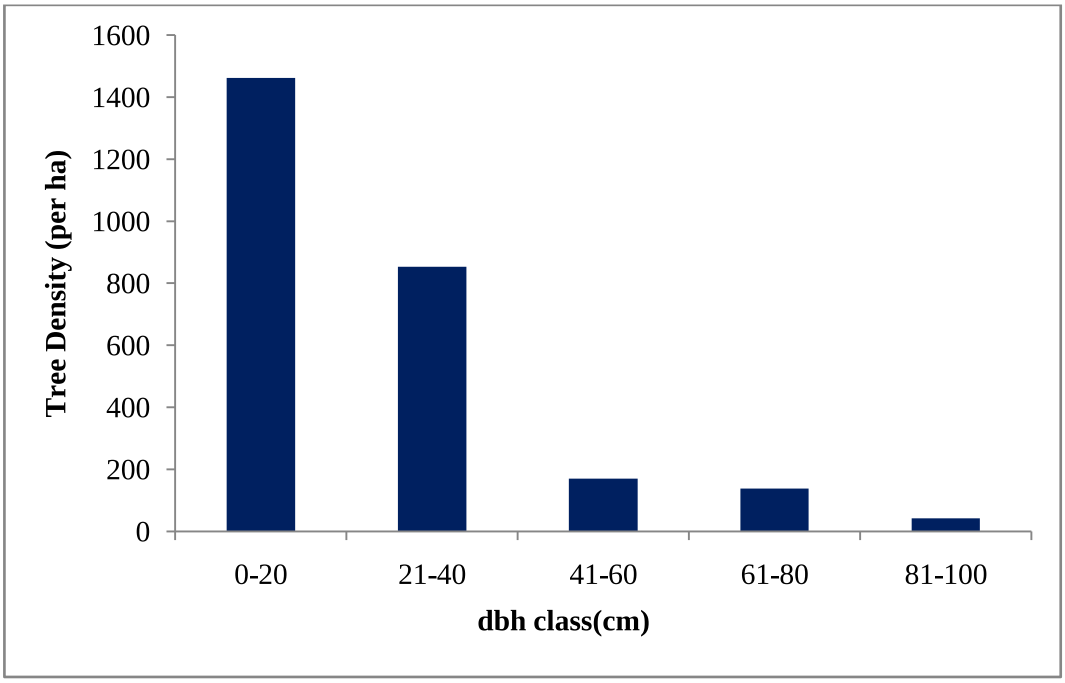


Fig. 6: Over all density-diameter distribution of trees.

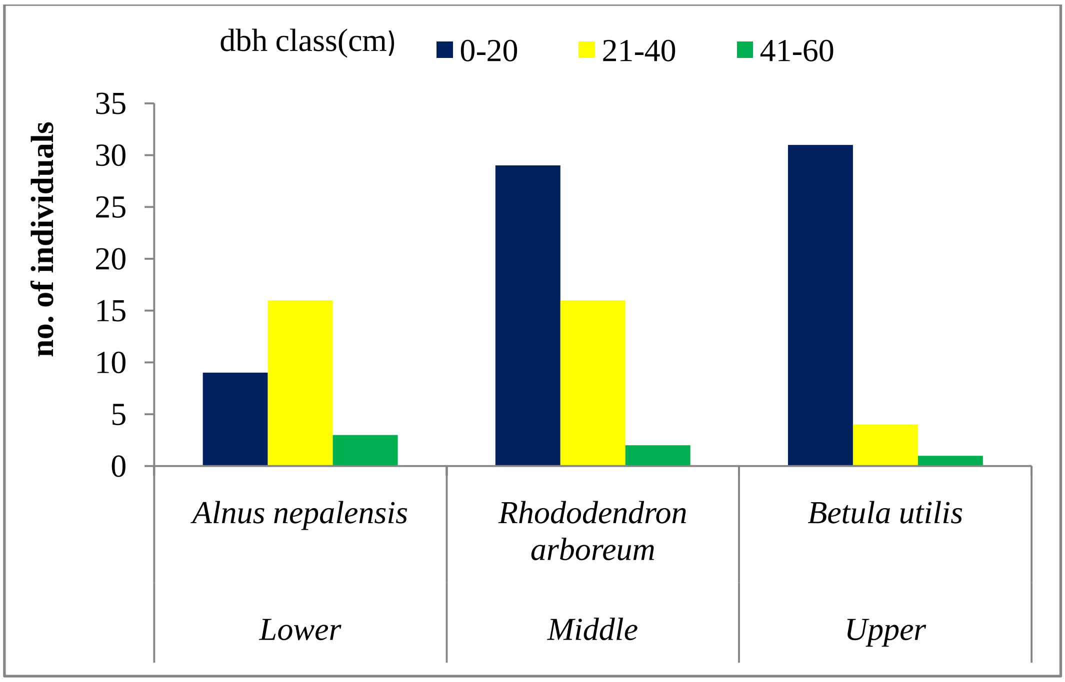


Fig. 7: Size class distribution of dominant tree species along three elevational sites.

An overall, distinct difference in stem size class distribution was evident in the three elevational sites of forest. The size class distribution consistently decreased with increasing size classes of tree from < 20cm to > 80cm dbh. The low size class of < 20cm dbh was more abundant and formed 1856 stem/ha in middle elevational zone, 1696 stem/ha in upper elevational zone and 852 stem/ha in lower elevational zone. Whereas tree density of dbh class 21-40cm was greater (1312 stem/ha) in middle elevation followed by lower elevation (864 stem/ha) and upper elevational zone (384 stem/ha). Similar result was also performed in dbh size class of 41-60cm; however the matured tree density size class of 61-80cm dbh were more abundant and performed 320 stem/ha in lower elevation followed by 96 stem/ha for middle elevation and completely absent at upper elevational zone. The old matured tree species above dbh size class 80cm were only present at lower elevation site and were completely absent in other two elevation sites (Fig5). At the time of study, there were 181.33 mature stems/ha in ACA; the presence of mature trees (> 60cm dbh) is the result of prolonged forest management in ACA and the small bole and stumps in ACA are signs of early succession. Among the three studied sites, all sites exemplify mono-dominant forests, but the predominant species varied across the sites. *Alnus nepalensis* formed 37.84 % of the forest stand density with a basal area contribution of 50.24 m^2/ha in lower elevation sites. *Rhododendron arboreum* gained dominance in middle elevation occupying 42.73% of the forest stand with a basal area of 76.53 m^2/ha and *Betula utilis* had a density of 54.55 % with a basal area of 23.83 m^2/ha in upper sites. *Betula utilis* had 86.11 % of stems in the lower dbh class category (0-20 cm) in upper elevation whereas in lower elevation 32.14 % of stems of *Alnus nepalensis* belonged to this size class and in middle *Rhododendron arboreum* had 61.7% of the stems that belonged to 0-20cm dbh class (Fig. 7). Among the three dominant species, all three species were skewed towards the size class (0-60cm dbh). The stem size classes above 60cm dbh were completely absent for all three species (Fig. 7).

4.5. Diversity parameters along elevational gradient

To assess the overall status of biodiversity in Modi River basin, different diversity indices were used. Altogether 30 tree species were collected from study area. Species richness of tree species was highest in lower elevation in comparison to middle elevation and higher elevation. It was observed that maximum species richness (9) was noted at elevation of 1400m whereas minimum at an elevation of 3400m and 3600m that contains only single taxa. Simpson's index (D) for tree was highest in 1400 m. Some other elevational range had a good dominance (D) value these include 1200m (3.248), 1800m (2.941) and 3000m (2.56). Shannon wiener diversity index (H') was maximum at elevation 1400m (1.977) followed by 1200m (1.4) and 1000m (1.227) showed in Appendix 2.

Table6: Coefficients of environmental variables with CCA axes.

