Dendroclimatological study of subalpine *Abies spectabilis* forests in Dolpa of Northwestern Nepal

A Dissertation Submitted for the partial fulfillment of
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Submitted by:

Shiba Raj Ghimire
Ecology and Resource Management Unit
Exam Roll No: 6278
Batch: 2008/2010
T.U. Regd. No:-5-2-390-2-2005

Central Department of Botany, Tribhuvan University
Kirtipur, Kathmandu, Nepal

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CERTIFICATE

This is to certify that the dissertation work entitled **"Dendroclimatological study of subalpine *Abies spectabillis* forests in Dolpa of Northwestern Nepal"** Submitted by **Shiba Raj Ghimire** has been carried out under our supervision. The entire work was based on the results of his primary fieldwork and has not been submitted for any other academic degrees. We, therefore, recommend this dissertation to be accepted for the partial fulfillment of Master of Science in Botany from Tribhuvan University, Kathmandu, Nepal.

Shrestha

Dr. Bharat Babu Shrestha

Supervisor

Lecturer

Central Department of Botany
Tribhuvan. University

Kathmandu, Nepal

Narayan

Narayan Prasad Gaire

Co-Supervisor

PhD Scholar

Nepal Academy of Science And Technology

Khumaltar Kathmandu, Nepal

TRIBHUVAN UNIVERSITY
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CENTRAL DEPARTMENT OF BOTANY
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KIRTIPUR, KATHMANDU
NEPAL

EXPERT COMMITTEE

The dissertation work submitted by Mr. Shiba Raj Ghimire entitled **"Dendroclimatological study of subalpine *Abies spectabilis* (D.Don) forests in Dolpa of Northwestern Nepal"** has been accepted for the partial fulfillment of Master of Science in Botany (Ecology & Resources Management).

NRKhanal
External Examiner
Prof. Dr. Narendra Raj Khanal
Central Department of Geography
Tribhuvan University, Kirtipur

Devkota
Internal Examiner
Dr. Anjana Devkota
Central Department of Botany
Tribhuvan University, Kirtipur

Bshrestha
Dr. Bharat Babu Shrestha
Supervisor
Central Department of Botany
Tribhuvan University, Kirtipur

Narayan
Narayan Prasad Gaire
Co-Supervisor
Ph.D. Scholar
Nepal Academy of Science &
Technology, Khumaltar

Head of Department
Prof Dr. Pramod Kumar Jha
Central Department of Botany
Tribhuvan University
Kathmandu, Nepal

Central Department of Botany

Date: May 17, 2013

Phone: 4331322, Fax: ++977-1-4333515, Post Box: 26429
E-mail: info@cdbtu.edu.np, Webpage: www.cdbtu.edu.np

Abstract

Climate and tree growth relationships give valuable information in Dendroclimatic research which describes the sensitivity of trees to the climate. *Abies spectabilis* is one of the potential species for dendroclimatological studies. It responds sensitively to the climate. This study aims to analyze the growth responses of *A. spectabilis* to local climatic parameters of the study site by using tree- ring chronology. This dendrochronological research was carried out at Toridwari community forest of Majhphal village area, Dolpo in July 2011.Three vertical transects were selected. In each transect a quadrat of 20 m × 20 m was sampled from the upper species limit of the *Abies spectabilis* at tree line. Quadrats in each transect were laid at about 50 m walking distance from each other. Altogether, nine quadrats were sampled between 3592 and 3728 m asl.102 sampled from 90 trees of *Abies spectabilis* was taken. The coring of trees was performed with the help of Sunto –increment corer. After the preparation of samples using different techniques, the widths of the cores were measured at 0.01 mm of precision with the help of LINTAB measuring system linked with TSAP – win software. A 235 - year tree – ring chronology of *A. spectabilis* dating back to 1777 was developed. A quantitative analysis of the relationship between tree growth and climate based on a correlation and response function showed that the radial growth of tree – rings was statistically significant and negatively correlated with mean maximum temperature for the month of May (correlation coefficient 0.554 , $P< 0.01$), and March (correlation coefficient 0.43, $P< 0.05$) of the current year. In addition to that, a significant and negative correlation was found with mean temperature of May (correlation coefficient 0.43, $P<0.05$). Precipitation does not show any significant relationship with tree ring the study area. This study showed relatively low mean sensitivity (< 0.2).

Key words: climate change, tree-ring, Dendroclimatology, tree-line

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Shiba Raj Ghimire

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Acronyms

%	Percentage
°C	Degree Centigrade
ARSTAN	Auto- Regressive Standardization
asl	Above sea level
DBH	Diameter at Breast Height
DHM	Department of Hydrology and Meteorology
e.g	Example
EPS	Expressed population Signal
et al.	And others
etc.	Etcetera
GPS	Global positioning System
Ha	Hectare
IPPCC	Inter-governmental Panel on Climate Change
Km	Kilometers
LINTAB	Linear positioning Table
m	Meter
mm	Millimeter
NAST	Nepal Academy of Science and Technology
SPSS	Statistical Package for Social Sciences
TSAP	Time Series Analysis Program
VDC	Village Development Committee

1. INTRODUCTION

1.1 Background

Dendrochronology refers to the study of tree rings, and the association between annual growth layers and specific calendar years. The word ‘Dendrochronology’ is derived from the Greek words *Dendro* (meaning “tree”), *chrono* (meaning “time”), and *logos* (meaning “to study”) (Fritts 1976).Tree rings can be used in dating historical events, such as the age of old wooden structures. The branch of dendrochronology dedicated to investigating past climates using tree rings as proxies is termed *dendroclimatology*. Dendroclimatological research is based on the principle of uniformitarianism. This principle states that the physical processes causing variation in today's environment are the same processes that have acted throughout time or in other words, “the present is the key to the past” (Fritts 1976, Speer 2010). Dendrochronology can be applied to very old trees to provide long-term records of past temperatures, rainfall amounts, fires, insect outbreaks, landslides, hurricanes, tree line dynamics, gap phase study, productivity assessment, and ice storms, etc. (Fritts 1976, Speer 2010). Knowledge of past climatic variations and their effects is necessary for a better understanding of how to plan for potential climate changes in the future. In understanding past climate scenarios, the current issue of climate change and its causes can be more thoroughly perceived. The key assumption in dendrochronology is that such chronologies in most cases reflect environmental conditions (Fritts 1976). Various studies have already considered dendrochronology as an appropriate and effective tool for the prediction of past climatic information (e.g. Cook *et al*. 2003, Sano *et al*. 2005, 2012, Chhetri 2008, and Borgaonkar *et al*. 2011). And further systematic climatic studies based on the tree rings can help us to understand ongoing climate change patterns.

