Response of *Pinus wallichiana* to Climate Change: A Case Study from Manaslu Conservation Area, Western Nepal

A dissertation submitted for the partial fulfillment of the requirement for the completion of Master's degree in Environmental Science

Submitted to

Central Department of Environmental Science

Tribhuvan University

Kirtipur, Kathmandu, Nepal

Submitted by

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Declaration

I, Sangita Pant, hereby declare to the evaluation committee that this thesis entitled **Response of *Pinus wallichiana* to Climate Change: A Case Study from Manaslu Conservation Area, Western Nepal** is a research based on my original work, and all the sources of information used are duly acknowledged. This work has not been submitted to any other university for any academic award.

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II

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Letter of Recommendation

This is to certify that **Ms Sangita Pant** has prepared this dissertation entitled **Response of *Pinus wallichiana* to Climate Change: A Case Study from Manaslu Conservation Area, Western Nepal** as a partial fulfillment of the requirements for the completion of the Master's degree in Environmental Science majoring in Mountain Environment. This study is based on scientific investigation carried out by the student under our supervision and guidance. We, therefore, recommend this dissertation for final approval and acceptance.

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Letter of Approval

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v

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Abstract

This study mainly focuses on dendro-ecological response of *Pinus wallichiana* to climate change. The study was carried out in two community managed forests, namely Thangming and Chhak of Prok VDC in Manaslu Conservation Area (MCA) in western Nepal. Vegetation sampling was done by quadrate method, and the sample quadrates were located by stratified random sampling technique. Four vertical transects were laid along the elevation gradient running parallel to each other with 200 m difference starting from 2,100 m asl to 2,700 m asl. Altogether 28 quadrates (size: 20 m × 20 m) were laid on both north and south-facing slopes (18 in north and 10 in south). Diameter at Breast Height (DBH), basal diameter and height of each individual tree of *P. wallichiana* were recorded. A total of 105 tree cores were collected by using Swedish increment borer. A detailed ecological survey was carried out in each plot with GPS recording. The forests of both aspects were dominated by *P. wallichiana.* Northern aspect was associated with *Cedrus deodara, Rhododendron arboreum, Castanopsis indica,* etc. The north facing slope had denser forests (1437.5 no. /ha) than the south-facing slope (643.75 no. /ha). Tree density of *P. wallichiana* decreased with increase in altitude in southern aspect; however, no such consistent trend was seen in the northern aspect. There was significant difference in *P. wallichiana* density between two aspects (t-statistic 0.37, $p < 0.05$). The average seedling and sapling density of *P. wallichiana* on the north and south slopes was 173.75 no./ha; 293.75 no./ha and 218.75 no./ha; 256.25 no./ha respectively. From the tree ring analysis a 91 years old tree was recorded from northern aspect of the forest. The average annual radial growth was 1.30 mm/yr and 0.90 mm/yr for northern and southern aspect respectively. The ring pattern showed the fluctuation in the ring width with the temporal change in environmental condition. The growth of *P. wallichiana* was favored by pre-monsoon temperature and monsoon rainfall. This shows that fluctuation in any climatic condition in these months will change the growth pattern of the *P. wallichiana*.

Keywords: *aspect, DBH, dendrochronology, density, species association, tree core, tree ring*

Table of Content

Contents

List of Figures

List of Tables

Acronyms and Abbreviations

cm	Centi meter
DBH	Diameter at Breast Height
DB	Basal Diameter
DHM	Department of Hydrology and Meteorology
DPL	Dendrochronology Program Library
GPS	Geological Positioning System
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
m	meter
mm	millimeter
m asl	meter above sea level
MCA	Manaslu Conservation Area
MoE	Ministry of Environment
NAST	Nepal Academy of Science and Technology
NTNC	National Trust for Nature Conservation
Ppm	Parts per millieum
SPSS	Statistical Package on Social Science
TSAP	Time Series Analysis and Presentation Program
VDC	Village Development Committee

Chapter I: Introduction

1.1 Background

1.1.1 Climate Change and Its Impacts

Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC 2007). The recent climate change is mainly comprehended as a result of modification of natural climatic conditions and the chief factors which favor this are natural and anthropogenic. For meeting the ever increasing energy demands, human activities such as burning of fossil fuels and deforestation has resulted in the increased concentration of green house gases in the natural environment. Among the various green house gases, carbon dioxide is considered as the most important and its level has increased from 270 parts per million (ppm) prior to the industrialization to 379 ppm in 2005 (IPCC 2007). The temperature increase in the Himalayan region has been greater than the global average of 0.74 °C over the last 100 years (IPCC 2007).

Climate change is affecting a wide variety of organisms including changes in the distribution, physiology and phenology of some species (Hughes *et al* 2009). Increasing temperature have caused the early onset of spring activities in plants, such as budburst and flowering (Spehn 2011). Likewise, increased temperature and rainfall variability have resulted into shifts in agro- ecological zones, prolonged dry spells, and higher incidences of pests and diseases (MoE 2010). Another widely observed phenomenon due to climatic change is the upward or pole ward migration of plant species, which has led to an overall increase in the number of species on mountain summits (Grace *et al* 2002; Kirdyanov et *al* 2012; Korner 1998). From the various observations in the past experimental studies and current ecophysiological and ecological understanding, it has been seen that forests are highly sensitive to climate change (Kirschbaum & Fischlin 1996; Holtmeier 2009). Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides (Dale *et al* 2001). Temperature is the key climatic factor which sets rather narrowly defined growth-physiological limits to plant life at high elevation in general and to trees in particular (Korner & Paulsen 2004). Annual temperature of 1^{o}C is sufficient enough to bring substantial changes in the growth and regeneration capacity of many tree species (Korner 1998; Kirdyanov *et al*

2012; Sharma *et al* 2008). In general, the temperature changes at a rate of 6 °C/km on mountain slopes but 0.01-0.006 °C/km of horizontal distance in the mid-latitudes (Ohsawa 2006). This suggests tight species interactions in mountain environments compared to those of horizontal, latitudinal changes. With climate change the suitable habitats for many species are likely to shift at a faster rate than the maximum natural rate at which many species can migrate and establish. Global models based on a doubled carbon dioxide climate predicted that a substantial fraction of the existing forests will have to change from the current vegetation types to new vegetation types (Kirschbaum & Fischlin 1966; IPCC 2007).

Mountains are the rich repositories of biodiversity and home to many of the endangered species. In mountains, vegetation rapidly changes with elevation over relatively short horizontal distances so these areas are the most unique areas for detection of climate change and assessment of climate related impacts (Whiteman 2000). Mountains have diverse vegetation and varied microclimatic and ecological conditions (Sharma *et al* 2010). Biodiversity in the mountain areas are sensitive to climatic factors and are likely to have different vulnerability thresholds according to the species, the amplitude and the rate of climatic change (Beniston 2003). There is a lack of reliable data to assess current effects and to predict the impacts of climate change and future trends in the Himalaya. For this reason, the Himalayas remained a ''white spot'' in the 4th Intergovernmental Panel on Climate Change report (Manandhar *et al* 2009). Due to climate change, the growth of many conifer species is increased in the western Himalaya (Borgaonkar *et al* 2011). However, such kind of study are lacking from the Nepal Himalaya.

1.1.2 Dendrochronology as a Tool to Study Climate Change

Tree is a recorder, a biological databank that records and stores the information from the environment. To know the growing processes and how trees react to the different ecological and climatic factors we should be able to read and understand this information. Dendrochronology is a branch of science which deals with the study of tree rings. It includes all tree ring studies where the annual growth layers have been assigned to or are assumed to be associated with specific calendar years, and the science of reconstructing past climate by use of tree rings is known as dendroclimatology (Fritts 1976). Some basic principles and concepts of dendrochronology include:

- The uniformitarian principle (the present is the key to the past)

- The principle of limiting factor (a biological process such as growth cannot proceed faster than is allowed by the most limiting factor)
- The concept of ecological amplitude (each species depending upon its hereditary factors which determine its phenotype, may grow and reproduce over a certain range and habitats)
- Site and species selection
- Sensitivity (variability in ring widths)
- Repetition
- Cross dating (the procedure of matching ring width patterns among trees and wood fragments in the given area and it includes matching of ring wood patterns among specimens)
- Standardization (procedure of correction of the ring wood for the changing age and geometry of the tree)
- Modeling growth environmental relationships, and
- Calibration and verification (Fritts 1976)

Dendrochronology can be applied to very old trees to provide long term records of past temperature, rainfall, fire, insect outbreaks, landslides, hurricanes, and ice storms etc. (Fritts 1976; Cook *et al* 2003). Dendrochronological data nets are being set up for dating purposes and climatic and ecological studies (Schmidt 1999). The study of past climatic variation and its effect is also necessary for a better understanding of the future planning potential especially in the climatic change scenario (Fritts & Swetnam 1989). Climate change study so far in Nepal is generally conducted by using meteorological data. The record of past climatic variation, based on meteorological observations, extend back only for a short period and does not represent the range of natural climatic states that have existed in the geological recent past (Lamarche 1974). Many meteorological stations in the country do not have long term and continuous data. Hence, it is necessary to develop regional chronology using other proxy source like tree ring and by incorporating more sites for the reconstruction of past climate so that the station with long term meteorological data could be used (Khanal *et al* 2002). Dendroecology provides an exact time control as well as historical perspective to ecological investigations. (Fritts & Swetnam 1989)

Trees are one of nature's most accurate timekeepers. Their growth layers, appearing as rings in the cross section of the tree trunk, record evidence of floods, droughts, insect attacks, lightning strikes, forest fires, and even earthquakes etc (Fritts 1976; Speer 2010). These rings can be analyzed for various characteristics to get information about local past climate. The annual rings of trees are an important source of paleoclimatic data because they can be accurately dated and the property of tree ring can vary in response to change in climate. Tree rings as a proxy of climate data could provide monthly or seasonal climate variations for the past over 1000 years (Kobayashi *et al* 2002).

1.1.3 *Pinus wallichiana*

The pines, belonging to Pinaceae family, are very important tree in the Himalayas, not only for their timber and secondary products, but also because they are invaluable for slope stabilization and re-forestation of denuded areas. There are two indigenous species of Pine: *Pinus roxburghii* and *Pinus wallichiana. P. wallichiana* (Blue Pine) is a coniferous evergreen tree native to the Himalaya, Karakoram and Hindu-Kush mountains, from eastern Afghanistan east across northern Pakistan and India to Yunnan in southwest China (Ghimire *et al* 2010). It is high altitude Pine, occurring from 1800-4000 m (Adrin 1990).It reaches, 45.72 to 60.96 m tall at maturity (http://dendro.cnre.vt.edu/dendrology/Syllabus2/factsheet.cfm?ID=779). It favors a temperate climate with dry winters and wet summers. It is broadly pyramidal in shape with a loose, open crown. Branches are often short and down-curved; occur in regular whorls. The leaves ("needles") are in fascicles (bundles) of five and are 15–20 cm long. The cones are long and slender, 16–32 cm (Orwa *et al* 2009).

Typical habitats of *Pinus wallichiana* are mountain screes and glacier forelands, but it also forms old growth forests as the primary species or in mixed forests. The plant is found sometimes in pure stand but often in association with other conifers including *Cedrus deodara*, *Abies pindrow*, *Picea smithiana* and *Juniperus indica* and with broadleaved species including *Quercus semecarpifolia*, *Betula utilis*, *Acer* and *Ilex* species (Earle 2009). In some places it reaches up to the tree line. Past studies have shown the potential of the species for the multiple aspects of dendrochronological studies (Bhattacharyya *et al* 1992; Cook *et al* 2003; Shah & Bhattacharyya 2012) because of its clear annual rings and its wide geographical coverage.

1.2 Statement of the Problems

Climate change is projected to occur at a rapid rate relative to the speed at which forest species grow, reproduce and re-establish themselves (IPCC 2007). Himalaya region is very sensitive to global climate change. The effect of climate change is already felt in the form of water availability (amounts, seasonality), biodiversity (endemic species, predator–prey relations), ecosystem boundary shifts (tree-line movements, high-elevation ecosystem changes), and global feedbacks (monsoonal shifts, loss of soil carbon) (Xu *et al* 2009).

Paleoecological and paleoclimatic studies are of key importance in establishing baselines and are the only means available for determining amplitudes and rates of change of vegetation to natural climate variations (Beniston *et al* 1996). The highlands of south central Asia possess a diversity of natural archives from which long detailed palaeoclimatic records might be developed (e.g. lake sediments, loess, tree rings, ice cores, glacier fluctuations, geomorphologic features, and palaeobotanical fossils) (Cook *et al* 2003). Despite this potential, relatively little is known concerning climatic changes in this region over the past millennium.

Mountainous country like Nepal is most prone to climate change. Lacking of long term instrumental climatic data is one of the major problems of studying climate change in Nepal. One of such alternative could be dendrochronology, and dendroclimatology (Chhetri & Thapa 2010). The study of past climatic variation depended entirely on recorded data. Other sources of climate data are needed to fill the gaps in recorded data.

Trees are generally considered to be most vulnerable to climatic stresses during the regeneration phase. Climate change affects flowering, pollination, seed formation, germination, and seedling survival (Johnston *et al* 2009). The annual growth rings of many trees are very important for past climatic study. They show climatic variations in the form of narrow and wide rings and such recorded information is available in long-lived and fossil trees (Ahmed 2010). Studies on the age structure of tree, in combination with tree radial growth and climatic records, will be helpful in reconstructing historical climates and increasing our knowledge on plant environment interactions (Gaire 2008).

The species like *Abies spectabilis* (fir), *Picea smithiana* (spruce), *Tsuga dumosa* (hemlock), *Juniperus recurva* (juniper), *Pinus wallichiana* (pine) and other soft wood conifers are the most suitable species for dendroclimatic study (Suzuki 1990; Bhattacharyya *et al* 1992; Cook *et al* 2003; Gaire *et al* 2011). As mentioned pines and firs are the most dominant species at higher altitudes of Nepal, this can be used to reconstruct the past climate. Various researches have been carried out in the Nepal Himalaya using these soft wood conifers like *Abies spectabilis, Pinus wallichiana, Pinus roxburghii, Cedrus deodara, Juniperus recurva* etc.

Pine tree-ring width exhibits great potential for dendroclimatology and climate reconstruction in Southeast Asia (Pumijumnong 2012). Studies done in the upper tree line areas of western Himalaya's show that the Himalayan Pine (*Pinus wallichiana* A. B. Jackson) is sensitive to climate change (Ahamed *et al* 2010; Shah & Bhattacharyya 2012). Climate belts shift would affect the makeup and locations of the forests (Bhuju *et al* 2010). *P. wallichiana* is a suitable species for dendroclimatic study for its clear and datable tree-ring sequences and synchronistic growth pattern (Bhattacharyya *et al* 1992; Cook *et al* 2003; Shrestha 2012). Exploratory work by Bhattacharyya *et al* (1992) found that this species crossdates well and its growth is reasonably well correlated with climate. As, Manaslu Conservation Area (MCA) is regarded as a land of conifer diversity, various conifers including *P. wallichiana* is suitable for its ring analysis. In terms of research, this area is comparatively less explored. Till date no detailed studies on the ecological and dendroclimatic status of *P. wallichiana* along its altitudinal gradient with respect to the north and south facing slope has been carried out.

1.3 Research Question

i. How does the forest structure change in an elevation gradient along with different aspects?

ii. What is the regeneration condition of *Pinus wallichiana?*

iii. Is there relationship between growth of *P. wallichiana* and climatic variables?

iv. How was the past climate history of the MCA?

1.4 Objectives

The main objective of the research is to study response of *Pinus wallichiana* to climatic variables. The specific objectives are:

i. To assess the forest structure of *Pinus wallichiana* forest in the elevation gradient of northern and southern aspect
ii. To study the regeneration condition of *P. wallichiana*
iii. To assess tree growth and climate (temperature and precipitation) relationship
iv. To reconstruct past climate of the MCA (temperature and precipitation)

1.5 Limitations

Due to the remoteness, steepness and rugged topography, slope with the similar feature could not be selected for comparing both aspect of the forest. Due to this, equal numbers of quadrate could not be maintained in each elevation in both aspects. Comparatively similar slope and aspect should be taken. More relevant data should have been achieved if the site with minimum anthropogenic pressure was selected. Length of chronology was 91 years which prevent further to reconstruct past climate.

1.6 Overview of Contents

This report is presented in six main chapters along with additional supporting sections of references and appendixes.

Chapter I is the introductory section, which includes the background of the study with short description on the climate change from global to local level and its possible impacts, dendrochronology as a tool to study climate change, about *Pinus wallichiana*. The statement of problem, research questions, objectives, limitations and overview of contents of the study are also explained in the first chapter.

Chapter II is the review of the literature concerned with the present study. Literature on climate change and dendrochronology from global level through regional understanding to Nepal, finally entering on MCA are reviewed in the chapter.

Chapter III is description of materials and methods. It presents the description of the study area: physical description, location, drainage, topography, climate and temperature, floral diversity, faunal diversity, physiographic diversity, socio-cultural and economic aspects of MCA**.** It covers the details of the methodology adopted for the research It includes research design, data collection methods.

Chapter IV presents the finding of the study. In this section the results are presented according to the specific objectives. This includes specific findings on the floristic and forest structure analysis, different forest structural parameters at tree, shrub and herb stratum, anthropogenic pressure in the study plots, climatic trend in local area especially temperature trend, age structure and regeneration of *Pinus wallichiana* .

Chapter V is the discussion portion which includes mainly comparison of the results with previous studies where available. The results on each specific objective are thus discussed here.

Chapter VI presents the conclusions of the study based on the findings and discussions. Some recommendations are also mentioned in this chapter.

Chapter II: Literature Review

2.1 Literature Related to Dendrochronology and Climate Change at Global Level

Fritts (1976) provided basic text book for dendrochronological analysis. This book gives detail information on dendrochronological research.

Phipps (1985) described the techniques for collecting and handling increment cores. Procedures include those for cleaning and maintenance of increment borers, extracting the sample from a tree, core surfacing, cross dating, and measurement.

Korner (1998) reassessed the high elevation treeline positions by compiling data for the worldwide position of climate-driven alpine treeline and discussed causes for treeline formation with a global perspective. He hypothesized that the life form tree is limited at treeline altitudes by the potential investment, rather than production, of assimilates (growth as such, rather than photosynthesis or the carbon balance, being limited).

Pensa *et al* (2005) reconstructed a 250-year-long chronology of Scots pine (*Pinus sylvestris*) height increment for the northern timberline based on material collected from four stands in Lapland: Finland and Sweden. The height increment of pine was lower in the 18th and 19th centuries than in the second half of the 20th century. They concluded that due to a strong common signal, height-increment series was a promising tool for reconstructing summer temperature on the regional scale at the northern timberline.

Kullman and Oberg (2009) studied elevational tree line change in the southern Swedish Scandes and quantified for the period 1915 AD -2007 AD and for two sub periods 1915 AD - 1975 AD and 1975 AD – 2007 AD. The study focused on *Betula pubescens* ssp. *Czerepanovii*, *Picea abies* and *Pinus sylvestris* at a large number of sites distributed over an 8000 km^2 area.