	CA1	**CA2**	**CA3**	**CA4**
Elevation	0.75135	-0.2864	-0.2088	0.456
Tree density/ha	-0.49965	0.1953	-0.2929	-0.6777
Slope	0.06933	-0.4575	0.3244	0.2385
Canopy	0.23143	0.6224	0.5662	-0.3898
DBH	-0.53924	0.4658	-0.1306	-0.2126
Height	-0.70925	0.3977	0.1095	-0.121

Abbreviations: CA= Canonical axis

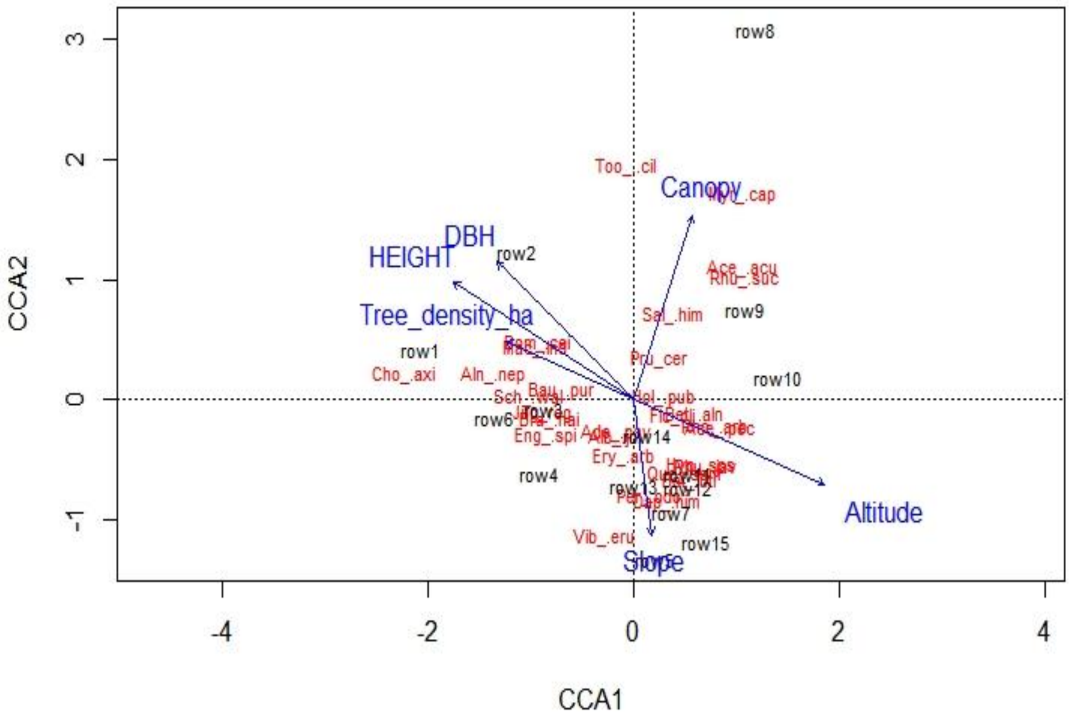


Fig. 8: Canonical Correspondence Analysis (CCA) plots showing the relationships between environmental variables and tree species. The length of an environmental vector indicates the degree of correlation.

CCA is another ordination technique that was used in this study to develop a linkage between the study area's environmental variables and vegetation data. Therefore it identified the presence, absence and /or occurrence of the individual species with respect to the various variables of the forest. The CCA bi-plot depicts the relation between environmental variables and vegetation data. Each dot in the plot denotes individual species. The arrow shows the extent of variation in the environmental variables. The longer the arrow is the greater its effect on vegetation type is. Here from the above figure it can be said that most of the species shows strong abundance in third and fourth quadrat that is with slope and elevation. The bi-plot based on the CCA results revealed that the elevational gradient was the environmental variables that greatly affected plant species composition (Fig. 8). Moreover, *Ficus oligodon, Rhododendron arboreum, Betula utilis, Betula alnoides, Holarrhena pubescens* and *Acer pectinatum* were frequently influenced by the elevation. *Quercus semicarpifolia,* *Hypericum* species, *Rhus javanica* and *Persea odoratissima* also might be affected by elevation however slope had major effect on these species. Canopy was another variable that had a major effect on *Prunus cerasoides*, *Salix himalayensis*, *Acer acuminatum*, *Rhus succedanea*, *Toona cilita* and *Erythrina arborescens*. Similarly, *Alnus nepalensis*, *Choerospondias axillaris*, *Bombax ceiba*, *Bauhinia purpurea* and *Macaranga indica* had a large positive correlation with height, dbh and tree density per hector. However, there were negative correlations for these species with slope and elevation of studied area. The other tree species like *Viburnum erubescens*, *Juglans regia*, *Engelhardtia spicata*, and *Adenanthera pavonina* etc were apparently not affected by any environmental

4.6 Species richness and diversity patterns of tree species along increasing elevation

4.6.1 Regression analysis

The regression analysis showed a moderately negative relationship between the Species richness (SR) along with elevational gradient (Fig. 9). Hence, the regression equation can be presented as: y = -0.353x + 6.695, where y is species richness and x is elevational gradient of Modi River basin. In this case, R^2=0.586, or 58% indicated that there was moderate negative relationship between the elevation and species richness.

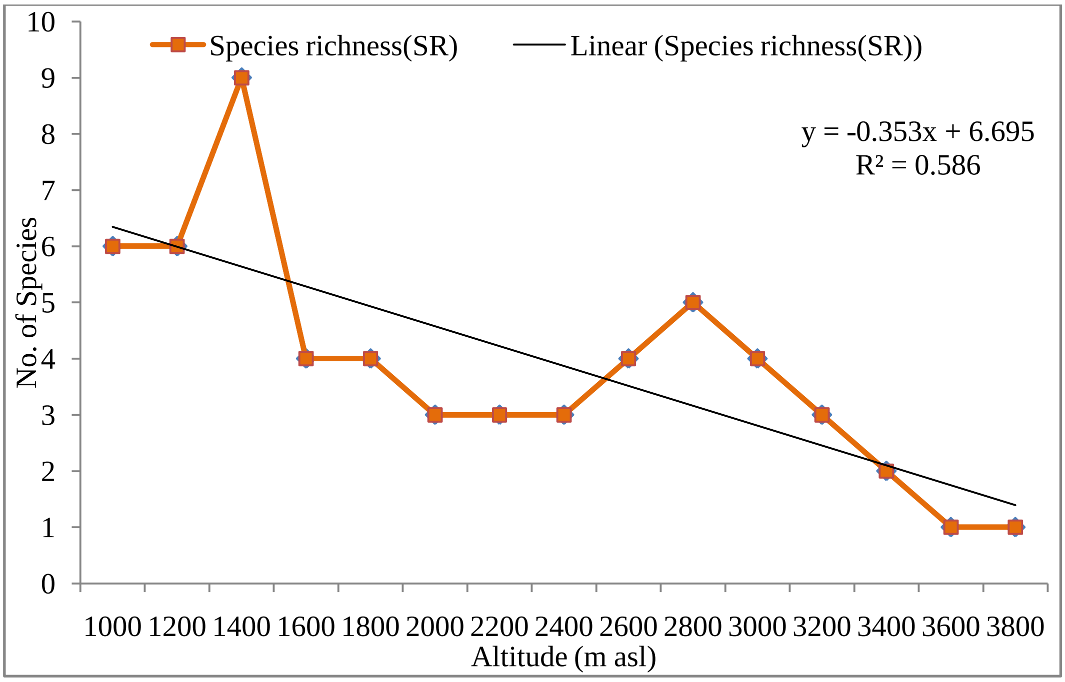


Fig. 9: Pattern of species richness along with elevational gradient.

Plant species richness at each level of elevation declined with increase in elevation at an exponential rate (y = 27.77e-0.47x) and this model explains about 98% of the trend as R^2 = 0.980 (Fig. 10).