Global climate change refers to changes in the Earth's climate due to the human interference with natural systems. In an effort to meet ever-increasing energy demands, humans have engaged in activities such as burning of fossil fuels and deforestation, which has resulted in an increased concentration of greenhouse gases in the atmosphere. There is worldwide consensus that the globe is warming at an unprecedented rate. The fourth Assessment Report of Inter-Governmental Panel on Climate Change (IPCC) Assessment Report indicated that the global surface temperatures have increased about 0.74° C (+/- 0.18° C) over the last 100 years (1906–2005).

Furthermore, this rate has almost doubled to 0.13° C (+/- 0.03° C) per decade over the last 50 years (Trenberth *et al*. 2007). In Nepal the average air temperature measured at 49 stations has revealed warming trends after 1977 ranging from 0.06 to 0.12°C yr^{-1} in most of the middle mountains and the Himalayan regions (Shrestha *et al.* 1999). Fundamentally, mountain ecosystems are complex and fragile. There is a high risk of landslides, soil erosion and slope failures which could seriously impact biodiversity, ecosystem, and the livelihoods of people. Climate change and its impacts affect a wide variety of organisms. Climate change is affecting the distribution, physiology, and phenology of some species, consistent with the theoretical predictions from long term data from the past half century (Hughes 2000). A slight increase in the mean annual temperature of 1°C is sufficient enough to bring substantial changes in the growth and regeneration capacity of many tree species.

Global warming draws attention of many scientists in the dendrochronological field since it reveals past climatic conditions (Fritts 1976). Trees grown in particular locations are influenced by climate variability, which determines the width of the tree rings. The discipline of dendrochronology seeks to examine variations in tree rings and their characteristic in most temperate tree species because the tree species found in temperate areas shows clear ring pattern in summer and winter seasons but it is not found in tropical and sub-tropical. Analyses of tree rings provide a means to extend back the record of climate information at high latitudes as well as high altitudes. Most trees in the temperate zone have discernible annual growth rings. As there is distinct variation in summer and winter climates, tree line ecotones are sensitive biomonitors of past and recent climate changes and variability (Kullman 1998; Camarero and Gutierrez 2004) and are ideally suited for climate change monitoring (Becker *et al.* 2007). Therefore, examination of the annual growth rings of a tree will reveal not only its age, but also the fluctuating climatic conditions during its lifetime (Dayton 2003).

The studies of the relationship of climatic parameters and tree rings growth patterns at tree line are very important in the forestry and environmental sectors to predict future growth and to investigate tree line dynamics (Speer 2010).In this context, a scientific study was conducted at the tree line of the Nepalese Himalaya to better understand the dynamics of a changing climate and its influence on tree growth. The dendrochronological researches are focused mainly on Central part of the country such as Langtang National Park (Chhetri 2008, Gaire 2008, Gaire et al. 2011,Ojha 2012), Kathmandu Valley (Bhuju and Gaire 2012) Ganesh Himal (Khanal and Rijal 2002) West- Central such as Mustang (Udas 2009, Shrestha N. 2012) , Manaslu (Suwal 2010), Myagdi Khola (Kobayashi O, Sano M and Sweda 2002) Eastern Nepal such as Sagarmatha National Park (Bhuju *et al* 2010), Kalinchok , Gonga Danda (Doughlas 2002, Bhattacharya et al 1992) . But very few researches are carried out in the Far-Western and Mid-Western part such as Humla (Sano *et al.* 2005), Rara lake and Jumla (Suzuki 1990, Cook et al. 2003) Dolpo (Brauning A. 2004) etc. Thus, this research was carried out at Dolpo District to fill the gap in dendrochronological research in the mid- western part of the Nepalese Himalaya. Here the present study was focused on the growth response of a tree line species *Abies spectabilis* (D. Don) Spach to climate variability in western Nepal. This work is small attempt to contribute to dendroclimatic research in the Nepalese Himalaya.

1.2 Justification of the Study

Dendrochronology is an emerging field of research in the 21st century. It aids in the study of climate change and in the long-term monitoring of impacts on tree growth due to climate change. Most researchers focus on the causes of glacier melting, and tree line shifting by using different ecological approaches, but they are not able to get appropriate results without long-term climatological data. Proxy methods are often used to understand climate change. Dendroclimatic study is also commonly used methods. Several tree species in Nepal such as *Pinus wallichiana, Pinus roxburghii, Abies spectabilis, Cedrus deodara, Juniperus recurva* etc. have been found promising for dendroclimatic studies (Bhattacharya *et al.*1992, Cook *et al*. 2003). In Nepal, *Abies spectabilis* has been widely used for dendrochronological studies (Chhetri 2008, Bhuju *et al.* 2010, and Gaire *et al*. 2011) because it has clear and dateable tree-ring sequences and synchronicity in growth pattern. Though there are great prospects of tree ring study in the multitude aspects of climatology, ecology, hydrology, archaeology, etc in Nepal, only few studies have been carried out so far (e.g. Suzuki 1990, Cook *et al*. 2003, Sano *et al*. 2005, Bhuju *et al*. 2010, Gaire *et al*. 2011). Most of the studies by Nepalese researchers have been limited in the climate-growth analyses. In recent years, studies in dendroecology mainly focusing on tree line dynamics with climate change have been initiated by Nepalese researchers (e.g. Chhetri 2008, Gaire 2008, Udas 2009, Bhuju *et al*. 2010, Gaire *et al*. 2010), however concrete result is yet to come. Much of the dendrochronological studies in Nepal have been carried out from the eastern and central Nepal. As western part of the country is relatively dry, it could be much appropriate for various dendrochronological samplings. Hence, this study was focused in western Nepal. In this study, *Abies spectabilis* was chosen because of its high dendroclimatic potential, and also because it forms a tree line in the study site. Using tree rings from *Abies spectabilis* as proxy, climatic trends in the northwestern part of Nepal was analyzed.

1.3 Objectives

The general objective of this study was to establish the relationship between tree ring size of *Abies spectabilis* and the climatic variables. The specific objectives formulated for the study are:

1. To establish the relationship between age and diameter of *Abies spectabilis* trees.
2. To develop tree ring chronologies of *Abies spectabilis*.
3. To assess the relationship between tree growth of *Abies spectabilis* and local climatic parameters (temperature and precipitation).

1.4 Limitations

1. Due to remoteness of the study area and lack of funding, core samples were collected from a limited area without replicate sampling from other areas.