Leonelli *et al* (2011) related climate warming with recent treeline shift in European Alps. They reconstructed the past treeline position for the last three centuries in a nearly undisturbed site by means of a dendrochronological approach. The reconstruction of the altitudinal dynamics at the study site reveals that the treeline shifted upwards of 115 m over the period 1901 AD–2000 AD, reaching the altitude of 2505 m in 2000 AD and 2515 m in 2008 AD.

2.2 Literature Related to Himalaya

Bhattacharyya and Yadav (1996) analyzed tree ring of *Pinus wallichiana* growing in subalpine region of the Kinnaur, north- west Himalaya. A chronology extending from 1621 AD - 1990 AD had shown that tree ring data could be used to study glacier behavior in this region. They also recorded that the annual ring widths of this species were low during the years having positive glacial mass balance recorded from some glacial advances reported during the recent past in the Himalayan and Trans Himalayan region.

Wang *et al* (2006) studied age structure of *Picea schrenkiana* forest along an altitudinal gradient in the Central Tianshan Mountains of northwestern China. They suggested that the study on age structure of tree limits, combining with information of climatic records and radial growth of trees, will be helpful in reconstruction of climate conditions in the history as well as in understanding the plant environment interactions. They proposed temperature and precipitation as a limiting environmental factor in determining the age structure of the species.

Ahamed *et al* (2010) provided the preliminary results of climatic studies based on two pine tree species of Himalayan area of Pakistan. They standardized ring width chronologies of *Pinus wallichiana* and *Pinus gerardiana*. Here both species showed some similar effects, responses and trends. Therefore they concluded that both species were suitable for paleoclimatic reconstruction back to at least 500 years.

Zafar *et al* (2012) carried out growth climate response of *Picea smithiana* from Afghanistan. They cross dated 24 cores and did not found the correlation between chronology and station data. As temperature and precipitation were weakly negatively correlated, they suggested that mean monthly temperature was not the most limiting factor to the growth in the study area.

2.3 Literature Related to Nepal Himalaya

Suzuki (1990) collected cores from the two forest stands, one dominated by *Abies spectabilis*, and the other by *Pinus wallichiana* - *Picea smithiana* around Lake Rara, Nepal, for dendrochronological study. He collected 198 cores from 105 conifers. It was found that the annual ring widths had significant similarities between cores taken from the same tree. The climatic change affected the large trees more strongly than it did the small trees.

Bhattacharya *et al* (1992) described 10 ring width based chronologies from Nepal and reviewed the prospects for further dendroclimatic work here. They pointed the good potentiality of some conifer tree species like: *Pinus wallichiana, Cupressus dumosa, Cedrus deodara*, *P. roxburghii* and *Abies spectabilis* for dendroclimatic study. They referred densitometry data to be more useful to study these species and the lack of meteorological data as an obstacle to further dendroclimatic work in Nepal.

Schmidt *et al* (1999) collected 1700 samples from archaeological excavations, old houses, monasteries and castles from South Mustang, Nepal. They established a master chronology for Nepal covering the time-span between 1324 AD- 1997 AD. This dendrochronological result provides useful information about the history of the local architecture, castles and monasteries along this old and famous trade route between Tibet and India.

Kobayashi *et al* (2002) built a 336-year ring width and maximum wood density chronology from 30 cores/18 trees of *Tsuga dumosa* from Myagdi Khola, Nepal. Ring width chronology showed a significant response to the early and premonsoon temperature, and pre to early monsoon precipitation and post monsoon precipitation.

Cook *et al* (2003) described the development of a tree-ring chronology network, represented by five indigenous tree species, in Nepal that is suitable for reconstructing temperature related climate forcing over the past few hundred years. They developed a long monthly temperature record for Kathmandu. With the help of tree ring climate relationship, they reconstructed past temperature which strongly reflect patterns of temperature variability associated with Little Ice Age cooling and warming into the 20th century, with the October–February season exhibiting the strongest increase in temperature over the past 400 years.

Sano *et al* (2005) reconstructed the past 249 years climate of western Nepal using ring width and wood density of *Abies spectabilis*. This reconstructed temperature for the past 249 years showed a warming trend from 1750 AD until approximately 1790 AD, followed by cooling until 1810 AD, then by a gradual warming trend well up to 1950 AD.

Gaire (2008) documented the recruitment and tree ring data of *Abies spectabilis* at the treeline of the high mountains of Langtang National Park, Nepal Himalaya. Tree ring analysis shows variation in between the radial growth in the recent years and in overall growth period. No significant shift was seen.

Udas (2009) used samples from 55 trees at treeline and forest sites of Dhulu Ban, Mustang District in west- central Nepal. She developed a 149 years tree ring chronology of *Abies spectabilis* dating back to 1860 AD. Tree growth responses over the Himalaya range irrespective of species, site, and altitude were strongly sensitive to moisture availability during the growing season; additionally the tree growth was controlled by temperature induced moisture stress during the summer.

Vijayaprakash and Ansari (2009) studied climate change and vegetation shift of *Abies spectabilis* D.on in the tree line areas of Gwang Kharqa in Sankuwasava district of eastern Nepal. The study mainly focuses on the rate of upward shift of *A. spectabilis*. They found that tree line vegetation was shifting at a faster rate i.e. 23 m in 10 years in the south aspect while it was reported 17 m in 10 years in the north aspect.

Bhuju *et al* (2010) studied dendroecology of high altitude forest at Sagarmatha National Park, Nepal. They draw positive correlation between ring width and monthly total precipitation of the most of the months of current year and negative correlation with previous year's precipitation.

Chhetri and Thapa (2010) studied tree ring and climate change in Langtang National Park, Central Nepal, They took 120 tree cores from 60 trees of *Abies spectabilis* from two different sites Chandanbari and Cholangpati area. Analysis of increment cores showed that trees in those stands were 100- 300 years old. The high mean sensitivity value (0.22 and 0. 20) indicated that high inter-annual variability was present in the ring widths and that the chronology was sensitive to yearly environmental changes; ring width was negatively correlated with minimum monthly temperature and positively correlated with total monthly precipitation.

Suwal (2010) conducted study in treeline ecotone of Nubri Valley at MCA. The crown architecture of the species showed that the ellipticity decreasesd with growth. The seedling and sapling ratio showed that the ratio was lower above the treeline showing harsh climatic condition to survive.

Bhuju and Gaire (2012) suggested that site selection is crucial for the suitability of *Pinus roxburghii* to dendroclimatic study. They studied plantation history and growth of old pine stands in Kathmandu Valley by using a dendrochronological approach. The plantation history of Sallaghari (Bhaktapur), Singha Durbar Baraf Bag and Kumari temple, Thapathali (Kathmandu) was determined around 1870 AD, 1900 AD and 1875 AD respectively.

Dawadi *et al* (2012) developed a 458-year chronology (back to AD 1552) based on 49 tree-ring cores from 41 Himalayan birch (*Betula utilis*) trees at two sites in the Langtang National Park, central Nepal. The chronology statistics shows positive correlation with precipitation in May and March - May ($p < 0.001$) and an inverse relationship with temperature in May and precipitation in August ($p < 0.05$). Thus, they concluded that the Himalayan birch ring-width chronology is an indicator for pre-monsoon precipitation variations in the central Himalayas.

Shrestha (2012) developed 99 years long chronology of *Pinus wallichiana* which range from 1913 to 2011 AD. Developed tree ring chronology of *P. wallichiana* had a mean sensitivity 0.145. The *P. wallichiana* tree ring and climatic relationship at Kunjo, Mustang indicates that this species is suitable for dendroclimatic study for its clear and datable tree-ring sequences and synchronistic growth pattern.

Chapter III: Materials and Methods

3.1 Study Area

3.1.1 Physical Description

Manaslu Conservation Area (MCA) lies in an upper region of Gorkha district in between 28^o 20' N- 28^{o}45' N latitude and 84^o 29' E – 85^o 11' E longitude. It is bordered by Tibet to the north and east, Manang district to the west, and Gorkha district to the south. Government of Nepal declared it as conservation area in December 1998 and entrusted to National Trust for Nature Conservation (NTNC) with management responsibilities for 10 years. In 2008, the government extended the management responsibility for another 10 years (NTNC 2010). MCA encompasses a total of 1,663 sq. km. area with seven VDCs, namely: Sirdibas, Chhekampar, Chumchet, Bihi, Prok, Lho and Samagaon. The lowest settlement is Jagat village in Sirdibas VDC at 1,370 m, while the highest settlement is Samdo village of Sama VDC at 3,830 m. MCA can be categorized into three geographical areas based upon natural setting and ethnicity: i) Nubri Valley in northwestern part encompassing Sama, Lho and Prok VDCs; ii) Kutang in the middle portion formed by Bihi VDC; and iii) Tsum Valley in the eastern part which includes Chumchet and Chhekampa VDCs.

3.1.2 Drainage

The Budi Gandaki River flows through the MCA. The river is fed by glaciers and other tributaries. Prok VDC consists of six tributaries with one Kal Tal (Lake).

3.1.3 Climate and Temperature

As MCA extends from 1,370 m from Jagat village to 8,163 m Mt. Manaslu http://www.ntnc.org.np/project/manaslu-conservation-area-project). There is extreme climatic contrast with tropical climate in the south to artic climate in the north. The southern part is warmer with an average temperature of 30 °C in summer and 10 °C in the winter while the northern part is very cold below freezing point. The six different climatic zones are noted in the region: tropical, subtropical, temperate, subalpine, alpine and arctic (NTNC 2010). Winter is very cold and there is snowfall for six months (December to May). June and September are the monsoon months with three-fourth of the annual rainfall. The post-monsoon period from October to November and winter months from December to February are usually dry. The average rainfall is 1,900 mm per annum. The southern part of the region gets more rainfall than the upper sub-alpine and arctic region in the north. Beyond Jagat, the force of the monsoon is drastically reduced and diurnal valley winds are more pronounced (http://nepalmountaineering.org/article-research). Figure 1 shows that the average annual maximum temperature (T max) is increasing but the minimum annual temperature (T min) are decreasing.

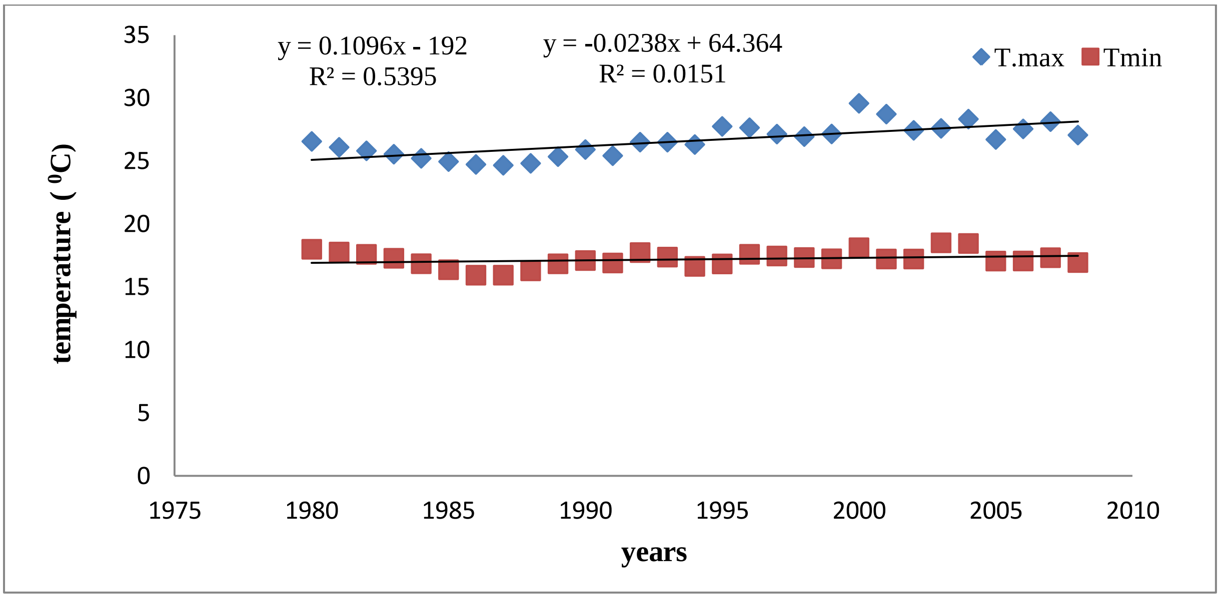


Figure 1: Annual temperature pattern recorded at Gorkha station (1980-2009)

The average annual precipitation is in decreasing trend while analyzing for the period of 1980-2009 (Figure 2).

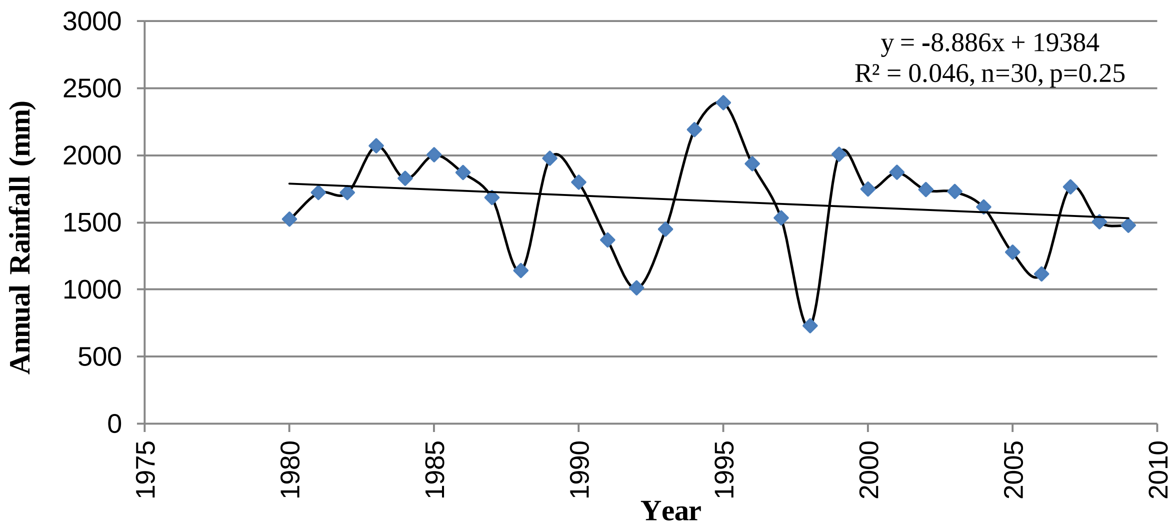


Figure 2: Yearly trend of mean annual rainfall at Gorkha station (1980-2009)

3.1.4 Floral Diversity

About 2,000 species of plants are found in MCA, of which 50 species are medicinal plants (NTNC 2010). There is a clear diversity of vegetation from tropical riverine forests to tundra vegetation due to the great variation in climate and elevation. One can encounter a variety of vegetation in a stretch of forest within less than 49 km distance. Vegetation changes are clearly noted in this region. MCA is rich in both floral and faunal biodiversity. It is also called land of conifer diversity. *Shorea robusta* (Saal), *Lagerstroemia parviflora* (Bot-Dhayero) is found in tropical hardwood forest. The subtropical forest lies at an altitude between 1,000 m and 2,000 m. *Schima wallichii*, *Castanopsis indicia*, *Pinus roxburghii* (Chirpine), *Duabanga* sp. (Pipal lampastti), *L. parviflora* (Bot- Dhayero), *Albizia mollis* (Siris) are the main tree species in this vegetation zone. At an altitude between 2000 m and 3000 m, the temperate vegetation of extensive forest of *Pinus wallichiana* (blue pine), *Picea smithiana* (Spruce), *Quercus semecarpifolia* (Oak) and *Latrix himalaica* (Larch) are predominant. The Budi Gandaki valley at 2700 m-3000 m is interesting due to the richness of conifer species. *Latrix himalaica* (Larch), *Picea simithiana* (Spruce), *Tsuga dumosa* (Hemlock), *P. wallichiana (*Blue pine), *Abies spectabilis* (Fir) and *Taxus baccata* (Yew) occur in one area. In no other part of Nepal has there been reported such a combination of conifer species (NTNC 2010). In Sub Alpine zone between 3,000 m and 4,000 m, rhododendron, fir-birch, juniper (*Juniperus recurva*) and spruce constitute the forests. Alpine Zone (above 4000 m) gives way to only dwarf junipers and dwarf rhododendron. There are alpine meadows and grasslands in this vegetation zone. Open meadow is prevalent in Alpine Zone above 4,000 m. Nival Zone lies above 5000 m altitude and has tundra vegetation in the form of lichen and herbal plants (http://nepalmountaineering.org/article-research).

3.1.5 Faunal Diversity

Manaslu has a fragile but diverse natural resource base and a rich cultural environment. About 33 species of mammals, 110 species of birds, three species of reptiles and 11 species of butterflies were reported from 11 types of forest of MCA. http://www.ntnc.org.np/project/manaslu-conservation-area-project). Black beer, *Hemitragnusm Jemalahicus* (Himalayan Thar), Assamee monkey, *Uncia uncia* (Snow leopard), *Ailurus fulgens* (Red panda) etc are some of the wild animals reported from the MCA.

3.1.6 Physiographic Diversity

MCA region presents a wide range of altitudinal variation and characterized by the snow peak Mountains, cirque- headed valleys, river valleys, steep slope, deep gorges, glacial valleys, ice fields, glaciers and glacial lands such as cirque, moraine deposit and arêtes. Variation in geological structure and soil, Mahabharat Lekh and higher Himalayan area are the two main physio-graphical regions. Geologically, the Mahabharat Lekh is the most complex zone composing of meta sedimentary rock of Precambrian period such as mica, schist, quartzite, garnet-mica, and gneiss. This area is highly fractured area due to tremendous tectonic thrust. The higher Himalayan Zone is composed of Precambrian high grade gneiss, schist and calcium silicate. It is actually the steeply elevated region of the higher Himalaya. Extreme soil variation is found in the region due to variability of climate and topography. Most hill soils are loamy and stony loams in upper hill slope and silt and sandy loam in the valley and terraces. The hill soils are relatively shallow and subjected to constant erosion (http://nepalmountaineering.org/article-research).

3.1.7 Socio- Cultural and Economic Aspects

The Manaslu region possesses a rich cultural heritage with several large Buddhist monasteries like Shringi Gompa in Bihi, Mu and Rachen Gompas in Chhekampar. Local examples of the harmony between religion and environment conservation can be seen throughout the region, as Lamas from monasteries have prohibited the locals to hunt wildlife. This has helped the wildlife to prosper. The culture is equally attractive and most follow Buddhism. Agriculture and livestock rearing are the main occupation of the people. Wheat, potato, millet, maize are the major crops produced.