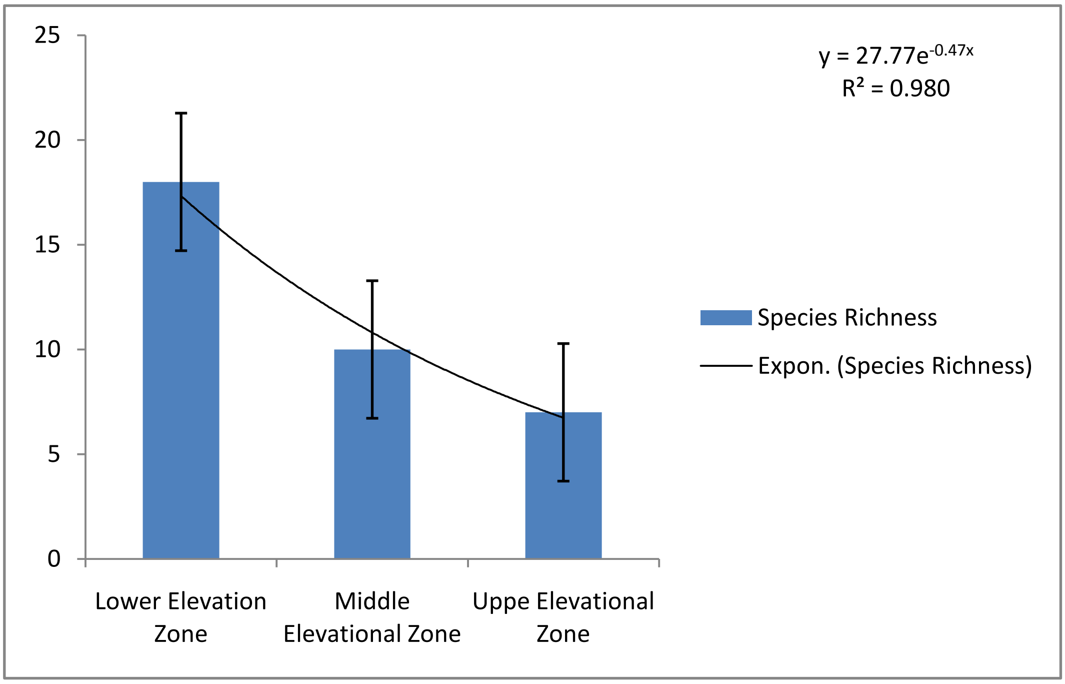
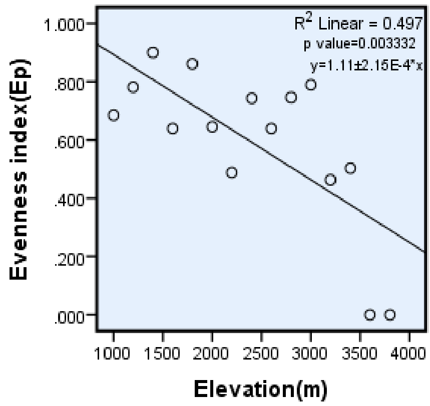
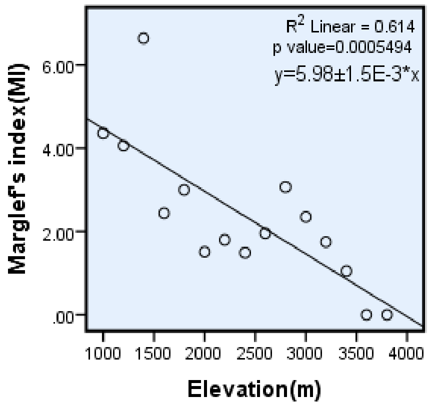


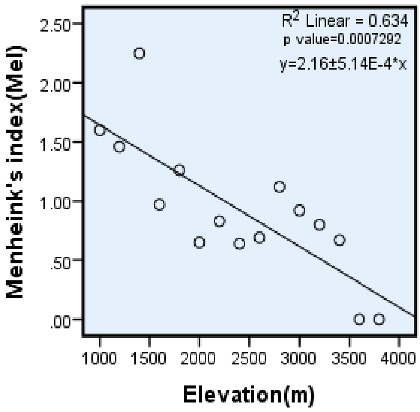
Fig. 10: Species richness and distribution trend along the various levels of elevational zones of the study area.


R2 Linear = 0.497
p value=0.003332
y=1.11±2.15E-4*x
Evenness index(Ep)
Elevation(m)

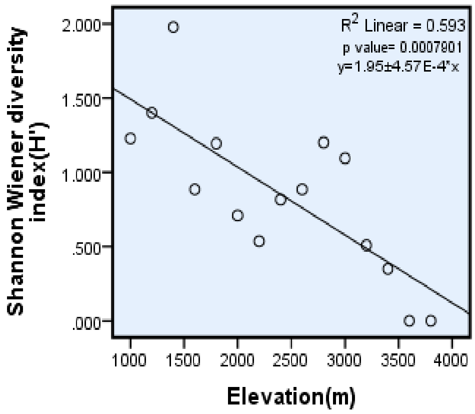
(a)


R2 Linear = 0.614
p value=0.0005494
y=5.98±1.5E-3*x
Marglef's index(Ml)
Elevation(m)

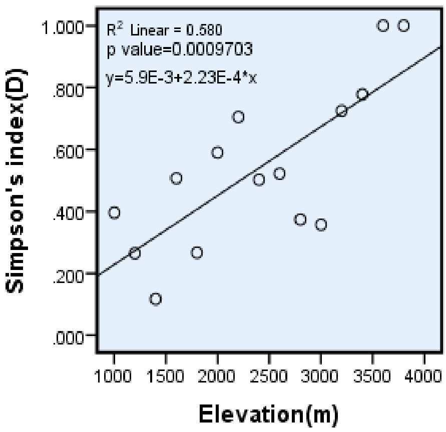
(b)


R2 Linear = 0.634
p value=0.0007292
y=2.16±5.14E-4*x
Menheink's index(Mel)
Elevation(m)

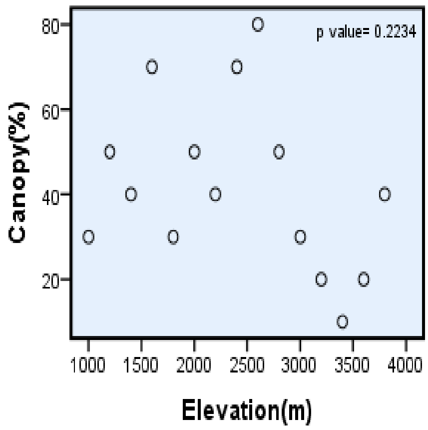
(c)


R2 Linear = 0.593
p value= 0.0007801
y=1.95±4.57E-4*x
Shannon Wiener diversity index(H')
Elevation(m)

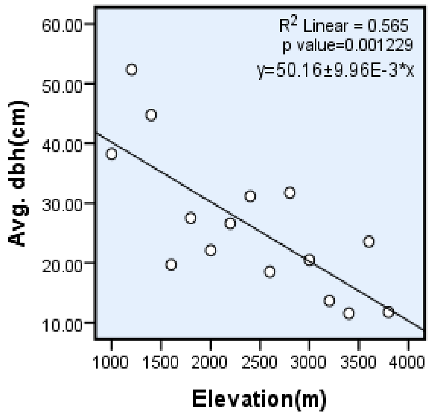
(d)

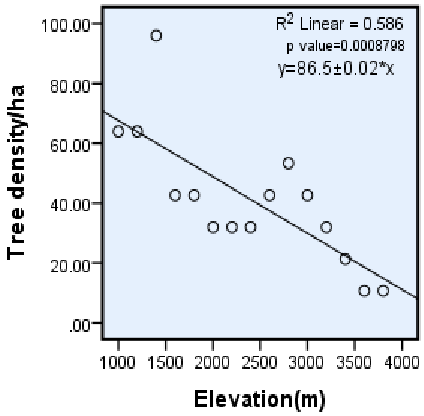

R2 Linear = 0.580
p value=0.0009703
y=5.9E-3+2.23E-4*x
Simpson's index(D)
Elevation(m)