2. The major obstacle was the lack of instrumental meteorological data for statistically calibrating the tree ring series and for conducting long-term studies. In this study, the data of the nearest meteorological station (Dunai) was available only for a relatively short period (16 years) and was incomplete; therefore, the data from another meteorological station (Jumla) was used to analyze the relationship between tree ring growth and climatic variables (temperature and precipitation) of 32 years.

2. LITERATURE REVIEW

Dendrochronology is the method of scientific dating based on the analysis of tree-ring growth patterns. This technique was developed during the first half of the 20th century originally by the astronomer A.E. Douglass, the founder of the Laboratory of Tree-Ring Research at the University of Arizona (Fritts 1976). The technique of dendrochronology can date the tree rings in many types of wood to the exact calendar year. Earlier the carbon dating was the single scientific method of dating the age of wooden objects though there is error of 20 years even on most accurate calculation. Later on in 1901 a reliable scientific method was developed for dating tree known as Dendrochronology. Development of the science of dendrochronology as opposed to simple counting of tree rings in a stump begins in 1901 with an observation on aridity in relation to elevation by Andrew Elicott Douglass. In 1970's Dendrochronology was extended for dating buildings (Fritts 1976). Dendrochronological study has been used by many researchers in the field of ecology and climate change.

2.1 Dendroecology

In general, growth of a tree is dependent on complex series of interactions between genetic and environmental factors; however, the former being more influenced by the latter (Fritts 1976). Due to covariance of various climatic parameters and complex physiological processes in plants, the detection of growth response in terms of single controlling factors often fails (Fritts 1976, 2001). Hereditary factors of a tree determine a certain range of habitat, thus the climatic factors may rarely be limiting to growth except in years of most extreme climate and other limiting local situations. At the margin of its natural range i.e. at tree line or timber line, the climatic control upon tree growth increases and climate becomes highly limiting factor to physiological processes thereby affecting total tree growth (Bhuju *et al*. 2010). A tree line is a transitional eco-tone between forest and non-forest vegetation (shrubs and grasses) at an elevational limit or it is simply an ecological limit for tree growth. Temperature and water supply are the dominant factors that govern various growth processes in woody plants (Kozlowsky and Pallardy 1997 cited in Leal *et al*. 2007).

In the recent time, the proxy information from tree rings, ice cores and lake sediments etc. are increasingly used to reconstruct climate and to understand climate variability in the past. Tree rings are highly suitable proxies because of their annual resolution, dating control, wide spatial distribution and the possibility of using simple linear models of climate-growth relationships which can be easily verified and calibrated to obtain quality data (Hughes 2002). Trees as a living stand or archeological piece which can store varied climatic information such as temperature and precipitation in a pattern of narrow and wide tree rings reflecting corresponding climatic signals which is broadly dealt with in the scientific field of Dendrochronology. Hence, by using trees growing on a particular site where climate is highly limiting to the tree growth processes, features of dated rings such as ring width, can be averaged year by year to obtain a time series of the growth response to past variations in climate (Fritts 1976).

The "sensitivity" of a tree refers to the responsiveness of ring width variation to changes in environmental conditions. As the number of factors limiting tree growth decreases, the overall sensitivity of the tree increases (Cook and Briffa 1990). The non- climatic parameters at tree - ring dynamics is considered as noise (Fritts 1976). Trees that lack sensitivity are referred to as being complacent (Stokes and Smiley 1968), as they exhibit little variation in ring width with changes in climate variables (Fritts 1976). Conversely, ring widths of a sensitive tree can vary dramatically in accordance with climatic variation (Schweingruber *et al.* 1990). The more the climate is variable from one year to the next, the more the tree-ring series vary and the more climatic information can be expected from tree-ring series. These tree-ring series can provide not only long records of climate proxy-data but also the measurement of the impact of climatic change on photosynthetic processes (Tessier *et al.* 1997).

Holtmeier (1994) reported that tree growth at timberline site is controlled by the characteristics of the climate i.e. the annual temperature regime and extreme climatic events. Furthermore, it is suggested that variable weather conditions and short-term climate extremes affect tree physiology and forest ecosystem stability more than average climatic conditions (Graham *et al.* 1990; Innes 1994). So, most studies that involve dendrochronology are conducted in temperate regions, where the majority of tree species produce a single and explicit growth ring each year (Fritts 1976, Speer 2010). Most of the studies in Nepal are focusing on dendroecology mainly on tree line dynamics (Gaire 2008, Bhuju *et al*. 2010, Suwal 2010, Gaire *et al*. 2011, Ojha 2012, and Shrestha 2012). However some studies are focusing on tree growth to climate relation analysis (e.g. Chhetri 2008, Udas 2009, Bhuju and Gaire 2012). None of these studies, so far have been able to reconstruct past climate.

2.2 Dendroclimatology

Some studies at high altitude shows that in semi-arid, arid and in sites having low water holding capacities, the positive sensitivity of temperature with tree growth is declining which is most likely due to temperature induced drought stress conditions (Dang *et al*. 2007). Similarly studies done in the Himalaya region also show that tree growth in these regions is limited by availability of moisture in the pre- monsoon season and can show negative relationship with temperature and positive with precipitation (Borgaonkar *et al*.1996; 1999; 2011,Yadav *et al*. 2004, Sano *et al*. 2005). However the relationship between tree ring growth and climate is strong from different ways and thus constitutes the basis for dendroclimatic studies (Leal *et al*. 2007).

Nepal has a wide geographical and climatic variation ranging from tropical to alpine regions that provides the scope for dendrochronological studies in its high mountains and in the Himalayas. However, dendrochronological studies from Nepalese Himalayas are rather few and incomprehensive (Sano *et al*. 2005). Nepal has a wide distribution of dendroclimatologically potential plant species; but in comparison to neighboring countries and other mountainous regions, the dendrochronological studies have been very limited although climate change is more pronounced in mountainous regions and have severe impacts on livelihoods. There is general lack of meteorological stations in mountainous areas of Nepal. Nepal has over 200 weather stations distributed throughout the country, but most were established only after 1960 for precipitation and 1970 for temperature (Shrestha *et al*. 1999, 2000).