3.1.8 Study Site Characteristics

Field study was carried out in April- May, 2012. Thangming of northern aspect and Chhak forest (Figure 1) of southern aspects of Prok VDC of MCA were selected as study area. Prok VDC is a part of Nubri Valley and occupies an area of 146 sq km.. Instead of dislocating the local people of a region for the sake of biodiversity protection, conservation areas make the local people responsible for all natural resources in the region as its custodian. People, therefore, become both the principal actors and beneficiaries to see that the resources are utilized in a sustainable manner to benefit future generations (http://www.forestrynepal.org/project/2924). In the study area the south facing slope was drier compare to north facing slope across the river owing to the direct exposure to the sun. The bare soil exposure percentage is higher in the southern aspect. This micro- climatic condition contributes to characteristic vegetation in both aspects of the valley.

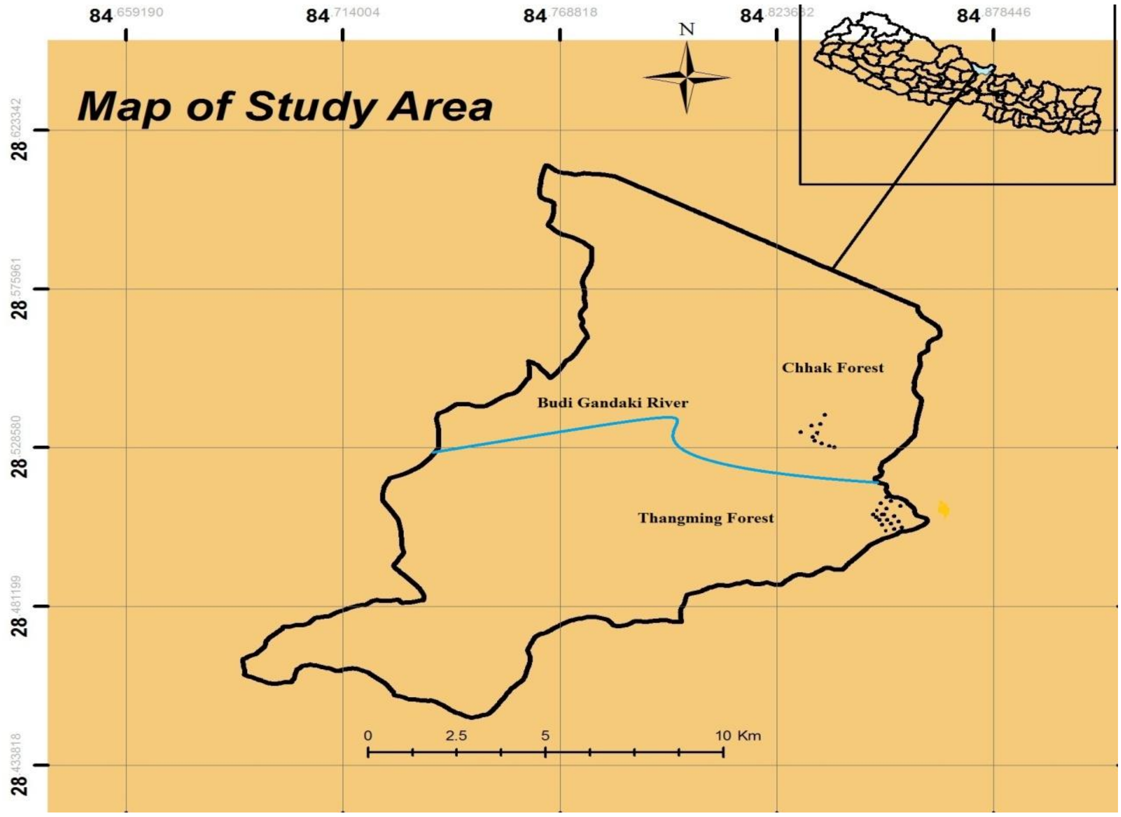


Figure 3: Map of study area showing Prok VDC with different plots in northern and southern aspect of the forest

Site description of the northern and southern aspect of the forest has been summarized in the following Tables 1 & 2,

Table 1: Site description of northern aspect- Thangming forest

S.N	Elevation (m)	Latitude (N)	Longitude (E)	Slope (°)	Ground Cover	Moisture Condition	Bare soil exposure	Canopy Cover	Sign of disturbance
1	2100	28°30'49.00"	84°51' 5.00"	50	95% litter, 5% grass	wet	low	90%	trampling(low), grazing(low)
2	2100	28°30'45.00"	84°51' 9.00"	45	99% litter, grass	wet	low	90%	not disturbed
3	2100	28°30'40.00"	84°51' 18.00"	42	90% litter	wet	low	80%	trampling(low)
4	2300	28°30'17.27"	84°51' 19.92"	25	80% litter	mesic	medium	85%	grazing (high)
5	2300	28°30'23.96"	84°51' 16.45"	45	40% litter, grass	wet	medium	65%	trampling, cutting (high)
6	2300	28°30'29.18"	84°51' 11.99"	43	90% litter	mesic	medium	80%	trampling, grazing, cutting
7	2300	28°30'37.00"	84°51' 5.00"	35	100% litter cover	wet	high	80%	trampling, grazing, cutting
8	2300	28°30'43.00"	84°50' 60.00"	25	80% litter	mesic	low	70%	trampling, cutting,grazing
9	2500	28°30'15.00"	84°51' 12.00"	40	70% litter, 30% grass,	mesic	medium	70%	trampling(medium), grazing(low)
10	2500	28°30'21.00"	84°51' 9.00"	30	30% grass,40% stone	mesic	medium	60%	cutting (low)
11	2500	28°30'25.00"	84°51' 6.74"	31	30% rock,50% grass	dry	medium	30%	grazing (high),trampling
12	2500	28°30'31.00"	84°51' 1.19"	30	50% bamboo, 100% litter	mesic	medium	75%	cutting (maximun dead wood)
13	2500	28°30'35.92"	84°50' 55.36"	43	50% bamboo, 100% litter	mesic	medium	50%	cutting, grazing, trampling
14	2700	28°30'15.31"	84°51' 2.82"	45	90% litter, 10% grass	wet	medium	50%	grazing, cutting, trampling
15	2700	28°30'20.46"	84°51' 1.10"	42	20% litter	dry	high	40%	grazing, trampling, cutting, fire

16	2700	28°30'25.30"	84°50' 59.85"	45	75% litter	mesic	medium	70%	trampling, cutting , grazing
17	2700	28°30'28.25"	84°50' 56.19"	40	85% litter	mesic	low	75%	grazing, trampling, cutting, fire
18	2700	28°30'31.14"	84°50' 52.92"	35	20%litter, grass	mesic	low	20%	grazing, trampling,cutting

Table 2: Site description of southern aspect – Chhak forest

SN	Elevation (m)	Latitude (N)	Longitude (E)	Slope (^{o})	Ground Cover	Moisture Condition	Bare soil exposure	Canopy Cover	Sign of disturbance
1	2100	28°31' 43.00"	84°50' 18.00"	25	50% litter, grass, cone	mesic	medium	60%	cutting, grazing, trampling
2	2100	28°31' 44.00"	84°50' 13.00"	30	40% litter, grass	mesic	medium	40%	trampling, grazing
3	2100	28°31' 47.00"	84°50' 6.00"	31	30% litter, grass	dry	high	35%	trampling, grazing, cutting
4	2100	28°31' 50.00"	84°49' 60.00"	30	40% litter, grass	dry	high	60%	trampling, grazing, cutting, fire
5	2100	28°31' 54.00"	84°49' 48.00"	20	30% litter,rock	dry	high	65%	trampling, grazing, cutting, fire
6	2300	28°31' 59.00"	84°49' 47.00"	15	80% grass,20 % rock	mesic	low	60%	trampling, grazing, cutting
7	2300	28°32' 5.00"	84°50' 1.00"	25	20% rock, 30% grass	mesic	medium	70%	trampling, grazing, cutting, fire
8	2500	28°32' 8.00"	84°50' 5.00"	40	50%grass, 50% stone	dry	high	70%	trampling, grazing, cutting, fire
9	2500	28°32' 6.00"	84°49' 57.00"	40	40% grass	mesic	medium	80%	trampling, grazing, cutting
10	2700	28°32' 18.00"	84°50' 9.00"	40	40% grass	dry	medium	50%	trampling, grazing, cutting, fire

3.2 Research Design

The research design for this study was analytic, descriptive and scientific. The overall research design is given in Figure 4.

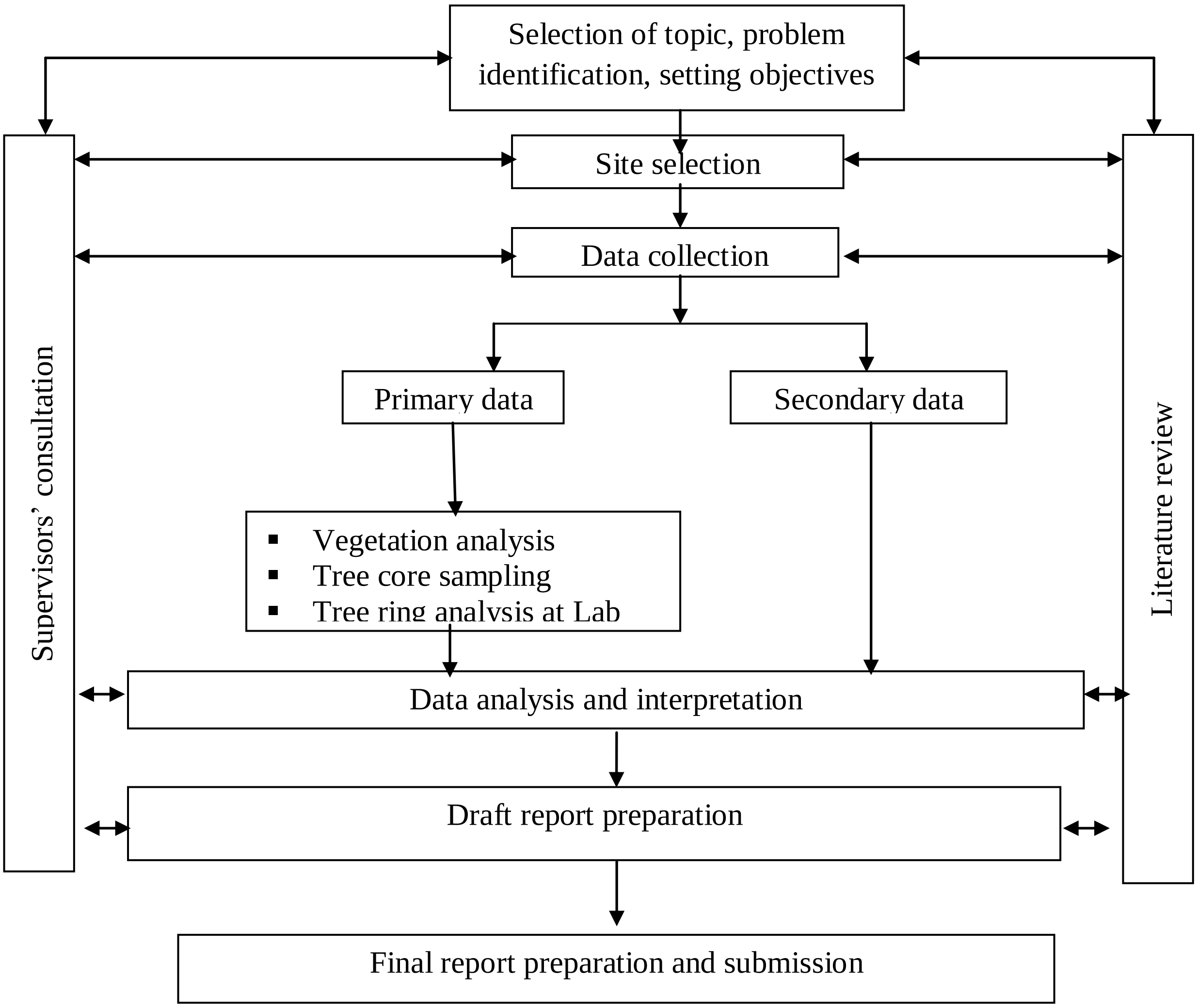


Figure 4: Schematic diagram of research design

3.3 Data Collection Methods

Primary and secondary data collection methods were applied in the research. Primary data was collected by field survey and laboratory analysis. Similarly, secondary data collection was carried out by reviewing different literatures of thesis, reports, journals, articles etc. Secondary data particularly temperature and precipitation of the nearby meteorological station has been collected from DHM. . Primary data collection in the field was carried by following ways:

3.3.1 Layout of Line Transects and Plots in Selected Site

A preliminary observation was carried out in the study area. The stand of *Pinus walliichiana* which occupies the dominant vegetation in the area was identified. Vertical transect was laid along the elevation gradient.

Four vertical transects were laid along the elevation gradient running parallel to each other with 200 m difference starting from 2,100 m asl to 2,700 m asl in both north and south facing slope. In each transect, five square plots (size: 20 m x 20 m) were laid out keeping the distance of 150 m horizontally. The sample quadrates were located by stratified random sampling technique. But due to the rugged topography altogether 18 and 10 plots were laid in northern and southern aspect respectively. In northern aspect forest five plots were laid in each transects and only three plots were laid in fourth transect. Similarly, one, two, two and five plots were laid in first, second, third and fourth transect respectively. The altitude, latitude and longitude were recorded using the e-trex Garmin GPS.

3.3.2 Biophysical Measurement

All the individual trees that occur in the sampling plots were counted. Diameter at Breast Height (DBH), basal diameter (DB) and height of each individual of *Pinus wallichiana* occurring in each quadrate was measured.

i. DBH: The DBH (1.37 m above ground) of each *P. wallichiana* was measured using a 5 m Kinglon diameter tape (D-tape). Similarly, basal diameter was measured for each individual from 0.5 cm height.

ii. Height: The height of of each *P. wallichiana* was measured using a Swedish Silva Clinometers. The tree height was measured by keeping a suitable horizontal baseline distance away from the base of the tree, from where the top and bottom of the tree was clearly visible.

iii. Canopy Cover: Canopy cover of the individual quadrates was estimated visually. Canopy cover graph was also plotted in the field for better estimation. Forest canopy can be classified as open (10-39% of the sky is obstructed by tree canopies), moderately closed (40-69% of the sky is obstructed by tree canopies) or closed (70-100% of the sky is obstructed by tree canopies) (http://ecoplexity.org/files/Measuring_Canopy_Cover_lesson_plan.pdf).

3.3.3 Ecological Analysis

i. Population Density

It is calculated by using the formula given by Kent and Coker (1992)

$$\text{Density (D) (no/ha)} = \frac{\text{Number of individuals of a species in a plot}}{\text{Area of plot (Sq. m)}} \times 10000$$

ii. Frequency

It is calculated as:

$$\text{Frequency of a species (\%)} = \frac{\text{Number of sampling unit in which a species occurred}}{\text{Total number of sampling units studied}} \times 100$$

iii. Diversity Index

Species diversity of an area can be calculated from the formula derived by Shannon and Weaner (1949). An index is used to measure the species diversity which is calculated as,

$$H = - \Sigma \text{ (} ni / N) \log (ni / N)$$

Where, H=Shannon index for species diversity

ni = importance value for each species

N= total of importance value of all species.

With this index, the higher the value, the greater will be the diversity.

iv. Dominance Index

Dominance indicates the amount of surface area occupied by a plant in a community. The formula for index of dominance according to Simpson (1949) is as follows:

$C = \Sigma (ni /N)^2$

Where, C = index of dominance

ni = importance value for each species

N= total of importance value of all species.

v. Similarity Index

Similarity between two communities can be calculated as:

$S=2C/ (A+B)$

Where, C= no. of common species

A= no. of species in community A

B= no. of species in community B

Similarity index ranges from 0 to 1.

vi. Basal Area

Basal area of each individual of *Pinus wallichiana* from all quadrates of both south and north facing slope was calculated using the formula.

Basal area$=\pi r^2 = \pi (DBH)^2 /4$

Where, r= d/2, π=3.1416; DBH= diameter of tree at breast height

vii. Regeneration Survey

Regeneration survey was carried out in all quadrates of each transect in both south and north aspects. Survey was carried out in whole quadrate (20 m × 20 m) by recording the number of seedlings and saplings of *P. wallichiana*. Individuals were categorized and enumerated into three height classes: tree (height >2 m), saplings (height: 0.5-2 m) and seedlings (height <0.5 m) following the classification used by Wang *et al* (2006), Kullman and Oberg (2009) and Gaire (2008).

3.3.5 Dendrochronological Analysis

i. Collection of Tree Core Samples

Tree core samples were collected from the breast height (1.37 m) with the help of Swedish increment borer. Attempt was made to collect at least two cores per tree from its two opposite sides. So, four cores from two trees were taken from each quadrant. Altogether 105 cores were collected from sample plots. The collected samples were carefully packed in a plastic straw and labeled the descriptions viz., tree number and core number.

ii. Processing of the Tree Core Samples

Trees cores or tree ring samples were analyzed in Tree ring- laboratory at NAST. The collected tree increment cores were air dried and glued into grooved sticks with the transverse surface facing up. The specimen details such as site name, name of the tree, number and date of collection was written on the mount for the future reference and permanent laboratory identification of the specimen. The samples were left for overnight for air drying. The surface of these cores was polished with different grade of sand paper ranging from 120 to 600 grits so that rings get clearly visible to study under the microscope.

iii. Counting and Dating of the Tree-Rings

Each ring of the cores was counted under the stereo zoom microscope. The age of the tree was obtained by counting the tree-rings of the core samples under stereo zoom microscope and assigned to the calendar year of their formation.

iv. Measurement of the Tree-Ring Samples

After dating the tree-ring sequences to exact calendar year of their formations, the width of each ring was measured to the nearest 0.01 mm precision with LINTAB measuring system attached to computer. Individual rings were measured by moving the core samples on the sliding stage under a Lin-tab measuring system attached to the PC having TSAP (Time Series Analysis and Presentation Program) with professional 0.62 ©2002-2008, a computer program. The measurements were subsequently recorded in the computer. The growth pattern of the target species were determined by measuring the distance between ring widths of the annual rings.

v. Cross dating

Crossdating is the most important principle as well as methodological step of dendrochronology (Fritts 1976). It involves matching of similar ring width patterns between different trees and is possible because the same or similar factors are limiting growth of several trees at a site in a similar way. As this limiting factor varies from year to year, so too does ring width. All the tree cores collected for dendroclimatological study were cross-dated by matching patterns of relatively wide and narrow rings to account for the possibility of ring growth anomalies such as missing or false rings. In some years, environmental or biological conditions are such that tree growth is severely reduced, with radial growth localized to certain radii, or not occurring at all. These rings are said to be 'missing' (Fritts 1976). A second type of anomalous growth ring i.e. false ring occurs as a result of changes in cell structure during the course of the growing season causing the formation of a band of narrow cells resembling.

vi. Detection of Error in Dating

After the measurement of ring width of each dated sample, the dating and measurement error of each sample was checked using a computer program, COFECHA, a computer assisted quality control program (Holmes 1983). This program checks the error in cross dating due to measurement and other ring width irregularities that might decreases the efficiency of ring-width time series for the tree-ring analysis. The program calculates cross correlations between individual series and an average chronology (Holmes 1992). The cores that were poorly correlated with the mean chronology, or had higher correlations when the dating of the core chronology was shifted, were rechecked and either corrected or eliminated.

vii. Chronology Development

The corrected ring width data was standardized using the computer program ARSTAN (Cook 1985; Cook & Kairiukstis 1990). It removes growth trends related to age and stand dynamics and retained maximum common signal. ARSTAN produces three mean index chronologies viz, the standard, residual and arstan chronologies. These three types of chronologies have unique time series characteristics. Moreover, the ARSTAN methodology uses autoregressive (AR modeling) to remove any autocorrelation effects.

viii. Statistical Assessment Tree Ring Chronology

Various statistics were calculated for both standard and residual chronologies to describe site chronologies. These were Mean sensitivity, Standard Deviation, Autocorrelation, Mean series correlation, Signal-to-noise ratio, Expressed population signal and percentage of variance explained by the first eigenvector of the chronologies. A species with a low autocorrelation, a high mean sensitivity and a high standard deviation has good potential for dendroclimatological studies.

ix. Tree Growth and Climate Relationship

Relationship between tree growth and climatic parameters (viz., temperature, precipitation and other) was analyzed to determine the limiting climatic factor responsible for the growth of tree in the study area. Simple linear and Pearson correlation was used to assess the relationship.

x. Reconstruction of Past Climate

This can be done by using the tree ring data and available climatic data. The climatic data and the dendrochronological data were correlated. We use transfer function explained by Fritts (1976) for the climate reconstruction.