(e)

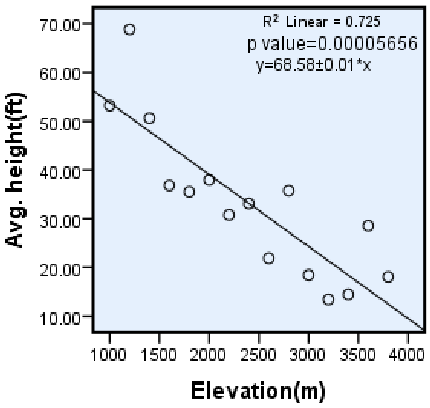

p value= 0.2234
Canopy(%)
Elevation(m)

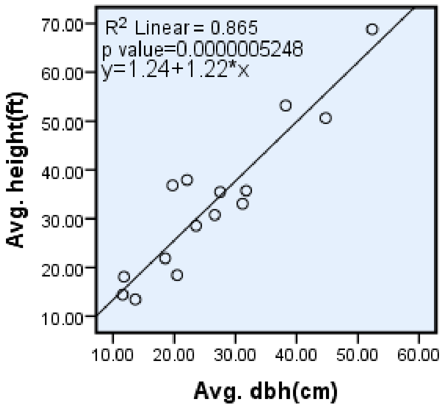
(f)



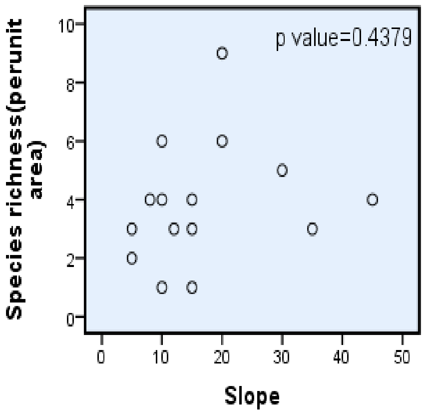


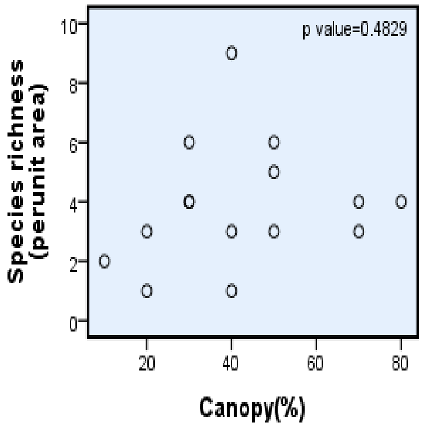
(g) **(h)**





(i) **(j)**





(k) **(l)**

Fig. 11: Linear regression analysis between the diversity parameters and environmental variables. a – i: a) Evenness index (Ep); b) Marglef's index (MI); c) Menheink's index (MeI); d) Shannon Wiener diversity index (H'); e) Simpson's index (D); f) Canopy (%); g) Avg. dbh (cm); h) Avg. density/ha; i) Avg. height (ft) along

with elevation (m). Similarly j) shows regression between Avg. dbh (cm) and Avg. height (ft); k-l) shows species richness with slope and canopy (%) .

Pearson correlation analysis showed that elevation and slope play an important role in regulating canopy coverage, tree dbh and height and species richness. The most significant relationship was Average height of tree that closely linked with average dbh of tree ($p < 0.01$) and increased with increasing tree dbh (Table 7). There was strong positive correlation of elevation with Simpson's index ($p < 0.01$) and significantly negative correlation with species richness ($p < 0.01$), Evenness index ($p < 0.01$), Marglef's index ($p < 0.01$), Menhinik's index ($p < 0.01$) and Shannon Weiner diversity index ($p < 0.01$) (Table 7). Similarly tree density, average dbh and average height of tree also declined ($p < 0.01$) with rising elevation.

Table7. Carl Pearson correlation coefficient between different parameters

		1	2	3	4	5	6	7	8	9	10	11	12
1	Altitude												
2	SR	-.766**											
3	MeI	-.773**	.965**										
4	MI	-.783**	.990**	.992**									
5	EP	-.705**	.763**	.723**	.757**								
6	H’	-.770**	.962**	.923**	.953**	.887**							
7	D	.762**	-.888**	-.852**	-.882**	-.945**	-.978**						
8	Density	-.766**	1.00**	.965**	.990**	.763**	.962**	-.888**					
9	Slope	-0.272	0.217	0.324	0.28	0.255	0.284	-0.323	0.217				
10	Canopy	-0.334	0.196	-0.004	0.1	0.304	0.256	-0.283	0.196	-0.084			
11	Dbh	-.752**	.777**	.766**	.776**	.546*	.757**	-.706**	.777**	0.261	0.177		
12	Height	-.851**	.703**	.702**	.708**	0.475	.673**	-.629*	.703**	0.231	0.243	.930**	

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

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

Abbreviations: SR=Species richness, D=Simpson’s index, H’=Shannon Wiener diversity index, MeI=Menheink’s index, MI= Marglef’s index, EP=Evenness index.

CHAPTER - FIVE

DISCUSSION

5.1 Forest composition

Tree species composition has been studied to enumerate and prepare the comprehensive description of the tree species along the Modi River basin of ACA, Nepal. The variation in elevational range and climatic conditions favors the diversity of flora. Plant diversity was directly influenced by environmental as well as biotic and abiotic factors. Plant diversity patterns and their relationship with soil and climatic factors vary along elevational gradient Bhattarai & Vetaas, (2003). The parameters like canopy, dbh and height of the tree species in studied area were not uniform (Decrease or Increase) and it was possible due to variation in geographic as well as light condition causing random pattern of distribution. In total 250 plant individuals were encountered. This was made up of thirty different species comprising of twenty one families searched on transect across the various elevational level. The result of the present study is much similar to 29 tree species reported by Chandra *et al*., (2010) from Garhwal Himalaya but much less than that of 113 species from temperate forest between 1800-2200m elevation of Subansiri district of Arunachal Pradesh reported by Behera & Kushwaha, (2007). However the Tree species richness in this study is much greater than that of 3 tree species from southern Manang Valley, Nepal (Ghimire *et al.*, 2008) and 16 tree species in two community forest of Dolpa District, mid west Nepal (Kunwar & Sharma, 1970). The tree species richness of the vegetation in the present study followed the trend as Lower elevational zone > Middle elevational zone > Upper elevational zone. Which is similar to that reported by Wiafe (2014) from patterns of tropical tree species richness along elevational gradients of mountain Afadjato, Ghana. On contrary Austrheim (2002) reported the trend as middle, lower and upper elevational zone.

5.2 Forest structure

The IVI of different tree species in different elevation gradients indicate considerable sharing of importance by number of species. This study shows an overall mixed type of forest along the basin. In the present studied area the average tree density 88.889 stem/ha and the average basal area of 11 m^2/ha was observed. However Bhuju *et al*.,

(2010) recorded a density of 445 stems/ha and total basal area of 11.2 m²/ha from the tree line region of the Sagarmatha National park. Similarly Gaire *et al.*, (2010) found the average tree density of 734 stem/ha and the average basal area of 20.56 m²/ha in the tree line eco-tone of Langtang National park. In another study Shaheen *et al.*, (2011) found the average tree density of 151 stems/ha and the basal area of 68.8 m²/ha in a western Himalayan moist temperate forest in Kasmir (Pakistan).