One objective of dendroclimatology is used in tree ring widths to obtain information about long-term variations in climate and to reconstruct past climatic history (Cook *et al.* 1999). Since dendrochronology is useful in analyzing the temporal and spatial patterns of climatic processes, empirical studies of the relationship between tree growth and climate in the temperate zone are typically carried out with dendrochronological methods (Cook and Kairiukstis 1990). The common practice of dendrochronology is the synchronization of variance among the samples from one tree, among several trees of one stand, or among regional datasets of samples (Fritts 1976). Systematic use of this synchronization, called "tree-ring cross-dating", most appropriately characterizes the discipline of dendrochronology (Fritts 1976, Fritts and Swetnam 1989). Tree-ring data plays an important role in climate change research (Sun *et al.* 2010). Since the study of historical climatic variability plays a vital role in understanding current and future climatic trends, as well as their relationship with social and economic stability. Knowledge about past climates is becoming increasingly important. However, dendrochronological studies from Nepalese Himalaya are rather few and incomprehensive (Sano *et al*. 2005). One of the major obstacles in dendro-climatic studies in Nepal is the lack of comprehensive meteorological data for statistically calibrating tree ring series and for conducting long-term climate studies. The longest meteorological record in Nepal is from the Indian Embassy Kathmandu for the period of 1921 to 1994 and many of the meteorological stations (mainly in high mountains) in the country were established only after 1960 for precipitation and after 1970 for temperature (Shrestha *et al.*, 1999; 2000). Thus, meteorological records from high elevations of the Himalaya in the country are not available or are relatively short and provide only limited information.

In Nepal, dendrochronological study began in late 1970s during which Rudolf Zuber collected tree ring samples of various species and habitat types. Suzuki (1990) and Bhattacharya *et al.* (1992) hinted about the potentiality of different species for dendroclimatological studies. Suzuki (1990) collected 198 cores from 105 conifer tree for dendrochronological study around Rara Lake and found climate change effect is more pronounced in large tree than small. Bhattacharya *et al.* (1992) developed tree ring network of *Picea smithiana*, *Pinus wallichiana*, *Pinus roxburghii*, *Abies spectabilies*, *Larix griffithiana*, *Tsuga dumosa*, *Juniperus recurva* and *Cedrus deodara* tree ring sample collected from 25 different localities with largest chronology between 1569-1978 from Langtang but he faced the paucity of instrumental meteorological data in Nepal for cross dating. Important climate reconstruction studies in Nepal were carried out by Schmidt (1992-93), Khanal and Rijal (2002), Kobayashi *et al*. (2002), Furuta *et al*. (2002) and Sano *et al.* (2002, 2005). Schmidt (1992-93) collected 400 specimens from Thini, Marpha and Dzarkot VDCs of Mustang and developed tree ring chronology of 537 years from 1455 to 1992. Sano *et al.* (2005) reconstructed the past 249 years' climate of western Nepal using ring width and wood density of *Abies spectabilis* which showed a warming trend from 1750s until approximately 1790, followed by cooling until 1810, then by a gradual warming trend well up to 1950.

Brauning (2004) developed chronology of *Abies spectabilis*, *Pinus wallichiana* and *Betula utilies* from Mughu and Dolpo region which possibly is the first dendrochronological study in broadleaved species (*Betula utilies*) in Nepal. Most intensive work was carried out by Cook *et al.* (2003) who demonstrated the possibility of reconstructing past climate in Nepal Himalaya using dendroclimatic techniques. He was the first to include an extensive network of 32 ring width chronologies from all over the country and reconstructed February-June and October-February temperatures dating back to 1546 and 1605 AD, respectively, and able to give good evidence for Little Ice Age cooling in the Nepal side of the Himalayas over the past 400 years.

Most of the dendroclimatic studies in Nepal are focused in the climate-growth relationship at tree line which has put the climatic reconstructions in the shadows. After the establishment of tree ring laboratory at Nepal Academy of Science and Technology (NAST) in 2009, researches on dendroclimatology and dendroecology by Nepalese researchers have been increased rapidly and studies have covered different parts of high altitude of eastern to western Nepal Himalaya.

3. MATERIALS AND METHODS

3.1 Study area

The study was carried out in the Dolpa district (28° 24' to 29° 43' N latitude and 82° 24' to 83° 38' E longitude) in the north-western part of Nepal. The district is surrounded by Tibet (the autonomous region of China) to the North and Northeast, Jumla and Mugu districts to the west, Myagdi, Jajarkot and Rukum to the south, and Mustang to the east (Figure. 1). The elevation of Dolpa district ranges from 1525 to 7625 m above sea level (m asl). The main water resources are the Thuli Bheri, Sani Bheri rivers and Shey-Phuksundo, Sundaha, Dudhdaha and Sakudaha lakes.The vegetation ranges from sub- tropical to alpine in the Dolpa distrct. The present study area is covered by *Caragana-lonicera* type, *Rhododendron* spp., *gerardiana*, *Hippophae tibetana*, and coniferous plants.

In the altitudinal ranges (3000-3600m) dominated by the species of *Juniperous indica* (Bertol., Misc) , *Rosa sericea* (Lindl.Monogr) , *Berberis aristata (DC.), Lonicera sp., Sorbus microphylla* (Wenz. Linnaea*)*, Similarly in the alpine scrubs is covered with *Betula-Rhododendron* forest, *Abies spectabilis* froest, and other associated species in this forest are ; *Lonicera myrtillus,* (Hook.F.& Thomson,J.Linn.Soc*) Clematis spp., Gentiana depressa (D.Don), Rhodiola himalensis (D.Don)*. In the altitude above 3600m, the dominat species are *Caragana brevifolia*, and *Lonicera spinosa*, when the altitude ascends up this type of vegetation is replaced by *Rosa sericea, Potentila fruticosa* (Lindl.exlehm*), Astragallus emodi (*Steud.*), Ephedra*, *Primula macrophylla (D.Don), Thermopsis sp., Rheum moorcroftianum* (Royle,*)* etc. and alpine grasslands and nivale zones are found respectively (Shrestha *et al.* 2006). This region falls into rain shadow area with annual rainfall of only 348.27 mm/year as recorded at Juphal station (1200 m asl.). The maximum temperature in summer is 29°C and winter is very cold with freezing temperatures down to negative 2.5°C.