3.3.6 Data Analysis

Collected ecological data were subjected for the further analysis. For ecological data analysis computer program SPSS 16.0 and MS excel 2007 were used. While collected tree cores, sample were preceded for laboratory analysis at Tree ring -lab of NAST. The DPL program, COFECHA, ARSTAN, EDRM, DENDROCLIM 2002 etc were used.

i. Climatic Data

In this study, temperature and precipitation data were taken to study the changes in climate. Studying the variations in temperature and rainfall is a suitable indicator to explain the changes in climate as many of the other variables are in one way or the other depends on these two variables. The monthly maximum and minimum temperature for the past 30 years from the nearest weather station in MCA was used. The climatic data was analyzed using Microsoft excel.

ii. Comparison of Growth *Pinus wallichiana*

Data of tree age (ring count), (DBH (cm) and height (m) was recorded from each transect of each altitude in southern and northern aspects. All *Pinus wallichiana* from each aspect was used for measuring the growth parameters. Comparison between southern and northern aspect was done.

Chapter IV: Results

4.1 Floristic and Structural Analysis

Table 3 and Table 4 present various forest structural parameters in the study site. The forest structural parameters especially density and frequency of tree species was calculated. This shows that the Thangming (northern aspect) forest was denser at an elevation of 2700 m. The density of a northern aspect forest was calculated as 1175, 1225, 1350 and 2000 no./ha at an elevation of 2100 m, 2300 m, 2500 m and 2700 m respectively. Based on the density and frequency data, this forest shows the dominance of *Pinus wallichiana* followed by *Cedrus deodara*, *Castanopsis indica*, *Rhododendron arboreum* etc. The frequency of *P. wallichiana* was calculated as 100 % at all the three elevations but its density was found lesser than *C. deodara* at an elevation of 2100 m. The average tree density at northern aspect of the forest was calculated as 1,437.5 no. /ha.

Table 3: Density and frequency of tree species on north facing slope along elevation gradients

Elevation	Name of species	Density (no./ha)	Frequency (%)
2100	*Pinus wallichiana*	875	60
	Cedrus deodara	300	80
	Total	**1175**	
2300	*Pinus wallichiana*	925	100
	Castanopsis incida	125	60
	Cedrus deodara	125	40
	Rhododendron arboreum	50	20
	Total	**1225**	
2500	*Pinus wallichiana*	850	100
	Cedrus deodara	225	40
	Castonopsis indica	75	40
	Rhododendron arboreum	200	60
	Total	**1350**	
2700	*Pinus wallichiana*	1250	100
	Castonopsis incida	25	20
	Cedrus deodara	400	40
	Rhododendron arboreum	200	80
	Quercus semecarpifolia	75	20
	Rhus wallichii	50	20
	Total	**2000**	
	Average Density	**1437.5**	

The southern aspect of the forest was dominanted by *Pinus wallichiana*. The density of the southern aspect forest was calculated as 1600, 525, 300 and 150 no./ha with an elevation of 2100 m, 2300 m, 2500 m and 2700 m respectively. At 2100 m tree density was higher with highest frequency of *Pinus wallichiana*. At 2700 m its frequency was calculated 20 % which was minimum value as compared to others. The average tree density of southern aspect forest was 643.75 no./ha. This shows that northern aspect forest had higher average density than southern.

Table 4: Density and frequency of tree species on south facing slope along elevation gradients

Elevation	Name of species	Density (no./ha)	Frequency (%)
2100	*Pinus wallichiana*	1600	100
2300	*Pinus wallichiana*	525	40
2500	*Pinus wallichiana*	300	40
2700	*Pinus wallichiana*	150	20
	Average density	**643.75**	

The average diversity index at northern and southern aspect of the forest was calculated as 0.32 and 0.24 respectively (Table 5). Diversity index shows that there is higher species diversity in northern aspect of the forest along elevation gradient. The diversity index value reaches upto 6.0. Higher the value higher will be the diversity index. However, dominance index was calculated higher in southern aspect (0.05) than northern aspect (0.04) of the forest. Its value ranges from 0 to 1. Similarity index of both aspect of the forest was calculated 0.28.

Table 5 : Diversity and dominance index of tree species at northern and southern aspect of forest along elevation gradient

	Diversity index		Dominance index	
Elevation	**Northern**	**Southern**	**Northern**	**Southern**
2100	0.30	0.36	0.02	0.18
2300	0.30	0.27	0.03	0.01
2500	0.31	0.20	0.04	0.01

2700	0.35	0.12	0.08	0.21
Average	**0.32**	**0.24**	**0.04**	**0.05**

Figure 5 presents the density of *Pinus wallichiana* along elevation gradient with different aspect. Both northern and southern aspect of the forest was found *Pinus wallichiana* dominant. In northern aspect forest density of *P. wallichiana* increases from 875 no./ha to 925 no./ha from 2100 m to 2300 m. While it decreases to 850 no./ha at 2500 m and finally it increases to 1250 no./ha at an elevation of 2700 m. The fluctuation in the density pattern may be due to human disturbance. During the survey several cut stump, sign of trampling, grazing were seen on the site. In northern aspect 2100 m and 2500 m was easily assessable, so, density was also found lower. The density of *P. wallichiana* in the southern aspect shows the decreasing trend with increasing elevation. It decreases from 1600 no./ha at 2100 m, 525 no./ha at 2300 m, 300 no./ha at 2500 m and 150 no./ha at 2700 m. At the lower elevation most of the trees were found regenerated from the cut stump.

ANOVA single factor analysis along different elevation in the two aspects of the forest shows that there was significant difference in *P. wallichiana* density between the aspects (t – statistic = 0.37, $p < 0.05$). A trend-line was drawn for both northern and southern density (Figure 5). The negative regression equation shows that the density decreases with increase in elevation and vice- versa.

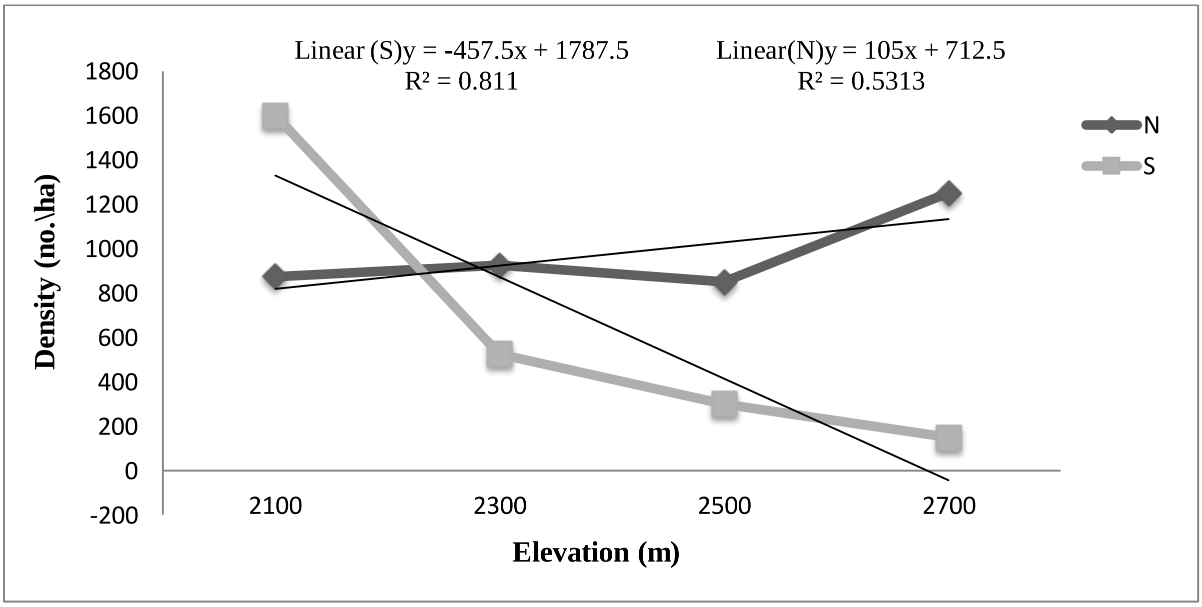


Figure 5: Density of *Pinus wallichiana* along different elevation gradient with different aspect

Table 6 shows the seedling, sapling and tree density of *P. wallichiana* along an elevation gradient of both northern and southern aspect of the forest. This shows higher density of tree at 2700 m as 1250 no./ha in northern aspect. Similarly, seedling and sapling density was found higher at 2300 m as 625 no./ha and 500 no./ha and respectively. The higher density of tree at 2700 m may be due to less human disturbance as this area has got higher slope angle of 45^o and difficult to reach. The higher number of seedling and sapling at 2300 m may be due to favorable environmental condition like soil condition, light cover, canopy cover etc.

Similarly, this elevation wise analysis showed that southern aspect forest had higher density of *P. wallichiana* tree at an elevation of 2100 m as 1600 no./ha. The seedling and sapling density of *P. wallichiana* was higher at an elevation of 2500 m and 2100 m as 375 no./ha and 625 no./ha respectively. The sapling density was found at a decreasing pattern from 2100 m-2700 m in southern aspect, while northern aspect didn't follow such pattern.

Table 6: Seedling/sapling/tree density analysis of *Pinus wallichiana* along different elevation in northern and southern aspects

Northern aspect				**Southern aspect**		
Elevation	Seedling	Sapling	Tree	Seedling	Sapling	Tree
2100	250	175	875	175	625	1600
2300	20	500	925	200	175	525
2500	300	325	850	375	125	300
2700	125	175	1250	125	100	150
Total	695	1175	3900	875	1025	2575
Average	173.75	293.75	975	218.75	256.25	643.75

4.2 Basal Area

Table 7 presents basal area of *Pinus wallichiana* at northern and southern aspect of forest along the elevation gradient. Average basal area of *P. wallichiana* at both northern and southern aspect of the forest was calculated along the elevation gradient. The total basal area at northern aspect of the forest was calculated as 12.51 m^2/ha, 18.92 m^2/ha, 13.41 m^2/ha and 11.06 m^2/ha at an elevation of 2100 m, 2300 m, 2500 m and 2700 m respectively. Similarly, total basal area at southern aspect of the forest was calculated as 6.22 m^2/ha, 11.34 m^2/ha, 4.37 m^2/ha and 14.44 m^2 /ha at an elevation of 2100 m, 2300 m, 2500 m and 2700 m respectively. Similarly, the average basal area in both northern and southern aspect of the forest was calculated as 13.97 m^2/ha and 9.09 m^2/ha respectively. The value of basal area shows that the northern aspect was denser and or matures than the southern aspect of the forest.

Table 7 : Basal area of *Pinus wallichiana* at northern and southern aspect of forest along the elevation gradient

Elevation (m)	Northern basal area (m^2/ha)	Southern basal area (m^2/ha)
2100	12.51	6.22
2300	18.92	11.34
2500	13.41	4.37
2700	11.06	14.44
Average	**13.97**	**9.09**

4.3 Regeneration

The regeneration of the *Pinus wallichiana* was assessed by observing its tree, sapling and seedling densities as well as the size class distribution like DBH and height.

DBH Class Distribution

Figure 6 shows DBH class distribution of *Pinus wallichiana* on northern aspect of the forest. DBH class distribution at northern aspect shows slightly unimodal bell distribution. *Pinus wallichiana* with the DBH class 20-25 cm as highest frequency of occurrence. This pattern was followed by DBH class of 30-35, 35-40 and 40-45 respectively. The highest DBH class on northern aspect was recorded as 70-75 cm. This shows most of the *P. wallachiana* tree were at developing stage. Here, no specific trend was found in the DBH class distribution; it means that the graph was sporadic. Disturbance was observed in 25-30, 45- 50 DBH class at different levels and times (Figure 6).

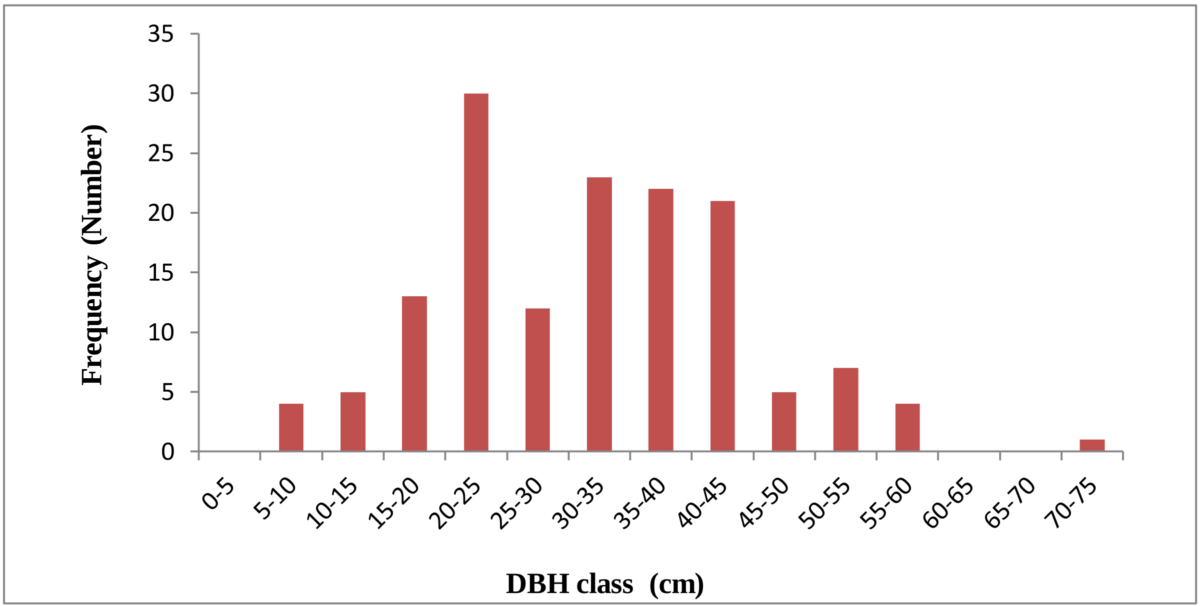


Figure 6: DBH class distribution of northern aspect of the forest

Southern aspect forest also showed the DBH class of 20-25 cm as highest distribution class (Figure 7). This pattern was followed by 10-15 cm and 25-30 cm. The DBH class distribution pattern in southern aspect forest is also an indication of developing *Pinus wallachiana* tree which has not reached maturity. Here, maximum disturbance (grazing, trampling, cutting, fire) was observed at DBH class of 15-20 cm, 45-50 cm and 65-70 cm.

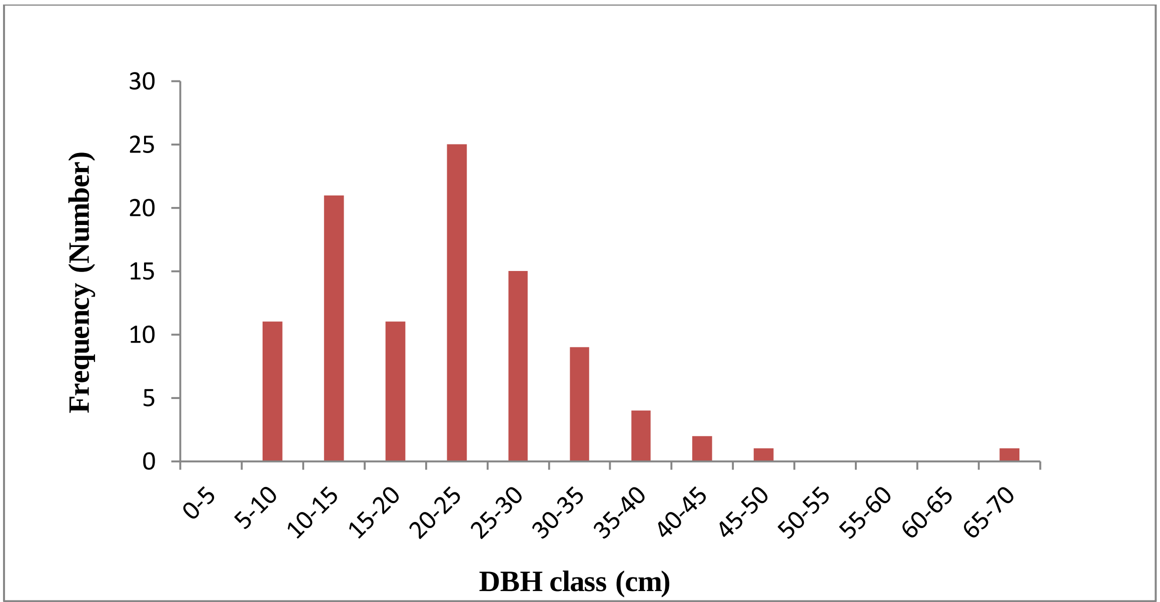


Figure 7: DBH class distribution of southern aspect of the forest

DBH frequency class distribution of *P. wallichiana* at both northern and southern aspect of the forest shows sporadic pattern. It did not show clear reverse J- shaped curve. This indicates that there was poor regeneration rate of *P. wallichiana* in both northern and southern aspect of the forest.

Height Class Distribution

The height class distribution of the northern aspect forest shows reverse J- shaped structure but large numbers of the trees were less than 3 m height (Figure 8). Here, the plants with the height greater than 2 m were considered as tree. This shows that most of the trees were in the juvenile stage. Here, maximum height class was 51-54 m.