In the upper elevation, based on IVI values *Betula utilis* was reported dominant species followed by *Rhodendron arboreum* and *Rhus javanica*. The maximum values of tree density were recorded for *Betula utilis* followed by *Rhododendron arboreum* and *Salix himalayensis*. Singh & Singh, (1992) reported the pure *Betula utilis* forest at around 3100m elevation on the southern slope of Kumaun Himalaya. Increasing soil moisture with elevation may be due to the combined effect of the increasing tree canopy cover, decreasing temperature and decreasing snowmelt water sources; High litter accumulation and soil organic matter decreases soil pH and Nitrogen of forest was better at upper elevations that appears to be favorable for the establishment of early succession deciduous broadleaved species like *Betula utilis* (Biswas & Mukherjee, 1994; Shrestha *et al.*, 2007). Similarly, Ghimire & Lekhak, (2007) reported *Betula utilis* as dominant tree above 3800m belt in a study from Annapurna range.

Similarly in middle elevation, *Rhododendron arboreum* was reported dominant with IVI value followed by *Myrsine capitellata* and *Alnus nepalensis* .The maximum value of frequency and density was recorded for *Rhododendron arboreum*, however, the highest and lowest values of total basal cover was recorded for *Rhododendron arboreum* and *Persea odoratissima* respectively (Table 4). *Rhododendron arboreum* prefers acidic soil for growth (Wurzburger & Hendrick, 2007 ; Stehn *et al.*, 2011; Li *et al.*, 2015) and the acidic environment is created by the degradation of acidic litter of *Rhododendron arboreum* (Maithani *et al.*, 1998). Probability of growth of *Rhododendron arboreum* species increases with the increase of elevation, with the increase of elevation the species richness decreases and hence the inter-specific competition also decreases (Choler *et al.*, 2001; Bruun *et al.*, 2006) and *Rhododendron arboreum* becomes a dominant species at around 2500m elevation. The total basal area of tree species is higher in middle elevational zone than lower and upper elevational zone. The forest having small basal area per hector showed the sparsely dispersed tree species in comparison with large basal area (Kunwar *et al*., 2008). Higher the tree density higher will be the basal area and vice versa. The differences in basal area of tree layer may be due to differences in species composition, elevation, aspect, age of trees, degree of disturbance, succession stage of plants, relatively favorable growing conditions, climatic factors, diseases and other insects (Berrill & O'Hara, 2016).

However in lower elevation *Alnus nepalensis* was reported as dominant species with highest value of IVI. The maximum frequency, density and total basal area were also recorded for *Alnus nepalensis* (Table 3). Pandey & Bajracharya, (2010) also reported that *Alnus nepalensis* as dominating species in community forests of Sikre VDC adjoining Shivapuri National Park Kathmandu. A pioneer species that grows well in full light, less fertile soil, high water content, near streams, gravelly land exposed by landslides and old cultivated land (Jackson, 1994). The densities and basal area of *Alnus nepalensis* as well as the other tree species were found to be the highest at the lower elevation and were found to have decreased with the increase in elevation and completely absent at the upper elevation zone (Table3). The matured trees were found to have contributed for the higher basal area at the lower elevation. Tree showing variation in dbh, height, density with different elevations are significant at ($P<0.05$), while canopy coverage was insignificant with different elevations (Table7).

CCA was then used to develop a relationship between the studied area sites vegetation and the environmental variables. The graph predicted that elevational gradient was the environmental variable among the slope, canopy coverage, dbh, height and tree density per hector that strongly affected the study area sites vegetation specifically *Rhododendron arboreum*, *Ficus oligodon*, *Betula utilis* and *Acer pectinatum.* Elevational gradient has many effects on a plant species; it influenced wind velocity, sun light and soil moisture may be combined effect of the increasing tree canopy cover, decreasing temperature, decreasing distance form snow melt water sources, high litter accumulation and organic matter that decrease soil pH (Biswas & Mukherjee, 1994). Mountain slopes with significant bioclimatic amplitude generally have more species at the bottom than the top (Vetaas & Grytnes, 2002). In the studied site slope had major effect on plant species like *Quercus semecarpifolia, Rhus javanica, Persea odoratissima* etc; however these species might also be affected by elevation. Changes in slope and aspect may lead to changes in hours of sunshine, humidity, and temperature, all of which affect community development (Virtanen *et al*., 2010). Canopy cover was another factor that strongly affect on the sites vegetation specifically *Prunus cerasoides, Rhus succedanea, Toona cilita* and *Erythrina arborescens.* Trees were maximum contributor for this high richness because it develops various environmental conditions especially the availability of light, soil nutrients and moisture. Woody canopy coverage showed a significant positive relationship with tree species diversity in Savannah Forest (Madonsela *et al.,* 2018) this is due to woody canopy cover embodies the interplay of multiple environmental gradients influencing tree species diversity in Savannah wood land. Baker & Barnes, (1998) reported that Physical factors (e.g., slope degree and being stony) are the most effective factors on plant dispersal and growth compared to the soil chemical content and human-induced factors, mainly due to their influence on water.

5.3 Species richness and diversity parameters

Species composition and species richness are important indicators for assessing the biodiversity (Husch *et al*., 2002) and may strongly depend and/or be influenced by the applied management practices. In the study, the values of Shannon-Weaver diversity index and Margalef's index did not show any increasing or decreasing tendency of values as the elevational gradient increased. Similar results have been observed by Rascón-Ayala *et al.*,(2018) in an elevational gradient of the Sierra La Laguna Biosphere Reserve, Mexico; however Vetaas & Grytnes, (2002) reported a decreasing of species and diversity richness as the increasing elevational gradient. The maximum species diversity was observed for lower elevational zone at an elevational range of 1400m, where in maximum value of Shannon Wiener index was recorded for 1400m (1.977) followed by 1200m (1.40) and 1000m (1.227) respectively (Appendix 2). The uniform pattern of species diversity was encountered in the elevational range of 1600-3200m with Shannon Wiener's index varying in between 0.509-1.201. However, the species diversity (0.349 to 0) falls exponentially with the increase in elevation beyond 3200m. Higher species diversity is an indication of maturity in the ecosystem (Marglef, 1963) and low species diversity is a result of incorporation of some species through competition. The value of Simpson's index (D) ranges between zero and one; within this index, one represents infinite diversity and zero, no diversity. Simpson's diversity value were observed 1 for quadrats above 3600m and minimum values were found for lower elevational zone at an elevation of 1400m (0.117) followed by 1200m

(0.265) and 1800m (0.267), respectively (Appendix 2). Evenness of species is expressed as relationship of species to each other. Species evenness ranges from zero to one, with zero signing no evenness and one, a complete evenness (Pielou, 1966). The maximum values for Evenness index (Ep) was found for lower elevational zone at an elevation of 1400m (0.9) followed by 1800m (0.861). The uniform pattern of Evenness index was encountered in elevational range at 1200, 2400, 2800 and 3000m the value ranges in between (0.789- 0.743), respectively (Appendix 2). The zero evenness value was also encountered above the elevational range of 3600m. Slow growth and poor seed dispersal capability of many species that sometimes attain mono-dominance also suggest that such community have not experienced major disturbance events and are not merely older secondary forests (Connell & Lowman 1989).

5.4 Species richness pattern

There is a general trend of monotonic declining species richness along elevational gradients (Wang *et al.*, 2006; Shimono *et al*., 2010; Bhattarai *et al.*, 2014). However for vascular plants, most studies indicate unimodal pattern of species richness along elevational gradient at large geographical scale (Sánchez-González & López-Mata, 2005). This pattern also applies well along the Nepalese Himalayan elevational gradient (Bhattarai *et al.*, 2004; Rokaya *et al.*, 2012; Bhattarai *et al.*, 2014). These comparability of the results, however, is often affected by potential biases, such as incompletely sampled gradients, differences in regional areal size, sampling method and taxon specific traits (Rahbek, 2005). In this study, I found bimodal pattern of species richness along the elevational gradient. Such pattern of species richness were also found by different researchers (Baniya *et al*., 2010; Acharya *et al*., 2011; Paudel & Šipoš, 2014; Paudel *et al.*, 2018).