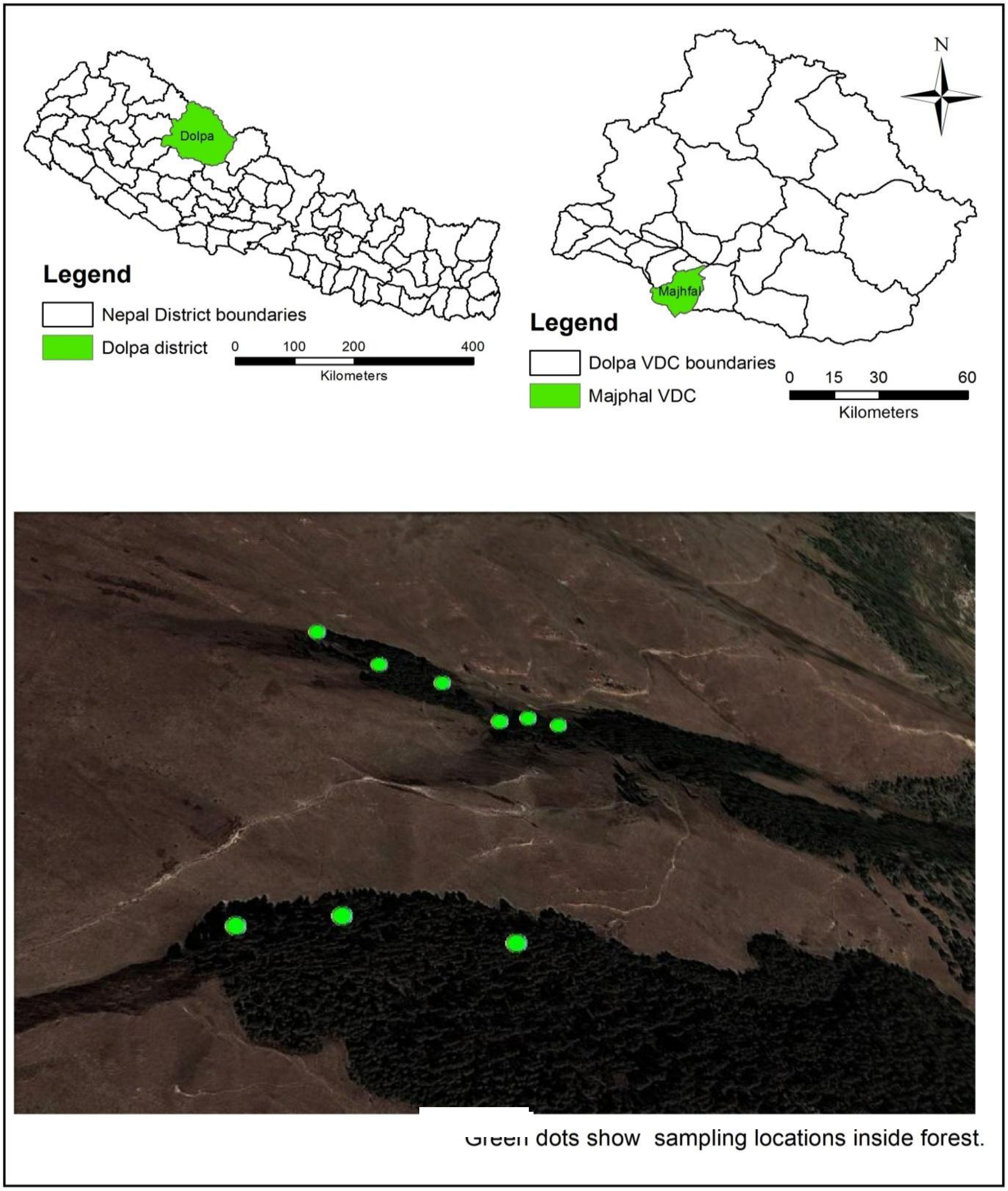
3.2 Site selection

The sampling sites were selected in such a way that the forest stands had no fire incidents in the recent past (i.e no fire marks at the base of trees), few stumps, no sign of landslides, and a well-defined treeline. The forest stands found in the Toridwari Community Forest of Majhphal VDC area met the above criteria. Samples were collected in August 2011. The community forest is situated at an altitude range between 2800 and 3728 m asl at tree line. *Pinus wallichiana, Picea smithiana, Cedrus deodara*, *Taxus baccata*, *Juniperus recurva* etc. are found mixed at lower elevations, but it is gradually being replaced by a mixed forest of *Abies spectabilis, Betula utilis* and *Rhododendron* spp. at its upper elevation. *Abies spectabilis* builds the tree line in the present study site, but at some parts of that region *Abies spectabilis* and *Betulla utilis* also form the tree line together.

3.3 Sampling design

The sampling followed the elevation gradient from the tree line at 3728 m asl downward to the elevation of 3592 m asl. Three vertical belt transects were defined on the North-east facing slope. Vertically there were three transect was selected.The distance between three transect was about 250 m. A quadrat of 20 m × 20 m was started from the upper species limit of the *Abies spectabilis* at tree-line. In each transect there were laid three quadrates. The second quadrat in each transect was selected by 50 m walking distance from the first quadrat.In total, nine quadrats (20 m × 20 m) were established in the tree line zone ranging from 3592 to 3728 m asl.

In each quadrat, geographic position, elevation, aspect, slope and canopy coverage were recorded. Geographic position (latitude and longitude) and elevation were recorded with GPS (eTrex, Garmin). Aspect and slope were measured by clinometer. The tree canopy was visually estimated in each of the sampling plots; canopy estimation was done from four corners and the center of each quadrat. Measuring tape and clinometer were used to estimate the height of trees. The DBH for each sample tree was measured with a DBH tape (Kinlon Japan). Individuals of *Abies spectabilis* were categorized into two height classes: trees (>3 m) and saplings (≤3 m) (Zobel *et al*. 1987). All tree species present in each sampling plot were recorded. There was some evidences of human disturbances such as the presence of stumps, cattle grazing and fallen trees. There was no evidence of fire. In addition, the age of seedlings and saplings was estimated by counting branch whorls and bud scars left on the main stem adopting the methodsuse by Camarero and Gutierrez 2004, Suwal 2010. Tree species were identified in the field using standard literatures (Stainton and Polunin 1984).



Green dots show sampling locations inside forest.

Figure 1: Map showing study area.

3.4 Sample collection and preparation

Sample cores of *Abies spectabilis* were collected using an increment borer (Haglof, Sweden). Ten individuals of *Abies spectabilis* were selected purposively from each plot, and core samples were taken. The tree core was extracted about 1.3 m above the ground with the aim of retrieving the pith portion with the maximum length and the easy handling of the increment borer. In this study altogether 90 core samples were taken, collecting single core from each of the trees. From 12 trees choosen randomly, second cores were also collected to check the presence of compression and reaction wood. Thus, altogether 102 cores were collected from the study area. Then the samples were wrapped with blotting paper for water absorbtion and labeling.