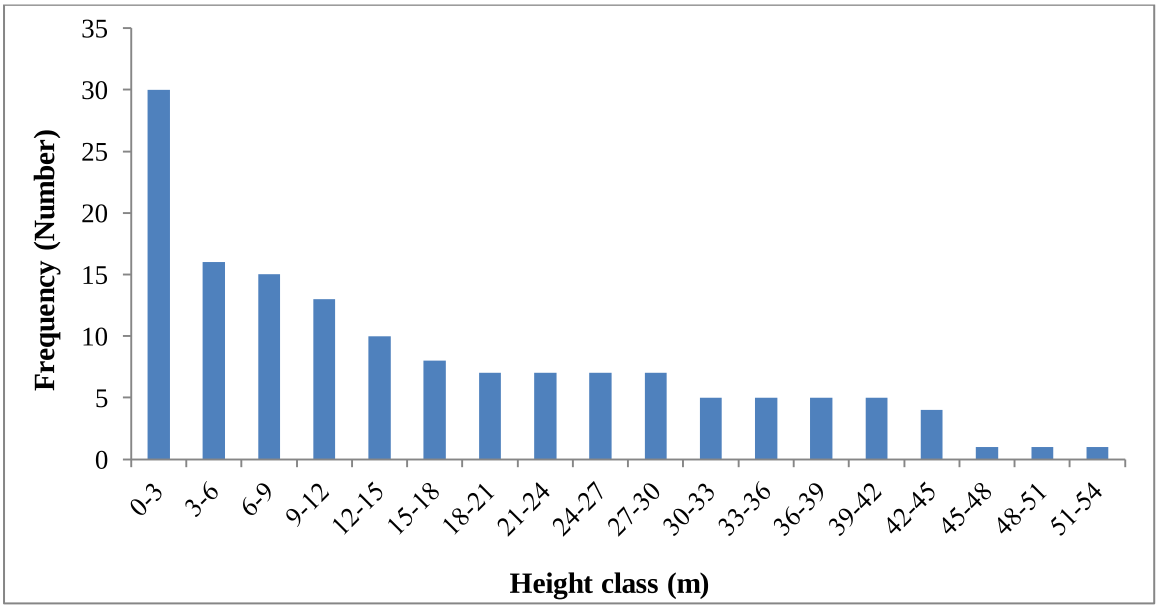


Figure 8: Height class distribution of northern aspect of the forest

Similarly, height class distribution of the southern aspect (Figure 9) showed that height class of 6-9 m has highest frequency followed by class 9-12 m. Here, maximum height class was 39-42 m. This result shows that the height class distribution of the northern aspect was greater than the southern aspect. The height class distribution shows that both the aspects were in the stage of regeneration and growing condition of plant height.

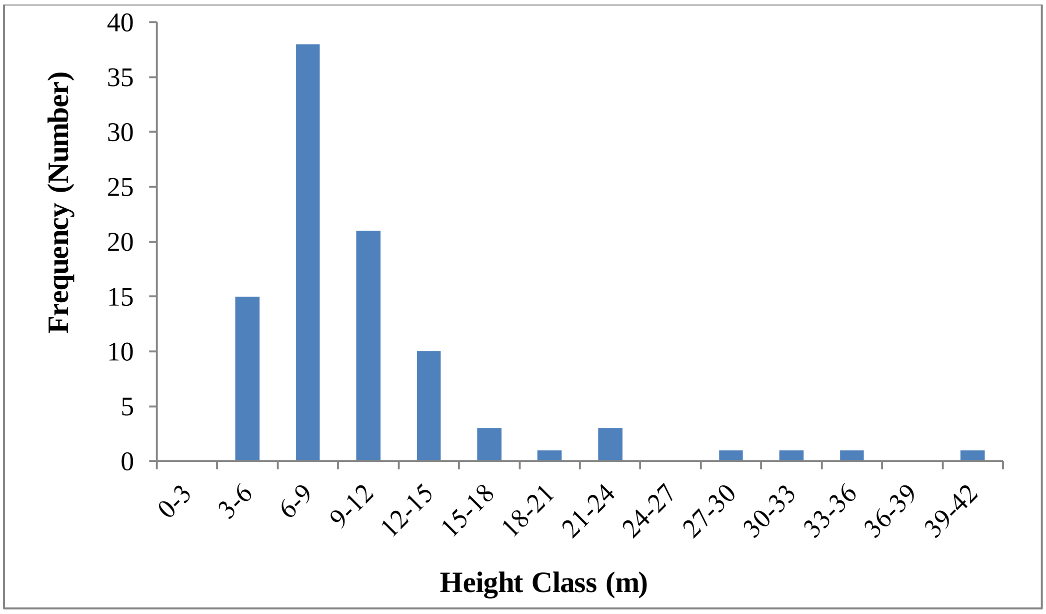


Figure 9: Height class distribution of southern aspect of the forest

Tapering

Tree taper is the degree to which a tree's stem or bole decreases in diameter as a function of height above ground. Tapering relation was analyzed by finding the differences of basal diameter and DBH of *Pinus wallichiana*. Tapering of both northern and southern aspect of the forest showed that basal diameter and DBH of *P. wallichiana* was statistically significant (t- statistic= 0.01, $p<0.05$ and t- statistic= 0.03, $p<0.05$ respectively). This showed that the shape of the *P. wallichiana* become gradually thinner at upper part. The tapering coefficient of northern and southern aspect was calculated as 0.82 and 0.78 respectively.

Canopy Cover

A regression analysis model between number of seedling/sapling and canopy cover was established for both northern and southern aspect of the forest (Figures 10 & 11). The negative regression equation shows that the regeneration increases with decrease in canopy cover and vice-versa. However, the relationship is very weak. Here, regression of seedling was found stronger than sapling.

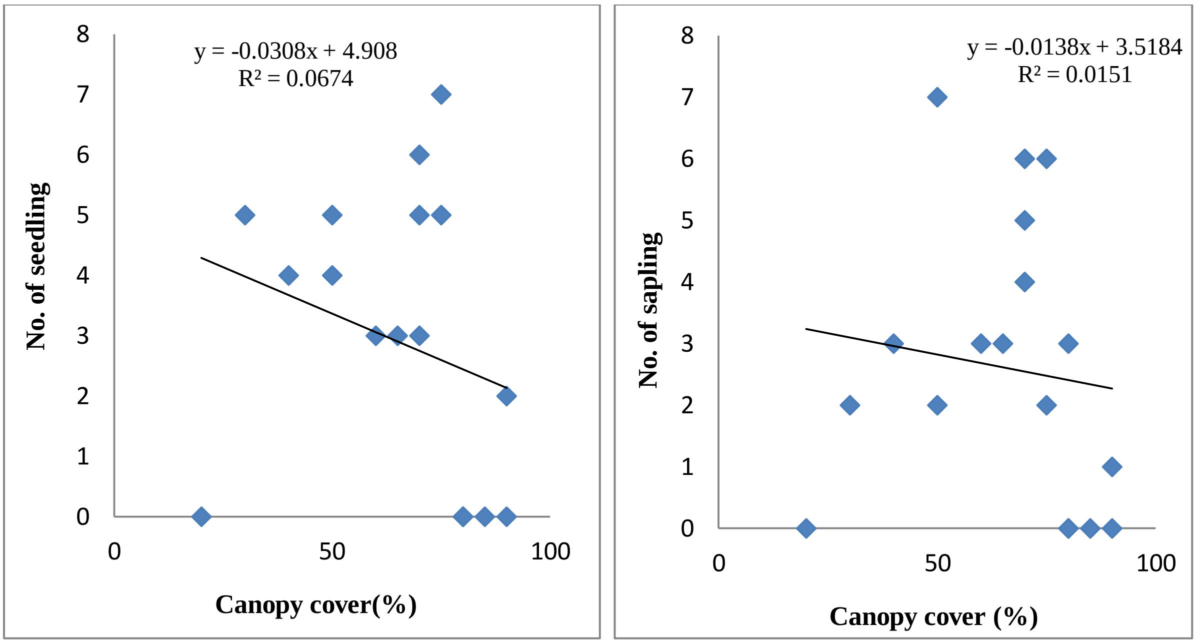


Figure 10: Relation between seedling /sapling and canopy cover of northern aspect of the forest

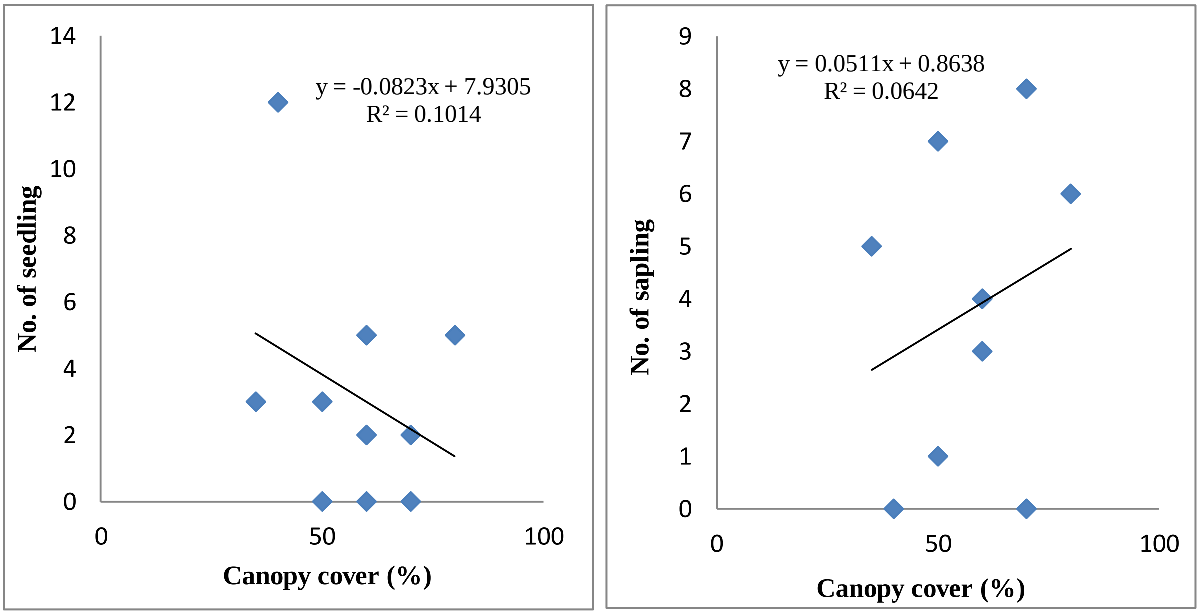


Figure 11: Relation between seedling/sapling and canopy cover of southern aspect of the forest

Dendrochronology

4.4 DBH- Age Relationship

DBH and age relationship in both aspect of the forest was studied by scatter plot diagram and fitting a trend on it. Both the aspect shows a positive linear relationship between DBH and age; however the relationship was weak between DBH and age.

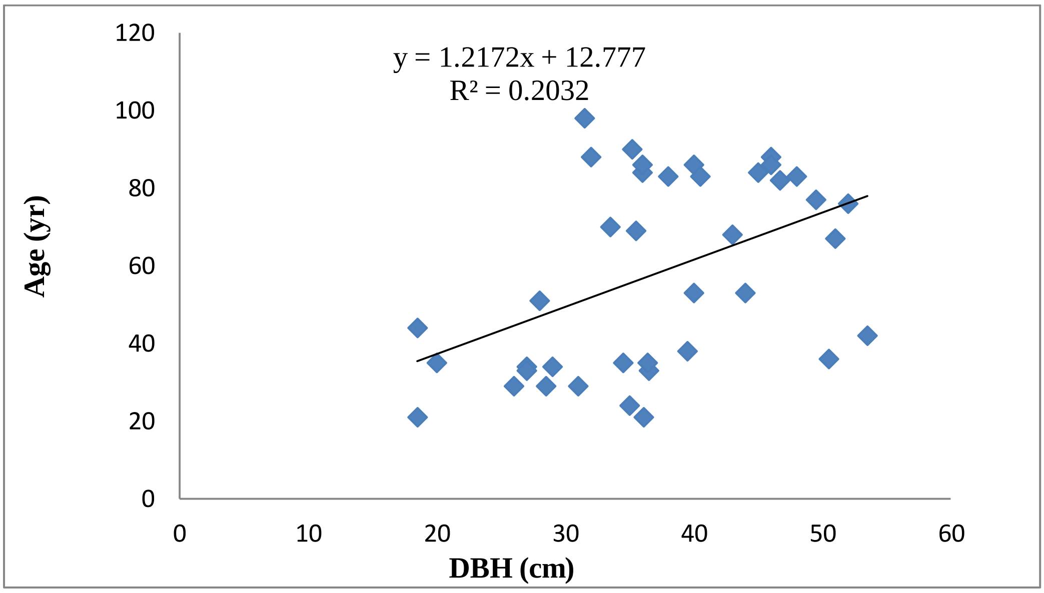


Figure 12 : DBH- Age relationship of northern aspect forest

In northern aspect forest the maximum tree was found between 70-90 yrs old (Figure 12). Oldest tree in the northern aspect of the forest was 91 years old with the DBH of 35.2 cm. The highest DBH was found 53.5 cm. Similarly, maximum tree was found in DBH of 20-30 cm with 20-30 yrs old in southern aspect of the forest (Figure 13). It was found 52 yrs tree with DBH 34 cm as the oldest tree in southern aspect of the forest. However, 45 cm was the highest DBH of southern aspect. This showed that the northern aspect of the forest was older than the southern aspect of the forest.

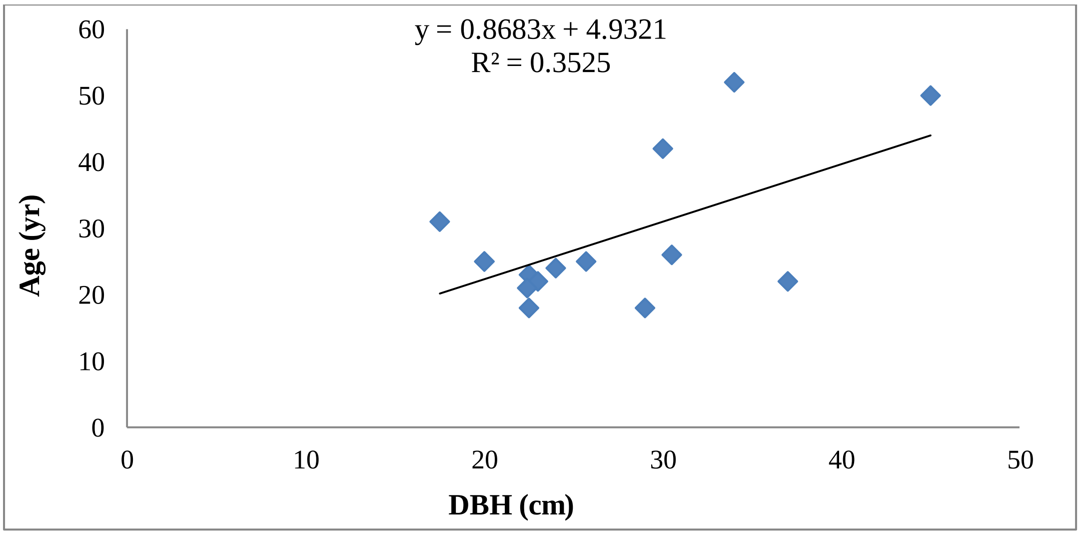


Figure 13: DBH- Age relationship of southern aspect forest

4.5 Local Climatic Data

Climatic data available at the local stations were analyzed and trends in these data were presented in Figures 14 to 20 and Table 8. The data was taken from Department of Hydrology and Metrology (DHM), 2010.

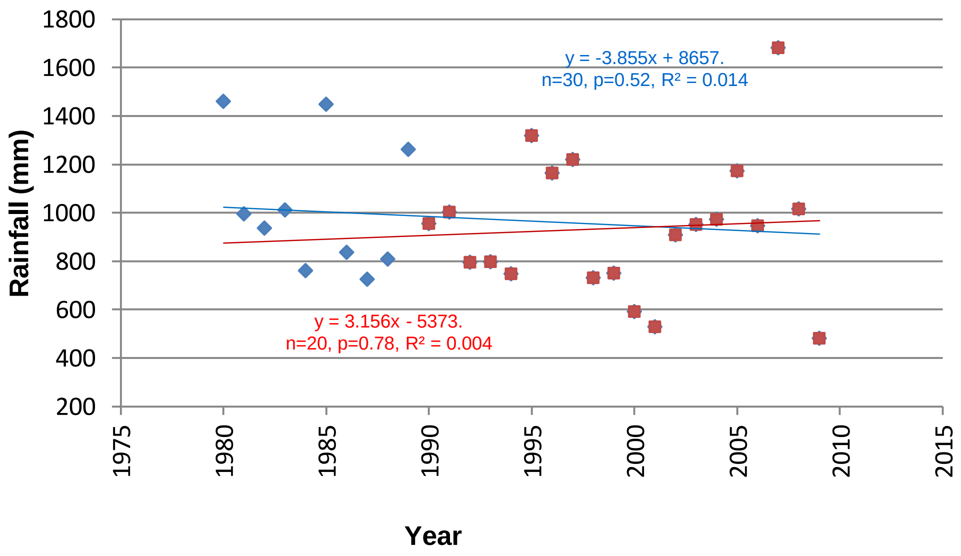


Figure 14 : Variation of annual rainfall with time at Chame, Manang

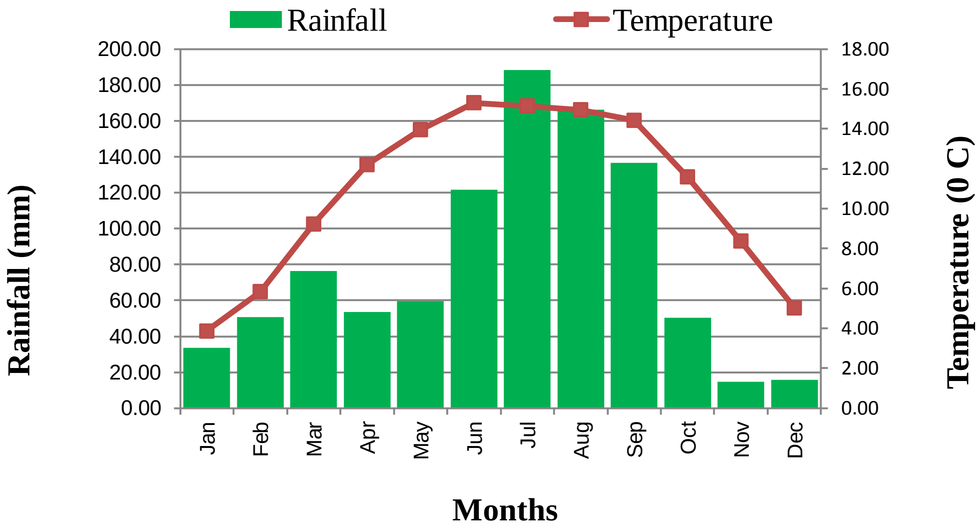


Figure 15: Mean monthlyrainfall and Temperature at Chame, Manang (1980-2009)

Trends of different climatic parameters recorded in the local stations were analyzed and results were presented in Table 8. The mean annual rainfall of Chame, Manang, meteorological station was 966.9 mm (SE = 51.12, SD = 280.01, Max = 1682.6, Min = 482.3). The monthly average temperature was found to be highest for the month of July and lowest was for month of November (Figure 14). Recorded highest maximum temperature was 23.4 ^{0}C at month of June 1998 and observed lowest minimum temperature was -4.5 ^{0}C during January of 1999 and 2000. In this station during past 30 yrs (1980-2009) there was decreasing trend of rainfall by 3.85 mm/yr which is statistically insignificant (n = 30, R^2 = 0.014, p = 0.52). However, there is an increase in annual rainfall by 3.16 mm/yr in between 1990-2009, which is also insignificant statistically (p = 0.78, R^2 = 0.004) (Figure 14). In Chame, there was an increase of mean annual temperature by 0.017 ^{0}C/yr. In recent years particularly after 2000, mean minimum temperature is decreasing while mean maximum temperature is increasing significantly (Figure 14). There is wide variation in monthly temperature trends.