The distribution of species richness along elevation gradients is governed by a series of interacting biological, climatic and historical factors (Colwell & Lees, 2000). Eilu & Obua, (2005) have also suggested that different elevations and slopes influence the species richness. Tree species richness showed an overall bimodal trend along the elevational gradient; richness was high at lower elevation, decreased with increasing elevation up to 2600m and increased above up to 2800m after that sharply decreased with increased elevational gradient. This falls within the general pattern of an initial increase in species richness with elevation, followed by a peak and then a decline with further increased elevation has been made in Nepal Himalayan (Grytnes & Vetaas, 2002). Similar result was found of plant species diversity in the southern slope of mountainous region of Ili River valley (Xu *et al*., 2011). The bimodal pattern may be caused by the interaction of water and energy along the elevational gradient, but several non environmental factors may also influence the patterns such as area (Whittaker *et al.*, 2001). The highest elevational limit (3740m) observed in present study corresponds the highest limit 3900m of tree species recorded in Langtang (Pandey *et al*., 2016); suggesting more or less equal range of elevational distribution for trees in Modi River basin of ACA region and Langtang region. Tree species peak at low elevations might be the result of high energy availability as predicted by Rosenzweig, (1995). The southern slope of the sub- Himalayas received high rainfall as a result of fewer heavy rainfall events while the lesser Himalayas received high rainfall as a result of the high frequency of relatively weak but persistent rainfall i.e. At middle elevational zone, rainfall peaks along the Lesser Himalayas at elevation between 2000–2200m (Shrestha *et al.*, 2012). Whereas seasonal variation in temperature starts increasing from 2200m therefore, increase of tree species richness at about 2800m might be caused by influence of precipitation and temperature. This zone, characterized by high humidity and oscillation of temperature i.e. seasonal variation of temperature offers favorable conditions for evolving different life forms such as flora, fauna, birds and insects, which many species can exploit (Vetaas, 2006); Such assumption on underlying mechanism of elevational gradient of species diversity is also documented in other taxa in Nepal Himalayan. (Paudel & Šipoš, 2014) suggest that this zone should be cloud forest in the greater Himalayas at elevation between 2500 and 3200m (Dobremez, 1976).

Mountains generally have a conical shape and as the elevation band with certain set of environmental and climatic conditions decrease with increasing elevation. With a reduced area, there are fewer micro sites for plants to occupy through the development of specific adaptive traits. The 200 meter interval used in this studied sites do not represent equal area because of the topography of Modi River basin of ACA. Therefore, the area effect could also account for the decline of species richness of trees along Modi River basin in high elevation ranges (Zobel, 1997). After controlling the effect of area (environmental variables) species richness declined on an average with increasing elevation, but with peaks at relatively lower elevational zone (1000-1400m) and intermediate elevation (2600-2800 m) exhibiting a bimodal pattern (Fig9). Similar patterns have been observed for threatened species richness along Nepal Himalayan (Paudel *et al.*, 2012) and birds in the Himalayas (Paudel & Šipoš, 2014). But most other taxa (ferns, trees, and mosses) have unimodal patterns with peak of species diversity at intermediate elevations (Grytnes & Vetaas, 2002; Bhattarai *et al*., 2004; Oommen & Shanker, 2005; Grau *et al*., 2007; Wang *et al*., 2007; Subedi *et al*., 2015). The tendency of overlapping habitats and resources in middle elevation area could be partially responsible for the higher species richness (Trigas *et al.*, 2013). Mark *et al.*, (2000) found topographic features (elevation, slope and exposure) to be responsible for the macro scale patterns of alpine vegetation distribution on Mount Armstrong in New Zealand. Other factors, such as ecophysiological constraints, soil fertility, topography, reduced growing season, low temperature and low productivity (Körner, 1998) may also affect the pattern of species richness along elevation gradients. Human activities, such as changes in land use, have a long lasting and direct impact on species richness in mountain environments.

5.5 Size class distribution

The regeneration studies in tree line of Nepal Himalayan have shown reverse J-shaped density diameter distributions and good regeneration, which may result in an upward movement of tree line (Gaire *et al*., 2014). However, in some regions bell shaped density diameter distribution pattern were observed indicating poor regeneration (Sujakhu *et al*., 2014). The lower number of the high diameter classes or absence of classes above 50 cm dbh also indicated sustainable anthropogenic impacts in high mountains (Sujakhu *et al*., 2014).

The reverse J- shaped stem distribution showed that the forests at the lower elevation had both recent regeneration as well as the very old growth stem (dbh > 80cm). The forest at the middle and upper elevation lacks the large sized trees (dbh > 80cm). Similar results were found by (Kharal *et al.*, 2017) at three different elevational ranges in Manang District. Gaire *et al.*, (2012) have shown the size class structure, age, dbh, and height indicates the regeneration conditions in the forest. Size class distribution of trees provides the population structure of forest (Saxena & Singh,

1984) and are extensively used to understand regeneration status of forest. The density diameter curve of the tree species on present studied sites deviated from typical reverse J-shaped structure (Fig.9) that is the indication of regeneration similar to the results of Vetaas, (2000). Similarly, Måren *et al.*, (2015) found an inversely J-shaped size class distribution of *Pinus* and *Juniperus* species on the north and south facing slopes of the Manang valley. However, Wangda & Ohsawa, (2006) found continuous to sporadic regeneration of different tree species along the elevational gradient in a dry valley slope of Bhutan.

The size class < 20cm dbh consist of maximum number of individuals followed by 21-40cm dbh class within all three forest sites; a sufficient young stands to replace the old mature stands. Only three size classes were observed in upper elevational sites however four and five size classes were observed in middle and lower elevational sites respectively. Trees were smaller in upper elevational forest (dbh 0-60cm) than in middle (dbh 0-80cm) and lower elevational zone (dbh 0-100cm). According to dbh classes, the numbers of young individuals of adult were maximum having <20cm range and follows a gradual inverse proportion. This shows the presence of higher density of young trees of the overall species, which signifies a healthy growing forest, provided the appropriate forest conservation management practices applied. In studied area, the basal area marks its peaks at the middle elevation sites which were because of the presence of greater number of adult tree species (Rhododendrons) compared to the other sites. The relatively lower basal cover of the trees at above 3000m may be the result of the greater young woody plant density to be the effect of cold and harsh climatic conditions (Acharya *et al.*, 2011). This indicates that the trees in upper elevational sites were younger than in middle and lower elevational site forest along Modi River basin of ACA, Nepal. However in the studied area it was found that upper elevational site lacked the higher dbh classes of tree species (>60cm). It may be due to adverse environmental conditions for development of tree at high elevation. A reduction in radial growth at higher elevation is related to the shortened growing period largely as a result of delay in start of seasonal growth (Tranquillini, 1979); or this might be due to the cutting of large trees for timber and firewood.

CHAPTER – SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study reveals that tree species found along the Modi River basin exhibit varying patterns of distribution along different elevational and climatic gradients. Tree species richness along the elevational gradient of Modi River basin in Annapurna conservation area (ACA) has been interestingly concluded that the tree species richness was found highest in lower elevational zone followed by middle and upper elevational zone. The overall species richness showed bimodal pattern due to different biotic and abiotic factors that influences the mountainous forest. The slopes also play significant role for changing the species composition due to change in humidity, sunlight and temperature of the plots that on the southern warmer slopes.

In the heterogeneous habitat the tree species showed complete turnover and high diversity. It is also concluded that the density of tree species were higher in middle elevational zone followed by lower and upper elevational zone due to tendency of overlapping habitats and resources in middle elevation area. There were large differences in species composition of adult trees and regenerating individuals in the different elevation zones. Each elevational zone was dominated by different tree species i.e. *Alnus nepalensis* at lower, 250 individuals belonging to 30 species of trees in the ACA and obtained result from the size class distribution of the trees resembling a reverse J-shaped population curve that indicates high tree species richness and density in lower girth class which gradually decrease with increase in girth class population size. The overall population structure shows regeneration of tree species in the forest is good and the future communities may be sustained unless there is any major environmental stress or interference exerted by human activities. Finally, from the above result it has been concluded that in high elevation Himalayan forest, elevation and site factors play a dominating role in distribution and regeneration of tree species.