3.4.1 Processing and laboratory analysis of samples

All the collected sample cores were glued into a wooden frame and were wrapped by paper-tape to allow for a week of drying. These cores were then sanded and polished successively through different grades of sanding paper (80, 120, 240, 300, 340, 400 and 600) until cellular structures and tree ring boundaries were clearly visible under the binocular microscope (Fritts 1976, Stokes and Smiley 1996). All the samples were brought to Dendro-Lab at Nepal Academy of Science and Technology (NAST), Khumaltar, Lalitpur, for age counting and further analysis.

3.4.2 Sample measurement and cross dating

After counting the number of rings, their width in each of the individual core was measured with an accuracy of 0.01 mm using a moving ring width measuring stage LINTAB, attacheed to PC having a computer program TSAP-win (RINTECH) as associated software and a stereomicroscope. By this way, number of rings in each core sample, and the width of each ring were determined. The alignment plotting technique with math graph of cross dating was used to date all properly mounted samples. Fritts (1976) suggested that cross dating, which matches the similar ring width patterns between trees and within tree cores, is the most important principle of dendrochronology. The ring width patterns may vary from year to year due to the influences of different limiting factors.

The radii of each sample tree were also cross-checked to find missing rings using the cross date math graph after the measurement of TSAP-win. The radii having error in dating rings were reexamined to trace the source of the errors and to correct them. Then COFFECHA was run again with the corrected measurements to check for the occurrence of any further errors. Then the ring series with errors shown by COFFECHA were excluded and further analysis was done. After that, out of 102 sample cores only 45 were used for developing chronologies.

3.4.3 Standardization and chronology development

All the ring-width data were standardized by using the computer software program, ARSTAN. There are several reasons for standerdization. Firstly, to remove non-climatic age trends from the ring width; secondly, to get the resultant standardized values; thirdly, to get an average mean value by maintaining the series for different growth rates. Similarly, Cook and Kairiukstis (1990) suggested that standardization transforms a non-stationary ring width into a new series of stationary, relative tree ring indices that have a defined mean of 1.0 and a relatively constant variance. Age counting enabled to discard widths below the threshold for chronology establishment; generally chronology is started above 50 years. For the analysis of ring width data, used a conventional negative exponential curve to detrend the tree ring series and remove age effects due to biological growth trends.

From the ARSTAN program a set of three chronologies was obtained for the study site: a) a standard chronology, reflecting variations after removing age effects, b) a residual chronology, which explains only the high frequency variations after removing autocorrelation from the standard chronology; and c) an ARSTAN chronology, composed of the residual chronology reincorporated with the pooled auto-regression.

Chronology statistics like mean tree ring width, mean index, standard deviation, standard error, autocorrelation, mean sensitivity etc. were calculated to enhance the dendro-climatic information. Autocorrelation, mean sensitivity, and expressed population signal (EPS) values play an important role in chronology development. Mean sensitivity is a measure of the relative difference in width between consecutive rings (Fritts 1976). Possible values range from 0 (indicating no change in ring width from one year to the next) to 2 (indicating a missing ring), with high mean sensitivity measurements interpreted as an indication that the ring-width series may have dendroclimatological utility (Fritts 1976). First-order autocorrelation is a measure of the degree to which a given year’s growth is correlated with the preceding year’s growth, with high values indicating that a significant portion of the observed ring width is a function of the preceding year's growth rather than exogenous factors. Theoretically, there is an inverse relationship between mean sensitivity and autocorrelation (Fritts 1976). This is because mean sensitivity measures the proportion of high frequency variance while autocorrelation measures the proportion of low frequency variance. Mean series correlation is used to determine the similarity of the individual ring width series in a chronology. It is calculated for within trees, between trees and among all the radii. Signal to noise ratio is a measure of the common variance in a chronology scaled by a measure of the total variance of the chronology.

Expressed population signal (EPS) is an indication of how well the site chronology estimates the population chronology (Wigley *et al*. 1984). In addition to that, by calculating the EPS values one can estimate the chronology confidently. Wigley *et al*. (1984) has suggested an EPS value of 0.85 as an acceptable value demonstrating a strong common signal present in a chronology. A high EPS value does not necessarily reflect common signals due to climate forcing, and that there might be some other external or internal factors responsible for such common signals. The EPS is based on the mean correlation between all series included and has a possible range from zero to one.

3.5 Meteorological data

The climatic data was obtained from the Department of Hydrology and Meteorology (DHM), Babarmahal, Kathmandu. The temperature and precipitation data were recorded at Dunai station from 1991 to 2005 which was the closest station from the study area, but some values were missing for both temperature and precipitation. Furthermore after 2005, the station was closed, therefore the long-term climatic data from that station was not available.The missing values were interpolated by averaging the mean monthly data throughout the years (Bhattacharya and Chaudhary 2003) and found a significant correlation with the precipitation and temperature record from the next station, Jumla. This being the case, the climatic data from Jumla was used for further analyses. Average of the recorded data were used for finding the missing values.The Jumla station lies in the North - western side of the Dolpa District. The aerial distance from Juphal station to the Jumla is about 45 km .

3.6 Data analysis

All the field data were entered and manage in Microsoft Excel 2007 software and then Statistical analyses were performed using SPSS 16.0 packages. A linear regression model between DBH and age of the *Abies spectabilis* was developed.

Population Density:

Population density is defined as the number of individuals of the species in any unit area. Density represents the numerical strength of species in the community. Density gives an idea of degree of competition. It is calculated as:

$$\text{Density (D) (No. / ha)} = \frac{\text{Number of individuals of a species in a plot} \times 10000}{\text{Area of quadrat} \times \text{total number of quadrats}}$$

Tree growth and climate relationship

Since temperature and precipitation data of Dunai and Jumla station were correlated with standard tree rings value which revealed that Jumla station had good correlation than Dunai eventhough it is nearer to the study site. Correlation analysis was used to examine how climatic variables (monthly mean temperature and monthly total precipitation) and the radial growth varied (Fritts *et al.* 1971; Fritts and Xiangding 1986). To analyze previous year climatic response function on the growth, last four months (September-December) of the year were taken. In the present study the tree ring chronology was between 1777 to 2011 since the climatic data ranging from 1979 to 2011 with standard chronology of same interval was taken to establish relationship between tree ring growth and climatic data of Jumla station. This period was selected because the conditions during the previous and current year growing season can affect the amount of carbon fixed and allocated to tree growth (Grissino-Mayer and Butler 1993; Foster and Brooks 2001 as cited in Harley *et al.* 2011).