Table 8: Descriptive statistics trends of rainfall in different meteorological stations

Summary Statistics	**Mean Annual Rainfall(mm)**			
	Chame	Larke	Jagat	Gorkha
Mean	966.9	1064.7	1252.4	1659.3
Standard Error of mean	51.1	88.5	97.7	66.1
Standard Deviation	280.0	485.0	535.0	362.1
Range	1200.3	1995.2	1805.9	1662.8

Minimum	482.3	490.4	143.0	728.1
Maximum	1682.6	2485.6	1948.9	2390.9
Count	30.0	30.0	30.0	30.0

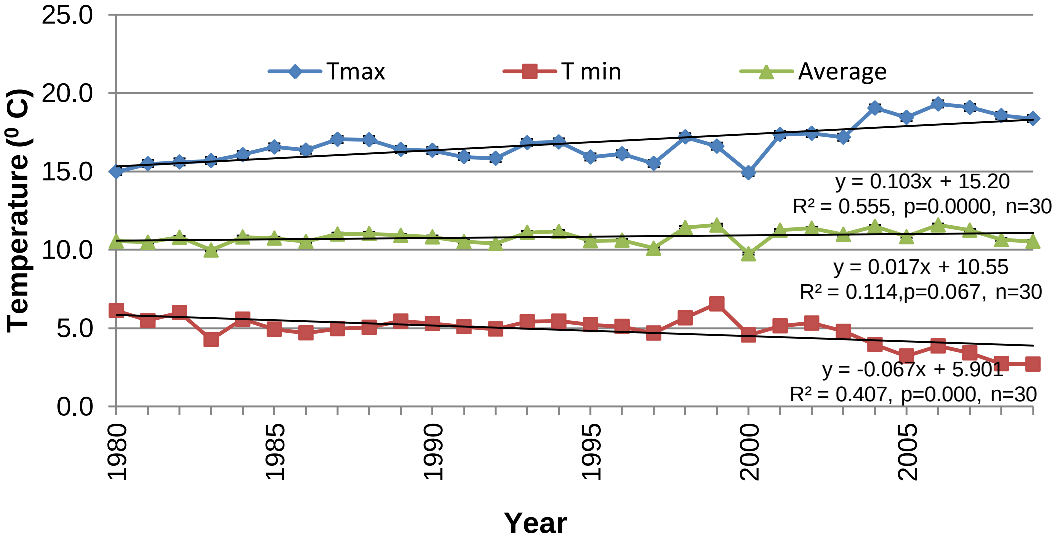
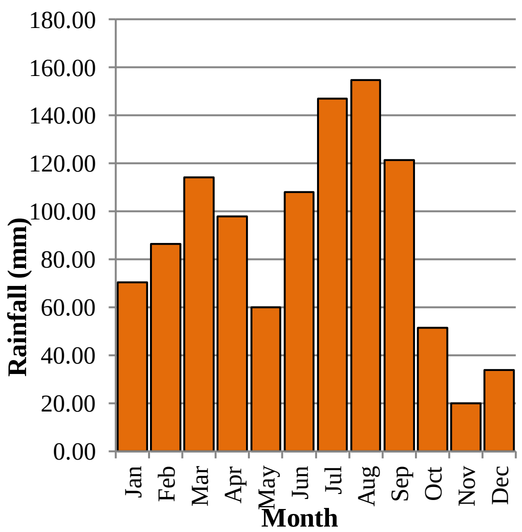


Figure 16: Yearly variation of temperature with time at Chame, Manang

Similarly, mean annual rainfall of different stations of Gorkha, namely Gorkha, Jagat and Larke was found to be 1659.3 mm (SE = 66.1, SD = 362.1, Max = 2390.9, Min =728.1), 1252.4 mm (SE = 97.7, SD = 535.0, Max = 1948.9, Min =143) and 1064.7 mm (SE = 88.5, SD=485.0, Max = 2485.6, Min = 490.4), respectively. In Gorkha district, in general, there was decrease in mean annual rainfall with increase in elevation irrespective of site (Table 8).



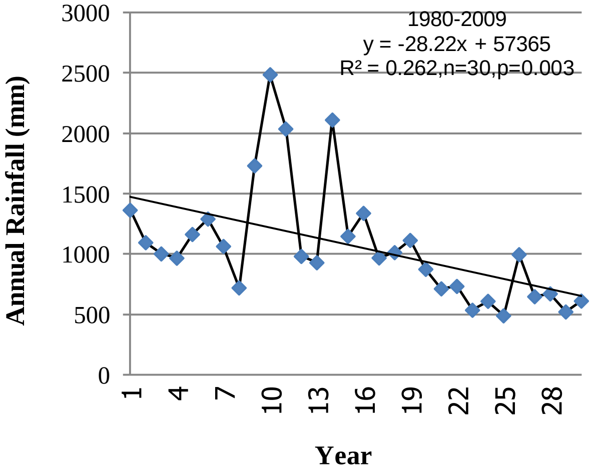


Figure 17: Mean monthly rainfall at Larke, Gorkha (1980-2009)

Figure 18: Yearly variation of rainfall with time at Larke, Gorkha

In Larke station (Figure 17 & 18) during past 30 yrs (1980-2009) there was a decreasing trend of rainfall by 28.22 mm/yr which is statistically significant (n = 30, r^2 =0.26, p = 0.003). This decreasing trend is more pronounce after 1987 with decrease in annual rainfall by 54.99 mm/yr in between 1987-2009, which is also significant statistically (p = 0.0003, r^2 = 0.46, n=23).

However in Jagat station, there was an increasing trend of rainfall by 34.17 mm/yr which is statistically significant (n = 30, r^2 = 0.31, p = 0.001) (Figure 19). This increment was more pronounced after 1990s. In the other hand, mean annual rainfall of Gorkha station was observed to be decreased by 8.89 mm/yr which is statistically insignificant (Figures 19 & 20). Hence, great heterogeneity (temporal and spatial) was observed in the climatic data of the region. The contrasting rainfall patterns in two stations of Jagat and Larke was due to its geographical structure.

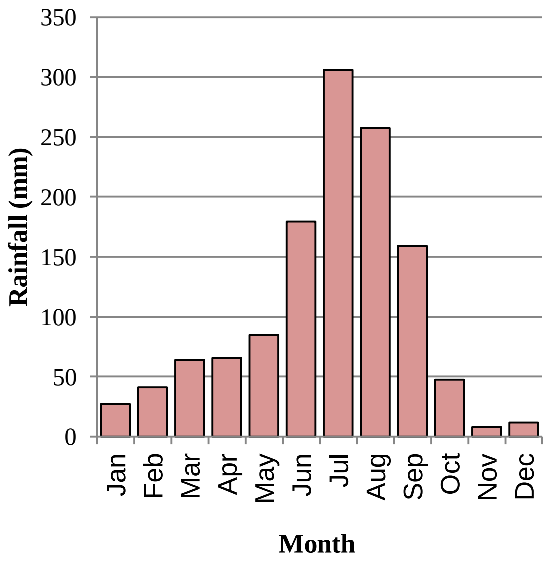


Figure 19: Mean monthly rainfall at Jagat, Gorkha (1980-2009)

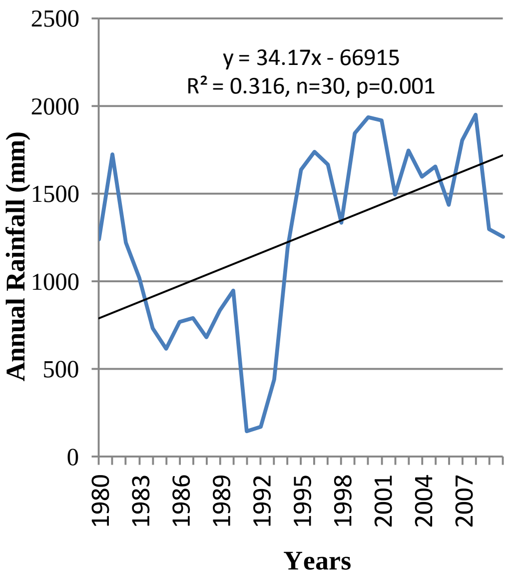


Figure 20: Yearly variation of mean rainfall at Jagat, Gorkha (1980- 2009)

Dating of Tree Ring Samples

Among the total 105 cores tree sampled, 25 cores which were greater than 50 years were successfully cross dated and used for further analysis. The COFECHA output of final series is given in Table 9.

Table 9: COFECHA output summary

Seq	Series	Interval	No. years	No. segments	No. flags	Correlation with master
1	PIWA018B	1960 - 2011	52	2	2	0.22
2	PIWA023B	1921 - 2011	91	4	0	0.39
3	PIWA027A	1936 - 2011	76	3	2	0.37
4	PIWA027B	1924 - 2010	87	4	1	0.50
5	PIWA028A	1923 - 2009	87	4	1	0.42
6	PIWA029A	1929 - 2011	83	3	1	0.27
7	PIWA029B	1930 - 2011	82	3	0	0.60
8	PIWA030A	1943 -2009	67	3	0	0.45
9	PIWA030B	1941 - 2010	70	3	2	0.18
10	PIWA033A	1946 - 2011	66	3	0	0.57
11	PIWA033B	1954 - 2007	54	2	0	0.79
12	PIWA034A	1942 - 2009	68	3	1	0.39
13	PIWA034B	1945 - 2008	64	3	2	0.31
14	PIWA035B	1950 - 2011	62	2	0	0.49
15	PIWA036A	1954 - 2008	55	2	0	0.42
16	PIWA036B	1951 - 2011	61	2	0	0.51
17	PIWA041B	1929 - 2011	83	3	0	0.54
18	PIWA042B	1938 - 2011	74	3	0	0.76
19	PIWA043A	1926 - 2010	85	3	0	0.68
20	PIWA043B	1927 - 2005	79	3	0	0.61
21	PIWA044A	1939 - 2006	68	3	0	0.69
22	PIWA045A	1929 - 2009	81	3	0	0.76
23	PIWA048A	1960 - 2011	52	2	0	0.4
24	PIWA055B	1921 - 2010	90	4	0	0.63
25	PIWA081A	1931 - 2010	80	3	0	0.63
	Total		1817	73	12	0.51

4.7 Tree Growth

For tree growth analysis the total 105 cores were categorized into five class interval from 0-20 to 80-100 yrs. This showed that class interval 80-100 yrs tree had lower mean value (1.46 mm/yr) whereas class interval 0-20 had greater mean value (4.71 mm/yr). The comparative analysis of different variables of the *Pinus wallichiana* growth in different years was calculated and presented in Table 10.

Table 10: Table showing tree growth (mm/yr) in different time period

Variables		**year class interval**			
	0-20	**20-40**	**40-60**	**60-80**	**80-100**
Mean	4.71	0.41	2.55	1.54	1.46
Standard Error	0.21	0.02	0.32	0.12	0.19
Median	4.82	4.03	2.43	1.43	1.14
Standard Deviation	1.11	1.60	1.20	0.54	0.78
Kurtosis	1.23	2.12	0.30	0.77	0.14
Skewness	0.40	0.84	0.71	0.81	1.13
Minimum	0.26	0.93	0.91	0.58	0.60
Maximum	7.81	9.31	5.21	2.77	3.18

Similarly, tree growth analysis of tree was also categorized into northern and southern aspect of the forest. This showed that the mean growth at northern aspect of the forest (1.28 mm/yr) was higher than that of southern aspect of the forest (0.90 mm/yr). Table 11 shows the list of different variables with their values in both aspect of the forest. The t- test statistis shows that the growth in northern and southern aspect was statistically insignificant (t- statistic = 0.19, p= 0.05).

Table 11 : Table showing tree growth (mm/yr) at different aspect with different variables

Variables	Northern Aspect	Southern Aspect
Mean	1.28	0.90
Standard Error	0.04	0.08
Median	1.33	0.83
Standard Deviation	0.37	0.46
Skewness	-0.36	2.00
Minimum	0.32	0.38
Maximum	5.37	9.31

4.8 Tree Growth- Climate Relationship

Annual radial growth of *Pinus wallichiana* was shown in Figure 21 along with the standard, residual and arstan chronologies. The graph shows the fluctuating trend in different year. The maximum growth was calculated in the year 1909 and in the year 1925 it reach to minimum value.

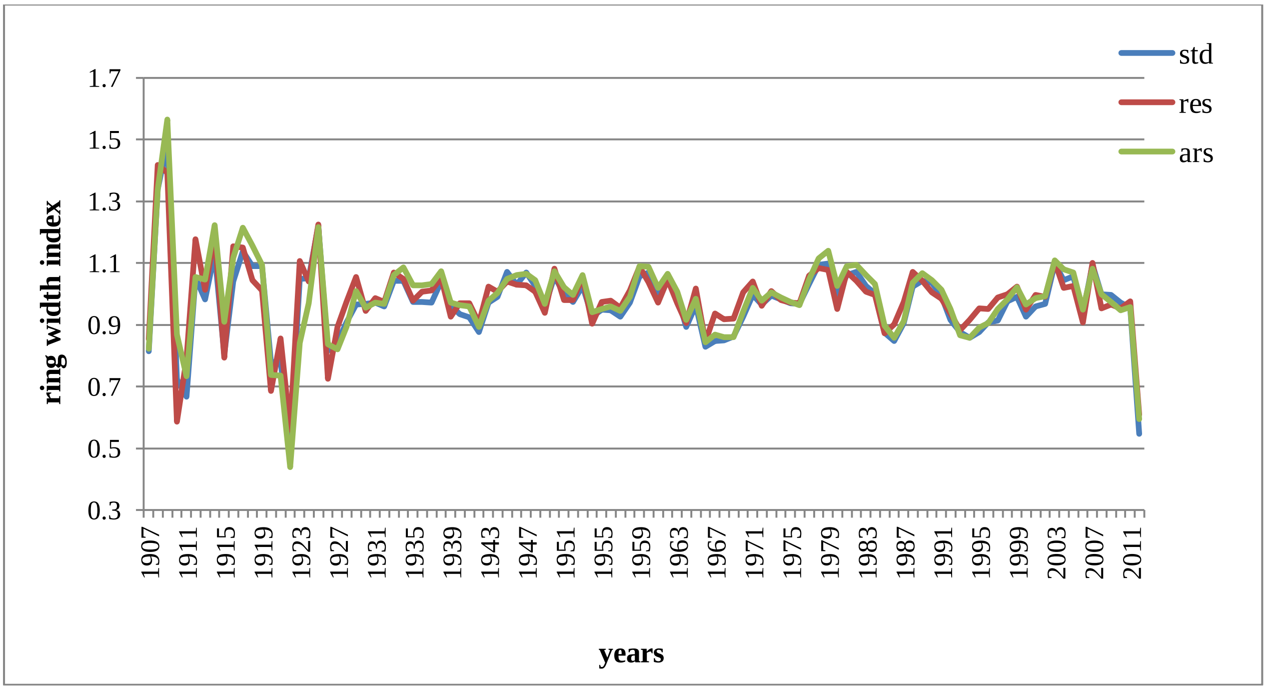


Figure 21: Annual radial growth of *Pinus wallichiana*

Figure 22 depicts correlation of standard chronology with mean monthly precipitation and temperature of the meteorological station. The correlation analysis was calculated between the standard chronology and with the monthly temperature and precipitation. Radial growth was positively correlated with mean temperatures of January (r= 0.11), February (r= 0.25), March (0.18), April (r=0.08), May (0.25), June (0.06), November (0.22), December (0.14) and temperature of previous November (0.02) but not significant statistically. While, the ring width was correlated negatively with the July, August, September, October of the current year and the temperature of previous September, October and December. Similarly, precipitation appeared to be another important growth-limiting factor in the mountains. Rainfall in October (r =- 0.38,) correlated negatively with the radial growth although it is statistically insignificant (*r* = 0.04). The tree growth was correlated positively with precipitation of March, April, May, June, July and August. Similarly, the radial growth showed negative correlation with the precipitation of the January, February, September, October, November of the current year and September and October of the previous year.

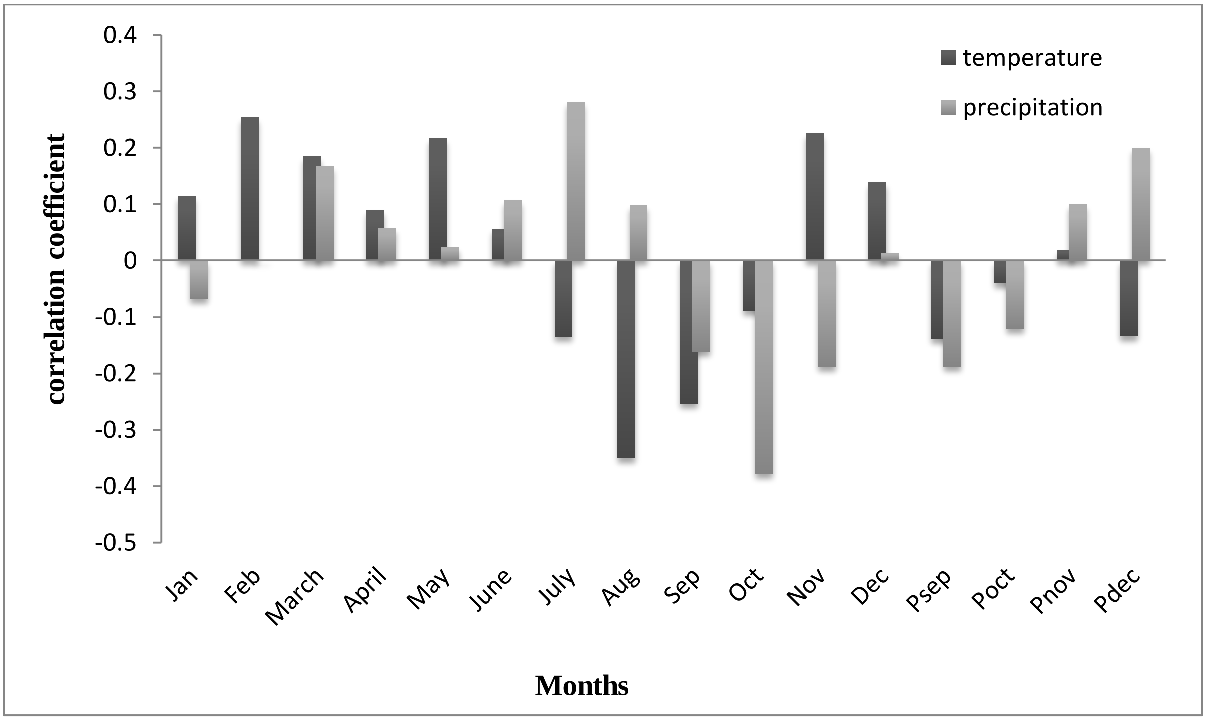


Figure 22: Tree growth- climate relationship

Chapter V: Discussion

5.1 Floristic Composition

The distribution of tree populations at the altitudinal range is the result of the interactions of various biological and physical factors in time. Watkinson (1997) cited in Chhetri (2004) reported that the natural population of trees increased exponentially in suitable conditions and when resources were freely available. The study showed that the both study area, Thangming (northern) and Chhak (southern) of the forest were dominated by *Pinus wallichiana*. Six different species were recorded in Thangming (northern aspect) forest with the dominance of *P. wallichiana* followed by *Cedrus deodara, Rhodonderon arboreum, Castanopsis indica* etc. whereas only *P. wallichiana* was recorded in Chhak (southern aspect) forest. Similar species variation was found in the research done in Manang valley of Nepal by Panthi *et al* (2007). They reported 58 species from northern aspect and 46 species from southern aspect. This showed that the southern aspect was dry and northern aspect was moist and favorable for the growth of different species and thus supported the higher species richness. The higher value of average diversity index at northern aspect (0.32) than southern (0.24) shows higher diversity at northern aspect of the forest. Similarity index shows that both the forests were 28 % similar.