6.2 Recommendations

Himalayan regions are geo-dynamically very active and are more sensitive to natural and human activities due to topographic and climatic variations over a short distance which are further augmented by deforestation, landslides, land degradation, desertification and glacier lake outburst floods.

Following recommendations have been suggested on the basis of the results of present study:

- Local people should be encouraged by ACA management in planting local fodder tree species in their farm land to reduce pressure on forest. Similarly, awareness is needed for the locals for the sustainable use of forest resources.

- Forest fire is a major problem in Nepal responsible for destroying large forest area every year. Therefore, local communities need to be made aware of forest fire and related threats of biodiversity loss and encourage plantation activities from ACA management. Impose strict rules to control illegal tree felling in the conservation area and provide alternate sources of fuel for local communities. This will reduce pressure on forest resources.

- This research is limited on the southern slopes of the basin so, further work should be carried on the northern slopes to understand the variation on species composition.

- To extract the actual problems and their possible solutions, further research is recommended based on the interaction of vegetation with biotic and abiotic factors.

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APPENDICES

Appendix 1. List of the site characteristics of forest ecosystem for species composition studied along Modi River basin in ACA.

Plot	Location	Elevation	Lat/Long	Aspect	Slope	Dom. Species
1	Birethant	1000	28°18'44.8"-N 83°46'43.2"-E	SE-142°	10°	*Alnus nepalensis* D. Don
2	Syaulibhaat	1200	28°20'0.91"-N 83°47'48.82"-E	SW-190°	20°	*Alnus nepalensis* D. Don/ *Bombax ceiba* L.
3	Kyumi	1400	28°22'24"-N 83°48'58.7"-E	SW-203°	20°	Mix Forest
4	Ghandruk	1600	28°24'18.2"-N 83°49'20"-E	SE-64°	14°	*Alnus nepalensis* D. Don
5	Jhinu	1800	28°24'39.6"-N 83°49'19.3"-E	SE-164°	45°	*Quercus semicarpifolia* Sm./ *Persea odoratissima* (Nees) Kosterm
6	Lower Sinu	2000	28°25'41"-N 83°49'29.3"-E	SE-180°	12°	*Alnus nepalensis* D. Don
7	Upper Sinu	2200	28°28'55"-N 83°49'59.9"-E	SE-124°	35°	*Rhododendron arboreum* Sm.
8	Bamboo	2400	28°27'38"-N 83°51'35"-E	SE-142°	5°	*Myrsine capitelleta* Wall.
9	Dovan	2600	28°29'06"-N 83°52'32"-E	SE-118°	8°	*Rhododendron arboreum* Sm.
10	Himalayan	2800	28°28'50"-N 83°53'8"-E	SE-118°	30°	*Rhododendron arboreum* Sm.
11	Himalayan	3000	28°29'27"-N 83°53'34"- E	SE-151°	10°	*Rhododendron arboreum* Sm./ *Betula alnoides* Buch.-Ham. ex D. Don
12	Deurali	3200	28°29'34"-N 83°53'34"-E	SE-151°	15°	*Betula utilis* D.Don
13	Deurali	3400	28°29'33"-N 83°54'26"-E	SE-120°	5°	*Salix himalayensis* (Andersson) Flod.
14	Deurali	3600	28°31'3"-N 83°54'28"-E	SE-113°	10°	*Betula utilis* D
15	MBC	3800	28°31'31"-N 83°54'25"-E	SE-147°	15°	*Betula utilis* D. Don

Appendix 2. Total species richness and diversity parameters of tree species along elevational gradient

Altitude (m)	SR	D	H'	MeI	MI	EP
1000	6	0.396	1.227	1.6	4.36	0.685
1200	6	0.265	1.4	1.46	4.06	0.781
1400	9	0.117	1.977	2.25	6.64	0.9
1600	4	0.507	0.885	0.97	2.44	0.639
1800	4	0.267	1.194	1.26	3	0.861
2000	3	0.59	0.709	0.65	1.51	0.645
2200	3	0.705	0.536	0.83	1.8	0.488
2400	3	0.502	0.816	0.64	1.49	0.743
2600	4	0.522	0.885	0.69	1.96	0.639
2800	5	0.374	1.201	1.12	3.07	0.746
3000	4	0.357	1.094	0.92	2.35	0.789
3200	3	0.725	0.509	0.8	1.75	0.463
3400	2	0.778	0.349	0.67	1.05	0.503
3600	1	1	0	0	0	0
3800	1	1	0	0	0	0

Abbreviations: SR=Species richness, D=Simpson’s index, H' =Shannon Wiener Diversity index, MeI=Menheink’s index, MI= Marglef’s index, EP=Evenness index,

Appendix 3. Distribution of tree species across 1000-3800 m elevational gradient.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Juglans regia			1			1										2
Acer acuminatum								1		1						2
Acer pectinatum										1	1					2
Adenanthera pavonina				1												1
Albizia julibrissin						1	1									2
Alnus nepalensis	1	1		1		1										4
Bauhinia purpurea			1													1
Betula alnoides											1					1
Betula utilis												1		1	1	3
Bombax ceiba	1	1														2
Brassaiopsis hainla			1	1												2
Choerospondias	1															1
Daphniphyllum				1											1	
Engelhardtia spicata	1		1													2
Erythrina arborescens			1													1
Ficus oligodon			1													1
Holarrhena pubescens		1														1
Hypericum sps.									1							1
Macaranga indica	1	1	1													3
Myrsine capitellata								1	1							2
Persea odoratissima				1	1		1									3
Prunus cerasoides			1													1
Quercus					1											1
Rhododendron							1		1	1	1	1				5
Rhus javanica										1	1	1				3
Rhus succedanea								1	1	1						3
Salix himalayensis													1			1
Schima wallichii	1	1	1		1											4

Toona ciliata		1														1
Viburnum erubescens													1			1
Total	6	6	9	4	4	3	3	3	4	5	4	3	2	1	1	58

Appendix 4. Species wise dbh distribution of tree species.

S.n	Species	Family	DBH Class					Total
			0-20	21-40	41-60	61-80	81-100	
1	*Alnus nepalensis*	Betulaceae	21	20	3	0	0	44
2	*Betula utilis*	Betulaceae	31	4	1	0	0	36
3	*Betula alnoides*	Betulaceae	5	1	0	0	0	6
4	*Albizia julibrissin*	Fabaceae	0	2	1	0	0	3
5	*Acer acuminatum*	Sapindaceae	1	2	2	2	0	7
6	*Acer pectinatum*	Sapindaceae	1	2	0	0	0	3
7	*Juglans regia*	Juglandaceae	1	2	1	0	0	4
8	*Bombax ceiba*	Malvaceae	0	0	0	5	2	7
9	*Brassaiopsis hainla*	Araliaceae	1	2	0	0	0	3
10	*Choerospondias*	Anacardiaceae	0	1	0	0	0	1
11	*Daphniphyllum*	Daphniphyllaceae	1	0	0	0	0	1
12	*Engelhardtia spicata*	Juglandaceae	0	0	0	4	2	6
13	*Erythrina arborescens*	Fabaceae	1	0	0	0	0	1
14	*Ficus oligodon*	Moraceae	0	1	0	0	0	1
15	*Holarrhena pubescens*	Apocynaceae	0	0	1	0	0	1
16	*Hypericum sps.*	Hypericaceae	1	1	0	0	0	2
17	*Macaranga indica*	Euphorbiaceae	2	1	0	0	0	3
18	*Adenanthera pavonina*	Fabaceae	1	0	0	0	0	1
19	*Bauhinia purpurea*	Fabaceae	1	0	0	0	0	1
20	*Myrsine capitellata*	Myrsinaceae	11	7	2	1	0	21
21	*Prunus cerasoides*	Rosaceae	1	0	0	0	0	1
22	*Quercus*	Fagaceae	0	2	2	0	0	4
23	*Rhododendron*	Ericaceae	35	21	2	0	0	58
24	*Toona ciliata*	Meliaceae	0	1	0	0	0	1
25	*Viburnum erubescens*	Adoxaceae	1	0	0	0	0	1
26	*Salix himalayensis*	Salicaceae	8	0	0	0	0	8
27	*Schima wallichii*	Theaceae	4	1	0	1	0	6

28	*Rhus javanica*	Anacardiaceae	3	2	1	0	0	6
29	*Rhus succedanea*	Anacardiaceae	1	4	0	0	0	5
30	*Persea odoratissima*	Lauraceae	5	3	0	0	0	8
			137	80	16	13	4	250

Appendix 5. Name of Tree species and their abbreviation.