4. RESULTS

4.1 Stand characteristics

The forest of the sampling site was dominated by *Abies spectabilis*. The higher values for stump density as compared to other disturbance factors such as tree felling, grazing, fires etc. suggest that the area was heavily disturbed by anthropo- zoogenic activities. In addition, the area near the study site was suitable for keeping herds of sheep, cows, buffalos and horses in rainy seasons and was easy to access for gathering firewood for cooking. It was obvious that percentage of *Abies* spp. was higher due to habitat suitability even though its stump cutting was higher. The total trees density was 569 stem/ha (Table 4.1) while sapling density was 25 stem/ha (Table 4.1). Similarly total density of Abies (sapling, trees) was 578 stem/ha (Table 4.1) and sapling density of *Abies spectabilis* was found 8 stem/ha (Table 4.1). The height of trees in the sampling plot range from 13- 45m. Similarly the DBH range from 15.6 – 110.4 cm (Table 4.1). The standard deviation value of DBH and height of the sampling tree was found to be 1.88 and 6.95 (Table 4.1) respectively.

Table 4.1 Stand characteristics of the sampling plots.

Stump density (stem/ha)	317
Tree falling density (stem/ha)	11
Total tree density (stem/ha)	569
Total sapling density (stem/ha)	25
Tree density of *Abies spectabilis* (stem/ha)	570
Abies spectabilis sapling density (stem/ha)	8
Sorbus microphylla density (stem/ha)	11
Wild rose density (stem/ha)	6
Average height of *Abies spectabilis* (m)	27
Average DBH of *Abies spectabilis* (cm)	40

4.1.1 Distribution of DBH and age structure of *Abies spectabilis*

Altogether 37 sampled trees with age ranges from 47 to 235 years were used to establish the age–DBH linear regression model at the study site. The result of the linear regression analysis between DBH and age of trees at the sampling site was positive and statistically significant (Figure 4.1).

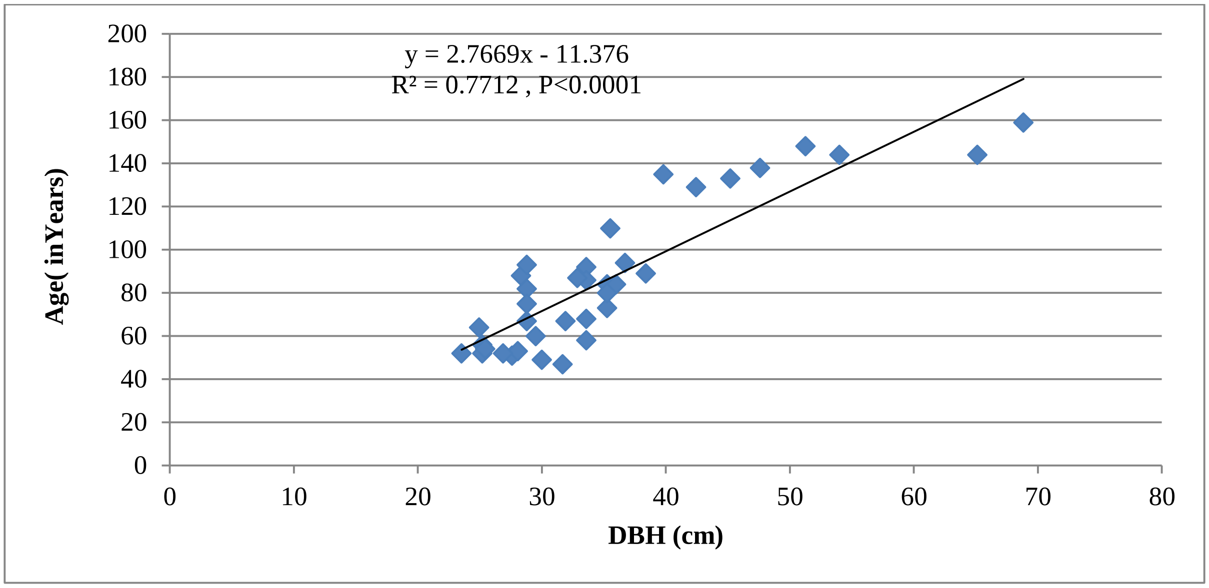


Figure 4.1: Relationship between the age and DBH of *Abies spectabilis*.

4.2 Temperature and precipitation trend

Variation in the temperature and precipitation from 1979 to 2011 are analysed to know the changing pattern of climate during that period using the Jumla meteorological station established at an altitude of 2300 m asl. The results are presented in the following ;

The average monthly temperature and precipitation trend of the area for 33 years (1979-2011) in the figure shows the precipitation variabilty from 9.6 mm in November to 182.44 mm in July whereas the average monthly temperature varies from 4.7 ° C in February to 20.7 ° C in July.

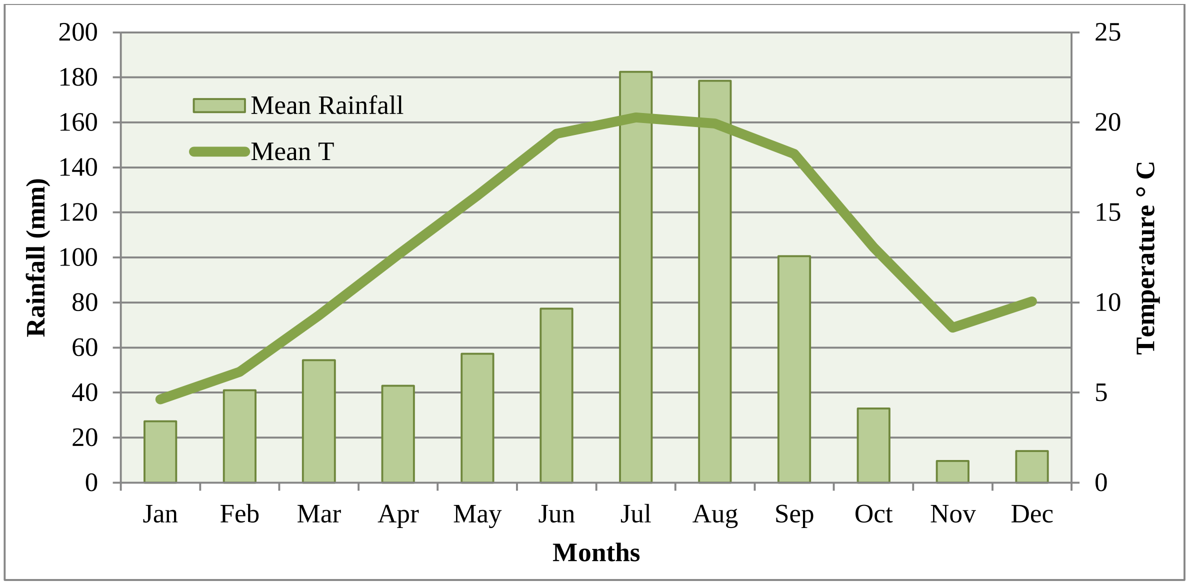


Figure 4.2: Mean monthly variation in rainfall and temperature(1979-2011) at Jumla station (Source : DHM , 2011)

The mean rainfall pattern from 1979 to 2011 shows that there has been a fluctuation in rainfall over the past 33 years.However the highest rainfall record was 1051.1 mm for the year1982 and the lowest rainfall was in the year 1984 with 628.2 mm.