Tree density of *P. wallichiana* increased from 875 no./ha to 925 no./ha from 2100 m to 2300 m and it decreased to 850 no./ha at 2500 m and finally increased to 2700 no./ha at 2700 m in northern aspect of the forest. This fluctuation may be due to the anthropogenic disturbance in the easily accessible area while the light cover, soil condition also have significant role in determining the density. While comparing, northern aspect forest was denser than the southern aspect forest. Southern aspect of the forest showed the decreasing density of *P. wallichiana* tree from 2100 m to 2700 m. Here, Blue pine did not show a wide range of altitudinal variation. Similar conclusion was drawn by Chhetri (2004). He calculated its density below 50 no./ha and found its occurrence sporadically in the lower altitudinal range of the study area. The study done by Panthi *et al* (2007) in Manag valley of Nepal showed a little change in species richness between 3000 and 4000 m asl. The small variation in species number may be due to seasonal movement of animals. This is consistent with patterns for overall interpolated species richness in the Nepal Himalaya found by Grytnes and Vetaas (2002). The maximum density at an elevation 2100 m at southern aspect was due to the regeneration of the *P. wallichiana* from the cut stump. This showed the rate of disturbance was high in the forest. During the field survey, high grazing rate of domestic animals like cow, goat was observed. Similarly, trampling, deforestation, extraction of resin was also recorded. The anthropogenic pressure at lower altitudes results in low plant diversity towards the bottom of the valley with most of the species being exotic in nature. Though the plant diversity was less at higher altitudinal ranges, the uniqueness is relatively high with high species replacement rates (Chawla *et al* 2008). The study done by Gairola *et al* (2008) revealed that from low to high altitude strata, size and density of trees decline sharply. The density of sapling and seedling do not follow the trend of trees and exhibit site/location specific trends. In the present study sapling and seedling did not exhibit uniform patterns across altitudinal range of the sites.

The average basal area of *P. wallichiana* was calculated as 13.97 m^2/ ha and 9.09s m^2/ ha at northern and southern aspect of the forest respectively. Similar conclusion was drawn by Ghimire *et al* (2010) in Manang valley where basal area of *P. wallichiana* at northern aspect (18.6 m^2/ha) was higher than southern aspect (11.8 m^2/ha) of the forest. The study conducted by Vijayaprakash and Ansari (2009) estimated the basal area of *Abies spectabilis* in decreasing trend along the elevation gradient in both northern and southern aspect of the forest. Similar trend was not reported in the study. Basal area value was inconsistent along different elevation gradient in both aspect of the forest. This may be due to various geological and environmental factors.

Bale and Charley (1998) concluded that northern aspect was moister with more canopy cover than southern aspect of the forest. Likewise, this finding was also supported by a study done in trans- Himalayan inner valley of Manag district, central Nepal by Panthi *et al* (2007). They found that species richness was significantly higher on the north facing slope than on the south facing slope. They also concluded that moisture and factors influencing evaporation (i.e. canopy and aspect), were the main environmental factors influencing species composition and richness in the dry inner valley of the trans- Himalaya. Studies done by Khan *et al* (2012) suggested that species diversity decreases along the measured ecological gradient under the influence of deforestation coupled with global climatic change. This also reported that the soil of northern aspect of the forest had high moisture which supports high biodiversity in return. Chhetri (2004) found the light level at the forest floor very low which might be because of presence of undergrowth such as *Dryophila* spp, *Rhododendron* spp, bamboo etc. causing in turn poor regeneration. Similar condition was observed in northern aspect of the present study at an elevation of 2100 m and 2700 m.

5.2 Regeneration

Regeneration of tree stands depends on a combination of factors controlling seed availability, germination, seedling growth and establishment. Regeneration of the tree species can be assessed by observing their size class distribution. The DBH class distribution of *Pinus wallichiana* didn't show the reverse J- shaped structure. The reverse J-shaped class distribution of trees in a community indicates the sustainable regeneration (Vetas 2000). Hence, the *P. wallichiana* in both northern and southern aspect of the forest indicate unsustainable regeneration. Umans (1993) also found an unsustainable regeneration of Himalayan silver fir (*Abies spectabilis*) in lower subalpine zone of Nepalese Himalaya. In case of unsustainably regenerating forest, Schmidt-Vogt (1990) concluded that the diameter distribution diagram showed a bell-shaped structure in the Himalaya. This indicated the lack of young trees as well as old large tree. However, studies done by Ghimire *et al* (2010) on regeneration of *P. wallichiana* in trans- Himalayan valley of north- central Nepal showed the reverse J-shaped distribution. Similar observations were made for *A. spectabilis* of Langtang National Park studied by Gaire (2008). There was similarity between the shape of DBH distribution and age distribution. Similar sustainable regeneration was observed in the study done by Khadka (2013) in *Rhododendron arboreum* along an altitudinal gradient of MCA.

Height class distribution of *P. wallichiana* also showed the fluctuating trend, it didn't show the reverse J-shaped class distribution pattern. Wang *et al* (2006) concluded that DBH–height relationship was significantly modulated by climate. With increasing winter coldness stress, a higher proportion of biomass was allocated for diameter growth than height growth. The canopy cover graph showed that the regeneration increases with decrease in canopy cover and vice versa. The highest concentration of seedling and sapling was observed at the middle altitude (2300 m-2500 m) in both northern and southern aspect of the forest. Similar observation was observed for *Rhododendron arboreum* at the middle altitude (2380 m-2580 m) of Thanging forest of MCA by Khadka (2013). Majila and Kala (2010) also observed similar trend in *Quercus leucotrichophora* of Binsar Wildlife Sanctuary. Generally, the density of seedling and sapling was found high in the area with high canopy gap. Similar trend was observed in the present study.

5.3 Dendrochronology

It is implied that different limiting factors played an important roles in shaping the age structure and regeneration of forest at different altitudes. In the mid altitudinal transect, density dependent competition between trees is probably the most important influencing factor (Wang *et al* 2004). Limiting environmental factors, e.g. temperature and precipitation, could play an important roles in determining the age structure of *Pinus* population in the high or low limit transacts. From the present study 91 and 52 years old *Pinus wallichiana* was found as the oldest tree in northern and southern aspect of the forest respectively. The age of the *P. wallichiana* showed that both the forest were in the stage of development.

From the tree ring analysis of *P. wallichiana,* 91 years long chronology dated back 1921 to 2011AD was developed with mean sensitivity of 0.26. Due to the false ring, double ring and resin of *Pinus wallichiana* difficulty was encounter in dating. Bhattacharyya *et al* (1992) also encounter problem during cross dating primarily due to strong serial persistence in the tree-ring series. Shrestha (2012) also developed tree ring chronology of *P. wallichiana* of Mustang, Nepal back to 1913 AD (99 years) with a mean sensitivity 0.145. Yadav *et al* (1997) developed 146 year chronology ranging from 1843 to 1988 AD of the same species with the mean sensitivity of 0.19 for Gangotri of the western Himalaya, India. Tree ring studies done by Brauning *et al* (2004) in the Dolpo- Himalaya (western Nepal) in *P. wallichiana* indicated the possibility to analyze summer rainfall at the western border region of the Indian summer monsoon. The pine chronologies were developed from 1675 to 1998 from 12 different trees.

Schmidt *et al* (1999) developed the first master chronology for Nepal covering the time- span between 1324 to 1997 AD. They developed a chronology from different area of Mustang, Manang and Khumbu using cores of different conifer species including *P. wallichiana*. A chronology from 1697 to 1996 AD was developed as largest chronology for *P. wallichiana*. Cook *et al* (2003) also developed *P. wallichiana* tree ring chronology from different locations of Nepal. Longest of them was from Archeological wood from Bhratang which was the longest recorded tree ring chronology of *P. wallichiana* so far from Nepal.

Tree Growth- Climate Relationship

Individual tree-ring series may show changed growth trends and divergent climate–growth associations even within a site. Radial growth of *P. wallichiana* in the study was positively correlated with mean minimum temperatures for January (r= 0.11), February (r= 0.25), March (0.18), April (r=0.09), May (0.22), June (0.06), November (0.22), December (0.14) and temperature of previous November (0.02) but not significant statistically. Similarly, radial growth correlated negatively with the rainfall in current October (r =- 0.38) although it was statistically significant (r = 0.04). Dang *et al* (2007) observed similar positive correlation with November temperature in Qinling Mountain, China from *Abies fargessi.* The correlation analysis carried out by Gaire (2008) showed that radial growth was significantly and positively correlated with mean minimum temperatures for July (r = 0.42,) and November (r = 0.21) of previous year although not significant statistically. Rainfall in November (r = 0.22) of the previous year and January (r = 0.38) March, April and May of the current year correlated positively with the radial growth although not significantly. The rainfall correlation was similar to this research.

Harley *et al* (2011) carried out correlation analysis between monthly mean rainfall and radial growth of *Pinus eliottii* revealed a significant negative correlation with current May precipitation and a significant positive correlation with current September precipitation. Shrestha (2012) concluded that March (r = 0.23), October (r = 0.45) and December (r= 0.42) temperature had negative relationship for the tree growth. Whereas, current September (r = 0.4) temperature had positive relationship for the tree growth. Genries *et al* (2012) found clear difference in climatic response between the southern and northern sub-regions: southern sites were more responsive to temperature dynamics while on northern sites Jack pine growth appeared negatively influenced by an excess of precipitation.

The chronologies developed by Borgaonkar *et al* ((2011) found the strong positive relationship to the mean annual and winter (December–February) temperatures of the concurrent year. Similar conclusion was drawn from the present study. Pumijumnong and Wanyaphet (2006) showed strong correlation with rainfall during September in case of *Pinus kesiya*. The observed spatio-temporal variability carried out by Shah and Bhattacharyya (2012) revealed inter-species tree growth variations were not uniform and suggests that no common factor influenced the radial tree growth in this region, which may be related to anthropogenic impact or nonclimatic factors.

Chapter VI: Conclusions and Recommendations

6.1 Conclusions

The ecological analysis on the study site showed that the northern aspect forest was denser than the southern aspect forestwith greater basal area and higher density of all size classes (seedling, sapling and mature) plants. Hence, northern aspect of the forest had higher species richness than the southern aspect with the higher dominance of *Pinus wallichiana.* The ecological significance of aspect is important because it influences diameter growth of tree, forest productivity, and species distribution. The density-diameter curve of *P. wallichiana* populations did not resembled a reverse J-shape which indicates the unsustainable regeneration pattern in the forest. The reverse J- shape structure of the height class indicates that both the forest was in the juvenile stage and was in the process of development. The topographic features of the mountain and other environmental and anthropogenic disturbance might have hindrance the advancement of the species in the present site.

The tree ring analysis found the 91 years *P. wallichiana* from northern aspect as the oldest among the 105 cores with the mean sensitivity of 0.26. Tree ring analysis also recorded 52 years old tree as oldest tree in southern aspect forest. Annual radial growth showed temporal fluctuation in ring pattern leading to weak climate growth relationship. The growth of *P. wallichiana* was favored by pre-monsoon temperature and monsoon rainfall. This shows that fluctuation in any climatic condition in these months will change the growth pattern of the *P. wallichiana.* Mostly the trees were juvenile and their chronology was short. So, further climatic reconstruction was limited. Single climatic factor like temperature is not responsible for the dynamics of growth in an altitudinal gradients for which careful and long term study of different climatic, ecological and dendrochronological and anthropogenic aspect is necessary. More detailed studies on the relationships between climatic change and forest regeneration rates are needed, which are especially important for understanding and predicting the ecological consequences of global warming on the dynamics of forest structure of high mountains.

6.2 Recommendations

This is the pioneer study on the forests of MCA focusing on the dendro-ecology of *P. wallichiana* along with elevation in two aspects of the forest.

Following recommendation has been highlighted from the research:

- Further dendroecological research of *P. wallichiana* is recommended. This will shed more light in understanding its dynamics.
- Long term monitoring of both population parameter and climatic variables is necessary.
- Collecting more tree cores from matures and undisturbed trees will be helpful in climate reconstruction.
- MCA should take immediate step in lessening disturbances and for the conservation of the forest.

References

Adrin., SJ., 1990. Trees and Shrubs of Nepal and Himalayas, Pilgrims Book House, Thamel, Kathmandu,Nepal., revised edition, pp. 212-215.

Ahmed, M.,Wahab, M., Khan, N., Palmer,J., Nazim,M., Khan,U.,Siddiqui, MF., 2010. Some Preliminary Results of Climatic Studies Based On Two Pine Tree Species of Himalayan Area of Pakistan, *Pakistan Journal of Botany*. 42: 731-738.

Bale, CL., JB, Williams., and JL, Charley., 1998. The Impact of Aspect on Forest Structure and Floristic in Some Eastern Australian Sites, *Forest Ecology and Management.*110: 363–377.

Beniston, M., 2003. Climatic Change in Mountain Regions: A review of Possible Impacts, *Climate Change*. 59: 5-21.

Beniston, M., Douglas, G., Adkikary,S., Andressen, R., Guisan,A., Holten, JI., Innes, J., Maitima, J., Prince, MF., Tessier, L., 1996. Impacts of Climate Change on Mountain Regions, Cambridge University Press, Cambridge, USA., pp 191-213. available at http://www.ipcc-wg2.gov/publications/SAR/SAR_Chapter%205.pdf (retrieved on 8/1 2013)

Bhattacharyya, A., Lamarche, VC., JR., and Hughes, MK., 1992. Tree- Ring Chronologies from Nepal, *Tree- Ring Bulletin*. 52: 59-66.

Bhattacharyya, A., and Yadav, RR., 1996. Dendrochronological Reconnaissance of *Pinus wallichiana* to Study Glacial Behaviour in the Western Himalaya, *Current Science*. 70: 739.

Bhuju, DR., Carrer, M., Gaire NP., Soraruf, L., Riondato, R., Salerno, F., and Maharjan, SR., 2010. Dendroecological Study of High Altitude Forest at Sagarmatha National Park, Nepal, *Contemprorary research in Sagarmatha (Mt. Everest) region, Nepal* (eds Jha, PK., & Khanal, IP). Nepal Academy of Science and Technology, pp.119-121.

Bhuju, DR., and Gaire, N., 2012. Plantation History and Growth of Old Pine Stands in Kathmandu Valley: A Dendrochronological Approach, *FUUAST J .Biol*. 2: 13-17.

Borgaonkar, AB., Sikder, AB., and Ram, S., 2011. High Altitude Forest Sensitivity to the Recent Warming: A Tree- Ring Analysis of Conifers from Western Himalaya, India, *Quaternary International*. 236: 158- 166.

Bräuning, A., Jansma, E., Gärtner, H., Schleser, G., 2004. TRACE - Tree Rings in Archaeology, Climatology and Ecology, *Proceedings of the DENDROSYMPOSIUM 2003*. 44: 8 - 12.

Chawla, A., Rajkumar, S., Singh, KN., Lal,B., and Singh, RD., 2008. Plant Species Diversity along an Altitudinal Gradient of Bhabha Valley in Western Himilaya, *J.Mt.Sci*. 5: 21-25.

Chhetri, PB., 2004. *Structure and Composition of Mixed Conifer Forests in Western Bhutan*, M.Sc Thesis. University of Natural Resources and Applied Life Sciences, Vienna.

Chhetri, PK., and Thapa, S., 2010. Tree Ring and Climate Change in Langtang National Park, Central Nepal, *Our Nature*. 8: 139- 143.

Cook, ER., 1985. *A Time Series Analysis Approach to Tree Ring Standardization*, PhD Dissertation. University of Arizona, Tucson, USA.

Cook, ER., and Kairiukstis, LA., 1990. Methods of Dendrochronology, Applications in the Environmental Sciences. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Cook, ER., Krusic, PJ., Jones, PD., 2003. Dendroclimatic Signals in Long Tree-Ring Chronologies from the Himalayas of Nepal, *International Journal of Climatology*. 23: 26-29.

Dale, VH., Joyce, LA., Mcnulty,S., Neilson, RP., Ayres, MP., Flannigan, MD., Hanson, PJ., Irland, LC., Lugo, AE., Peterson, CJ., Simberloff, D., Swanson, FJ., Stocks, BJ., and Wotton , BM., 2001. Climate Change and Forest Disturbances, *BioScience*. 51: 723-734. Available at http://www.bioone.org/doi/abs/10.1641/00063568%282001%29051%5B0723%3ACCAFD%5D2.0.CO%3B2

Dang, H., Jiang, M., Zhang, Q., Zhang, Y., 2007. Growth Responses of Subalpine Fir (*Abies fargessi*) to Climate Variability in the Qinling Mountain, China, *Forest Ecology and Management*. 24: 143-150.

Dawadi, B., Liang, E., Tian, L., Devkoa, LP., and Yao, T., 2012. Pre- Monsoon Precipitation Signal in Tree Rings of Timberline *Betula utilis* in the Central Himalayas, *Quaternary International*. 1- 6.

Earle CJ. 2009. Gymnosperm database: *Pinus wallichiana* AB Jacks. Available at: http://www.conifers.org/pi/Pinus_wallichiana.php

Fritts, HC., 1976. Tree rings and climate, Academic press London.

Fritts, HC., and Swetnam TW., 1989. Dendroecology: A Tool for Evaluating Variations in Past and Present Forest Environments, Academic Press Limited. 19: pp 111-175

Gaire, NP., 2008. *Ecology and dendroclimatology of treeline forest of Lantang National Park, Nepal Himalaya*, M.Sc Thesis. Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Gaire, NP., Dhakal, YR., Lekhak, HC., Bhuju, DR., and Shah, SK., 2011. Dynamics of *Abies spectabilis* in Relation to Climate Change at the Treeline Ecotone in Langtang National Park, *Nepal Journal of Science and Technology*. 12: 220-229.