Name of Trees	Family	Abbreviation
Juglans regia L.	Juglandaceae	Jug_reg
Acer acuminatum Wall. ex D.Don	Sapindaceae	Ace_acu
Acer pectinatum Wall. ex Pax	Sapindaceae	Ace_pec
Adenanthera pavoninaI L.	Fabaceae	Ade_pav
Albizia julibrissin Durazz.	Fabaceae	Alb_ jul
Alnus nepalensi D.Don	Betulaceae	Aln_nep
Bauhinia purpurea L.	Fabaceae	Bau_pur
Betula alnoides Buch.-Ham. ex D. Do	Betulaceae	Bet_aln
Betula utilis D. Don	Betulaceae	Bet_uti
Bombax ceiba L.	Malvaceae	Bom_cei
Brassaiopsis hainla (Buch.-Ham.) Seem.	Araliaceae	Bra_hai
Choerospondias axillaris (Roxb.) B.L. Burtt & A.W. Hil	Anacardiaceae	Cho_axi
Daphniphyllum himalayense (Benth.) Müll.Arg	Daphniphyllaceae	Dap_him
Engelhardtia spicata Lechen ex Blume	Juglandaceae	Eng_spi
Erythrina arborescens Roxb.	Fabaceae	Ery_arb
Ficus oligodon Miq.	Moraceae	Fic_oli
Holarrhena pubescens Wall. ex G.Don	Apocynaceae	Hol_pub
Hypericum sps.	Hypericaceae	Hyp_sps
Macaranga indica Wight	Euphorbiaceae	Mac_ind

Myrsine capitellata Wall.	Myrsinaceae	Myr_cap
Persea odoratissima (Nees) Koster	Lauracea	Per_odo
Prunus cerasoides Buch.-Ham. ex D. Don	Rosaceae	Pru_cer
Quercus semecarpifolia Sm.	Fagaceae	Que_sem
Rhododendron arboreum Sm.	Ericaceae	Rho_arb
Rhus javanica Miller	Anacardiaceae	Rhu_jav
Rhus succedanea L.	Anacardiaceae	Rhu_suc
Salix himalayensis (Andersson) Flod.	Salicaceae	Sal_him
Schima wallichii (DC.) Korth.	Theaceae	Sch_wal
Toona ciliate M.Roem.	Meliaceae	Too_cil
Viburnum erubescens Wall.	Adoxaceae	Vib_eru

Appendix 6. DCA ordination summary for Tree species.

Axes	DCA1	DCA2	DCA3	DCA4
Eigen values	0.6623	0.5347	0.3783	0.27558
Decorana values	0.6967	0.5129	0.1832	0.06924
Axis lengths	5.5801	3.6247	2.9875	2.11503

Appendix 7. Presence/ Absence data of Tree species in each plt.

Spp./ Plots	Plot_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_10	P_11	P_12	P_13	P_14	P_15
Jug_reg	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Ace_ acu	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Ace_ pec	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Ade_	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Alb_ jul	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Aln_ nep	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
Bau_ pur	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Bet_ aln	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Bet_ uti	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Bom_	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bra_ hai	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Cho_ axi	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dap_	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Eng_ spi	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ery_ arb	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Fic_oli	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hol_ pub	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hyp_ sps	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mac_ ind	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Myr_	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Per_ odo	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0
Pru_cer	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Que_	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Rho_ arb	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0
Rhu_ jav	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Rhu_ suc	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Sal_ him	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Sch_ wal	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0
Too_ cil	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Vib_ eru	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Appendix 8. Number of individuals, average height and dbh of each species inventoried per plot in each elevational sites.

Elevational Zone	Species	Plots						Height (Ft)	dbh (cm)
		1	2	3	4	5	Total		
Lower Elevational Zone	*Alnus nepalensis*	9	7	0	12	0	28	43.68	28.57
	Bauhinia purpurea	0	0	1	0	0	1	30	20
	Bombax ceiba	1	6	0	0	0	7	105.71	77.14
	Brassaiopsis hainla	0	0	2	1	0	3	29.33	24
	Choerospondias axillaris	1	0	0	0	0	1	60	40
	Daphniphyllum	0	0	0	0	1	1	30	20
	Engelhardtia spicata	1	0	5	0	0	6	75	80
	Erythrina arborescens	0	0	1	0	0	1	20	20
	Ficus oligodon	0	0	1	0	0	1	20	30
	Holarrhena pubescens	0	1	0	0	0	1	70	60
	Juglans regia	0	0	1	0	0	1	60	50
	Macaranga indica	1	1	1	0	0	3	38.33	18.67
	Persea odoratissima	0	0	0	3	4	7	35	18.29
	Prunus cerasoides	0	0	1	0	0	1	60	20
	Quercus semecarpifolia	0	0	0	0	4	4	42.5	42.5
	Schima wallichii	1	1	3	0	1	6	41.67	32.5
	Adenanthera pavonina	0	0	0	1	0	1	30	20
	Toona ciliata	0	1	0	0	0	1	45	30
Total no. of individuals in each plot		**14**	**17**	**16**	**17**	**10**	**74**		
Middle Elevational Zone	*Acer acuminatum*	0	0	5	0	2	7	45.29	46.71
	Acer pectinatum	0	0	0	0	2	2	37.5	35
	Albizia julibrissin	2	1	0	0	0	3	50	43.33
	Alnus nepalensis	16	0	0	0	0	16	33.125	19.31
	Hypericum sps.	0	0	0	2	0	2	31.5	22.5
	Juglans regia	3	0	0	0	0	3	54	28.33

	Myrsine capitellata	0	0	15	6	0	21	27.52	25.67
	Persea odoratissima	0	1	0	0	0	1	46	30.5
	Rhododendron arboreum	0	11	0	24	12	47	25.19	21
	Rhus javanica	0	0	0	0	3	3	40	30
	Rhus succedanea	0	0	2	2	1	5	31.8	29.52
Total no. of individuals in each plot		**21**	**13**	**22**	**34**	**20**	**110**		
Upper Elevational Zone	*Acer pectinatum*	1	0	0	0	0	1	15	8
	Betula alnoides	6	0	0	0	0	6	13.83	14.67
	Betula utilis	0	12	0	11	13	36	19.69	15.31
	Rhododendron arboreum	10	1	0	0	0	11	19.55	22.27
	Rhus javanica	2	1	0	0	0	3	21.67	33.33
	Salix himalayensis	0	0	8	0	0	8	14.375	11.25
	Viburnum erubescens	0	0	1	0	0	1	15	14
Total no. of individuals in each plot		**19**	**14**	**9**	**11**	**13**	**66**		

PHOTOPLATES

Field work and Herbarium Collection

Beautiful view of Annapurna Himal. **Landscape view from Chomrong.**

Study site and Data collection


Herbarium preparation


Cut stump of trees


Local people carrying timber beam and fuel wood