Gairola, S., Rawal, RS., and Todaria, NP., 2008. Forest Vegetation Patterns along an Altitudinal Gradient in Sub- Alpine Zone of West Himalaya, India, *African Journal of Plant Science*. 2: 42-48.

Genries, A., Drobyshev, I., Bergeron, Y., 2012. Growth- Climate Response of Jack Pine on Clay Soils in Northeastern Canada, *Dendrochronologia*. 30: 127- 136.

Ghimire, B., Mainali, KP., Lekhak, HD., Chaudhary, RP., and Ghimeray, AK., 2010. Regeneration of *Pinus wallichiana* AB Jackson in a trans- Himalayan dry valley of north- central Nepal, *Himalayan Journal of Sciences*.6: 19-26.

Grace,J., Berninger, F., and Nagy, L., 2002. Impacts of Climate Change on the Tree Line, *Annals of Botany*. 90: 537-544.

Grytnes, JA., and Vetaas, OR., 2002. Species Richness and Altitude: A Comparison between Null Models and Interpolated Plant Species Richness along the Himalayan Altitudinal Gradient, Nepal, *The American Naturalist* .159: 294-304.

Harley,GL., Grissino-Mayer, HD., and Horn, SP., 2011. The Dendrochronology of *Pinus eliottii* in the Lower Florida Keys: Chronology Development and Climate Response, *Tree-Ring Research.* 67:39-50.

Holtmeier, FK., 2009. Mountain Timberlines: Ecology, Patchiness and Dynamics, Springer Science+ Business Media. 2: Pp 1-3 available at http://books.google.com.np/books?id=C8y6Vb0JO8C&pg=PR3&source=gbs_selected_pages&cad=3#v=onepage&q&f=false

Holmes, RL., 1983. A computer-based quality control program. *Tree Ring Bulletin*. 43: 69–78.

Holmes, RL., 1992. Dendrochronology Program Library, Instruction and Program Manual, Laboratory of Tree-Ring Research, University of Arizona, Tucson, USA.

Hughes, NM., Johnson, DM., Akhalkatsi., and Abdaladze, O., 2009. Characterizing *Betula litwinowii* Seedling Microsites at the Alpine-Treeline Ecotone, Central Greater Caucasus Mountains, Georgia, Arctic, *Antarctic, and Alpine Research*. 41: 112-118.

IPCC., 2007. Climate Change. The Physical Sciences Basis. In Summary for Policy Makers, Geneva. 21.

IPCC., 2007. Climate Change 2007, Synthesis Report, Cambridge University Press, Cambridge.

Johnston, M., Campagna, C., Gray, P., Kope, H., Loo, J., Ogden, A., Neill, AN., Price, D., and Williamson, T., 2009. Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation: An Overview for Policy Makers and Practitioners. http://www.ccfm.org/pdf/TreeSpecies_web_e.pdf

Kent, M., and Coker, P., 1992. Vegetation Description and Analysis: A Practical Approach,CRC press, London

Khadka, L., 2013. *Age Structure and Regeneration of Rhododendron arboreum Sm. Along an Altitudinal Gradient of Manaslu Conservation Area, Nepal Himalaya*, M.Sc Thesis. Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Khanal, N., Rijal, SP., Yamano, M., Nagao, T., and Sweda, T., 2002. Tree-Ring Chronology from Ganesh Himal, Area, Central Nepal. In: *Proceedings of Geothermal/ Dendrochronological Paleoclimate Reconstruction across Eastern Margin of Eurasia, 2002*, International Matsuyama Workshop, Matsuyama, Japan. 12-19.

Khan, SM., Page, S., Ahmad, H., Shaheen, H., and Harper, D., 2012. Vegetation Dynamics in the Western Himalayas, Diversity Indices and Climate Change, *Sci, Tech. and Dev*. 31: 232-243.

Kirdyanov,AV., Hagedorn,F., Knorre,AA., Fedotova, EV., Vaganov,EA., Naurzbaev,MM., Moiseev, PA., and Rigling,A., 2012. 20th Century Tree-Line Advance and Vegetation Changes Along an Altitudinal Transect in the Putorana Mountains, Northern Siberia, *Boreas*. 41: 56–67.

Kirschbaum, M., and Fischlin, MUF., 1996. A Climate Change Impacts on Forests, Cambridge University Press, New York, USA. pp. 95- 129.

Kobayashi, O., Sano, M., Sweda, T., 2002. Climate Response of Tsuga dumosa Densitometric Variables from Myagdi Khola, Nepal, *International Matsuyarna Workshop*, Matsuyarna, Japan.

Korner, C., 1998. A Re-assessment of High Elevation Treeline Positions and their Explanation, *Ecologia*. 115: 445- 459.

Korner,C., and Paulsen, J., 2004. A World- Wide Study of High Altitude Treeline Temperatures, *Journal of Biogeography*. 31: 713-732.

Kullman, L., and Oberg, L., 2009. Post- Little Ice Age Tree Line Rise and Climate Warming in the Swedish Scandes: A Landscape Ecological Perspective, *Journal of Ecology*. 97: 415-429.

Lamarche, VC.,1974. Paleoclimatic inferences from long tree-ring research. *Science*. 183: 143-149.

Leonelli,G., Pelflni, M., Cella, UM., and Garavaglia, V., 2011. Climate Warming and the Recent Treeline Shift in the European Alps: The Role of Geomorphological Factors in High-Altitude Sites, *A Journal of the Human Environment*. 40: 264- 273.

Majila, BS., and CP, Kala,. 2010. Forest Structure and Regeneration along the Altitudinal Gradient in the Binsar Wildlife Sanctuary, Uttarakhand Himalaya, India, *Russian Journal of Ecology*. 41: 75–83.

Manandhar, P., Rasul, G., 2009. The Role of Hindu Kush- Himalayan (HKH) Mountain System in the context of a changing climate: A panel discussion, *Mountain Research and Development*. 29: 184-187.

MoE., 2010. National Adaptation Programme of Action to Climate Change, Kathmandu, Nepal. Ministry of Environment, Singhadurbar, Kathmandu, Nepal.

NTNC., 2010. Annual Report, National Trust for Nature Conservation, Satdobato, Lalitpur, Nepal.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., Simons, A., 2009. Agroforestee Database: A Tree Reference and Selection Guide .4: 1-5.

Ohsawa, M., 2006.Climate Change Impacts on Vegetation in Humid Asian Mountains, *Global Environmental Research* .10: *13*-20.

Panthi, MP., Chaudhary, RP., and Vetaas , OR., 2007. Plant Species Richness and Composition in a Trans- Himalayan Inner Valley of Manang District, Central Nepal, *Himalaya Journal of Sciences*. 4: 57-64.

Pensa, M., Salminen, H., and Jalkanen, R., 2005. A 250-year-long Height-Increment Chronology for *Pinus sylvestris* at the Northern Coniferous Timberline: A Novel Tool for Reconstructing Past Summer Temperatures, *Dendrochronologia* . 22: 75- 82.

Phipps, RL., 1985. Collecting, Preparing, Cross Dating and Measuring Tree Increment Cores, U.S. Geological Survey, Water Resources Conservations Report. pp. 85.

Pumijumnong, N., 2012. Dendrochronology in Southeast Asia, *Forest Ecology and Management*. 16: 123-156.

Pumijumnong, N., Wanyaphet, T., 2006. Seasonal Cambial Activity and Tree-Ring Formation of *Pinus merkusii* and *Pinus kesiya* in Northern Thailand in Dependence on Climate, *Forest Ecology and Management*. 226: 279–289.

Sano,M., Furuta, F., Kobayashi, O., Sweda, T., 2005. Temperature variations since the mid 18th Century for western Nepal, as Reconstructed from Tree Ring Width and Density of *Abies Spectabilis*, *Dendrochronologia*. 23: 83-92.

Schmidt, B., Wazny,T., Malla, K., Hofs, E.,Khalessi,M., 1999. Chronologies for Historical Dating in High Asia/Nepal, Tree Ring Analysis: Biological, Methodological and Environmental Aspects. Pp 205-211.

Schmidt-Vogt, D., 1990. High Altitude Forest in Jugal Himal (Eastern Central Nepal): Forest Type and Human Impact, *Geoecological Research*. 6: 23-27.

Shah, SK., and Bhattacharyya, A., 2012. Spatio- Temporal Growth Variability of Three *Pinus* Species of Northeast Himalaya with Relation to Climate, *Dendrochronologia*. 1- 13.

Shannon, C., and Weaner, W., 1949. The Mathematical Theory of Communication. University of Illinois Press, Urbana.117pp. (Taken from: Odum, EP., and Barrett, GW., 2007. Fundamentals *of* Ecology, Fifth edition. Akash Press, New Delhi pp 38- 41).

Sharma, E., Chettri, N., and Oli, KP., 2010. Mountain biodiversity conservation and management: a paradigm shift in policies and practices in the Hindu Kush- Himalayas, *Ecological Society of Japan*. 25: 909-934.

Sharma.E., Khadka, I., Rana, G., 2008.Mountain Biodiversity and Climate Change, *ICIMOD: International Mountain Biodiversity Conference*. 56

Shrestha, N., 2012 . *Response of Pinus wallichiana Tree Ring to Climate Variability in Mustang, Nepal*, M.Sc Thesis. Institute of Forestry, Tribhuvan University, Pokhara, Nepal.

Simpson, E.H. 1949. Measurement of Diversity. Nature, 163:688 (Taken from: Odum, EP., and Barrett, GW., 2007. Fundamentals *of* Ecology, Fifth edition. Akash Press, New Delhi, pp 38- 41.

Speer, JH., 2010. Fundamentals of Tree Ring Research. University of Arizona Press.

Spehn, E., 2011. Mountain Biodiversity Effects of Climate Change and How to Manage them, *Sustainable Mountain Development, ICIMOD*. 43-47.

Suwal, M. , 2010. *Tree species Line Advance of Abies spectabilis in Manaslu Conservation Area, Nepal Himalaya*, M.Sc Thesis. Central Department of Botany, Tribhuvan Universit, Kirtipur, Kathmandu, Nepal.

Suzuki, E., 1990. Dendrochronology in Coniferous Forests around Lake Rara, West Nepal, The *Botanical Magazine, Tokyo*. 103: 297-312.

Udas, E., 2009. *The Influence of Climate Variability on Growth Performance of Abies spectabilis at Tree line of West-Central Nepal*, M.Sc Thesis. International Master Program, Landscape Ecology & Nature Conservation, Ernst Moritz Arndt University of Greifswald, Germany.

Umans, L.,1993. The Unsustainable Flow of Himalayan Fir Timber, *Mountain Research and Development*. 13: 73-88. Available at: http://www.jstor.org/pss/3673645

Vetas, OR., 2000. The effect of environmental factors in the regeneration of *Quercus semicarpifolia* forest in Central Himalaya Nepal. *Plant ecology*. 146: 137-144.

Vijayaprakash, V., and Ansari, A., 2009 . *Climate Change and Vegetation Shift of Abies spectabilis D. Don in the Tree line Areas of Gwang kharqa in Sankhuwasava District of Eastern Nepal*, M.Sc Thesis. Forest and Landscape: Division for forest genetic resources, University of Copenhagen, Denmark.

Wang, T., Liang, Y., Ren, H., Yu, D., Ni, J., and Ma, K., 2004. Age Structure of *Picea schrenkiana* Forest along an Altitudinal Gradient in the Central Tianshan Mountains, Northwestern China, *Forest Ecology and Management*. 196: 267-274.

Wang, X., Fang,J., Tang,Z and Zhu, B., 2006. Climatic Control of Primary Forest Structure and DBH- Height Allometry in Northeast China, *Forest Ecology and Management*. 234: 264-274

Watkinson, AR., 1997. Plant Population Dynamics, in Plant Ecology, Blackwell Publishing Ltd., second edition, pp 237.

Whiteman, D., 2000. Mountain Meteorology, Oxford University Press, pp 355.

Xu, J., Grumbine, RE., Shrestha, A., Eriksson, M., Yang, X., Wang, Y., Wilkes, A., 2009. The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods, *Conservation Biology*. 23: 520-530.

Yadav, RR., Bhattacharyya, A ., and Par , WK., 1997. Climate and Growth Relationship in Blue Pine (Pinus wallichiana) from the Western Himalaya, India, *Korean Journal of Ecology*, 20 : 95-102.

Zafar, MU., Ahmed, M., Farooq, MF., Akbar, M., and Hussain, A., 2012. Growth- Climate Response of *Picea smithiana* from Afghanistan. *Sci, Tech. and Dev*. 31:301-304.

Website visited

http://nepaldendro.blogspot.com/2010/10/treelinetimberlineforestline-in-nepal.html (retrieved on 7/20/2012)
http://books.google.com.np/books/about/Plants_And_People_Of_Nepal.html?id=klAFeYz4YdYC&redir_esc=y (retrieved on 8/3/2012)
http://nepaldendro.blogspot.com/2010/10/treelinetimberlineforestline-in-nepal.html (retrieved on 7/20/2012)
http://books.google.com.np/books/about/Plants_And_People_Of_Nepal.html?id=klAFeYz4YdYC&redir_esc=y (retrieved on 8/3/2012)
https://groups.google.com/forum/?fromgroups#!topic/adendro/0dmOpNwU3p0%5B1-25%5D (retrived on 8/3/2012)
http://dendro.cnre.vt.edu/dendrology/Syllabus2/factsheet.cfm?ID=779) (retived on 7/10/2012)
http://en.wikipedia.org/wiki/Pinus_wallichiana (retived on 7/10/2012)
http://www.ntnc.org.np/project/manaslu-conservation-area-project (retrived on 9/14/2012)
http://www.forestrynepal.org/project/2924 (retrieved on 9/14/2012)
http://nepalmountaineering.org/article-research(retrived on 9/14/2012)
http://www.nepalvista.com/features/nepal-parks/?parkname=Manaslu (retrieved on 9/14/2012)
http://www.ipcc-wg2.gov/publications/SAR/SAR_Chapter%205.pdf (retrieved on 8/1 2013)
http://www.bioone.org/doi/abs/10.1641/00063568%282001%29051%5B0723%3ACCAFD%5D2.0.CO%3B2 (retrived on 8/4 2013)
http://ecoplexity.org/files/Measuring_Canopy_Cover_lesson_plan.pdf) (retrieved on 12/8/2013)

Appendixes

1. Tappering of *Pinus wallichiana* i.e relationship between DBH and basal diameter

S.N	DBH (cm)	Basal DBH(cm)	Tappering (cm)	DBH (cm)	Basal DBH(cm)	Tappering (cm)
1	26	31	5	22.5	31.3	8.8
2	27	30	3	25.7	37.5	11.8
3	31.5	40	8.5	23	32	9
4	32	43	11	37	44	7
5	29	38	9	20	31	11
6	20	30	10	17.5	23.5	6
7	40	50	10	29	40	11
8	38	49	11	22.5	31	8.5
9	36	46	10	30.5	24	-6.5
10	33.5	40	6.5	45	40	-5
11	45	50	5	24	29	5
12	46	50	4	20	25.3	5.3
13	43	54.5	11.5	22.4	26.5	4.1
14	35.5	47	11.5	9	14	5
15	51	58	7	7.5	15	7.5
16	44	53.5	9.5	30	40	10
17	39.5	49	9.5	24	35	11
18	36.5	42	5.5	6	18.5	12.5
19	18.5	22.5	4	17	20	3
20	11.4	14	2.6			
21	48	63.5	15.5			
22	52	57.5	5.5			
23	46	56	10			
24	49.5	64	14.5			
25	40.5	46	5.5			
26	46.7	51.3	4.6			
27	27	32.5	5.5			
28	40	54	14			
29	50.5	55.5	5			
30	53.5	62	8.5			
31	28.5	39	10.5			
32	36	43	7			
33	18.5	35.5	17			
34	35.2	41.5	6.3			
35	31	36	5			
36	36.4	41	4.6			
37	28	39.3	11.3			
38	35	40	5			
39	34.5	39	4.5			

40	36.1	41	4.9			
Total	**1456.3**	**1775.1**	**318.8**	**432.6**	**557.6**	**125**

2. Field data sheet

Field information sheet

Date: ……………………… Plot no: ……………. Aspect: ……………….

Habitat…………….. Slope…………………. Ground cover...………%

Moisture condition: wet/mesic/dry Stoniness: low/medium/high

Bare soil exposure: Low/medium/high Light cover: low/medium/high

Canopy cover graph code: …………

Sign of disturbance: trampling, dropping, fire, cutting, grazing,

Intensity: ……………………………………………….

Associated species: ……………………………………………….

S. N	Steam Diameter		Height		GPS Record				Habit	Remarks
	DBH	Basal	ϴ	length	Latitude	Longitude	Altitude	DBH (core code)		

3. Tree- ring correlation with temperature and precipitation

Months	**correlation with temperature**				**correlation with precipitation**			
	Standard	Residual			Standard		Residual	
	Corr. Coff	**P-**	**Corr. Coeff**	**P-value**	**Corr. Coff**	**P-value**	**Corr. Coff**	**P-value**
Jan	0.114	0.550	0.037	0.846	-0.068	0.722	-0.086	0.653
Feb	0.253	0.178	0.198	0.295	-0.001	0.996	0.038	0.843
March	0.184	0.330	0.090	0.635	0.167	0.377	0.253	0.177
April	0.088	0.645	-0.045	0.815	0.057	0.763	0.037	0.846
May	0.216	0.252	0.221	0.240	0.023	0.903	-0.072	0.703
June	0.056	0.769	0.173	0.361	0.106	0.575	0.045	0.814
July	-0.135	0.477	0.083	0.661	0.281	0.133	0.220	0.243
Aug	-0.351	0.057	-0.160	0.399	0.097	0.610	-0.058	0.761
Sep	-0.254	0.176	-0.233	0.215	-0.162	0.393	-0.173	0.361
Oct	-0.089	0.639	-0.024	0.898	-0.378	0.039	-0.545	0.002
Nov	0.225	0.231	0.180	0.340	-0.189	0.316	-0.056	0.770
Dec	0.138	0.468	0.152	0.424	0.013	0.946	0.007	0.969
Psep	-0.139	0.471	0.053	0.786	-0.188	0.328	0.002	0.992
Poct	-0.040	0.835	-0.006	0.976	-0.121	0.531	0.237	0.216
Pnov	0.018	0.926	-0.168	0.383	0.099	0.609	0.229	0.233
Pdec	-0.135	0.486	-0.259	0.175	0.200	0.299	0.268	0.160

4. Photo Plates

laying a line transect

measuring a DBH

measuring basal diameter

measuring a height of tree

taking GPS location of study area

recording a data

using Increament core borer to extract core

taking out core sample from a tree

core immediately taken out from a tree

air drying the cores

sanding and polishing samples

analyzing samples in tree ring - Lab