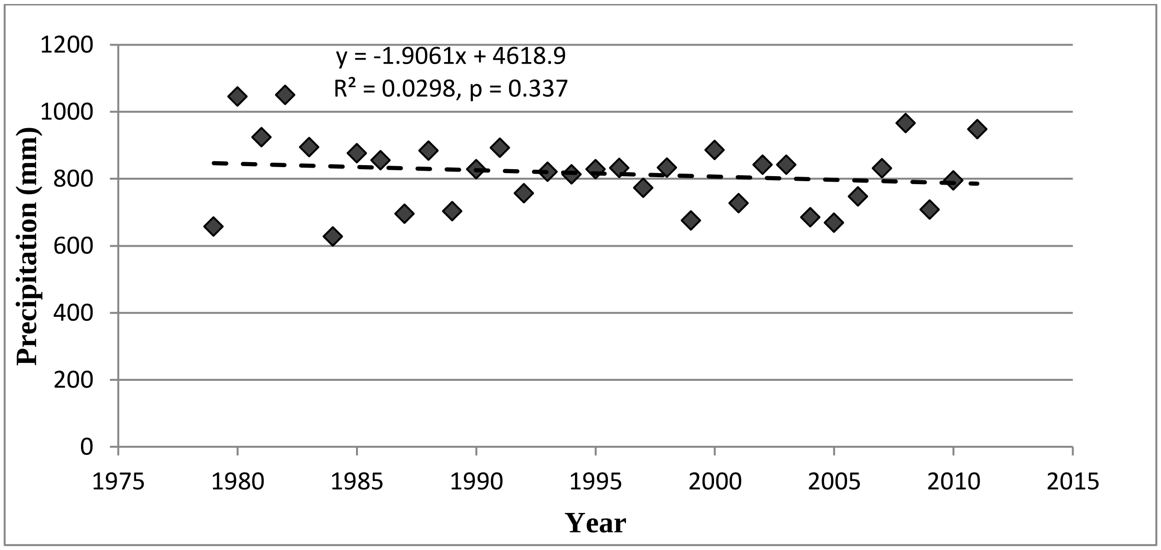


Figure 4.3 : Average precipitation trend from (1979-2011). Since the realtion was not significant the fitted line has been shown in dotted line. (Data source: DHM 2011).

The mean annual temperature trend for 32 years from 1979 to 2011 at Jumla weather station shows that the lowest temperature was 11.24° C in the year 2000. whereas the highest temperature in the past 33 years was in 2006 with 13.87 ° C. Since the temperature trend has been showing slightly increasing pattern.(Figure 4.4).

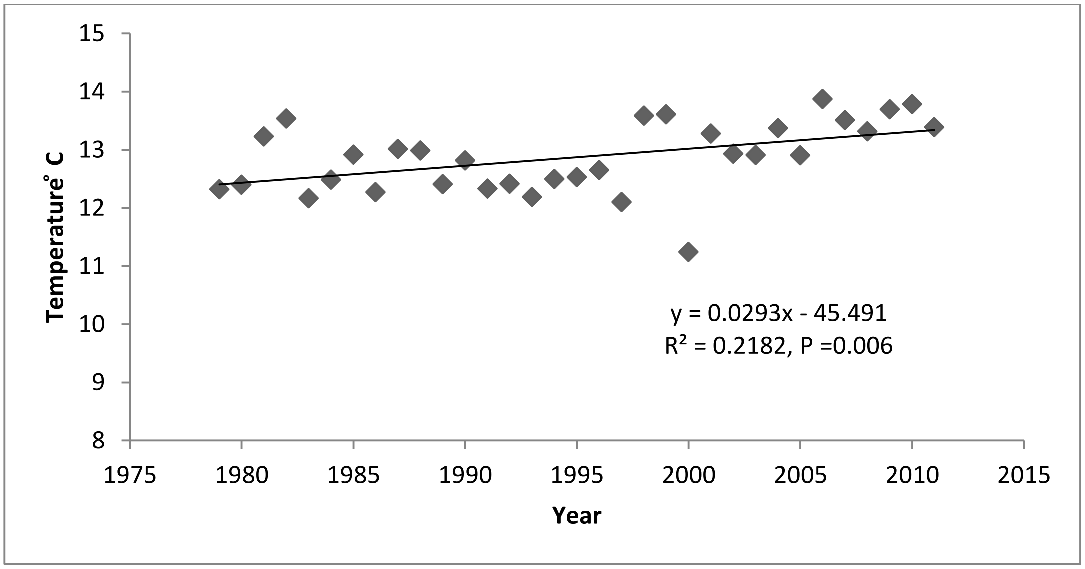


Figure 4.4 : Mean annual temperature in Jumla metereological station (1979-2011). (Source : DHM, 2011)

4.3 Tree ring chronology statistics

Out of 102 core samples from 90 trees of *Abies spectabilis*, 45 cores were successfully cross-dated. Cross dating was relatively difficult for those samples because tree rings were narrow and did not follow regular patterns. Even so, the pointer years common for some rings were recognized in every 2 or 3 decades (Figure 4.5). The series which were less than 50 years old and the correlations < 0.32 with the master series were eliminated from the final data set. The descriptive statistics of COFECHA are presented in Table 4.2 which shows high correlation between all the series and the master series.

Table 4.2: COFECHA output summary

Sequence	Series	Time Intervals	Numbers of Years	Number of segment	Number of Flags	Correlation with master
1	ABSB002B	1872-2005	134	6	0	0.427
2	ABSB003A	1925-2011	87	3	0	0.454
3	ABSB004B	1891-2011	121	5	0	0.474
4	ABSB007A	1956-2011	56	2	0	0.423
5	ABSB008A	1872-2011	140	6	0	0.4
6	ABSB014A	1800-2011	212	8	1	0.414
7	ABSB019B	1931-2011	81	3	1	0.342
8	ABSB023A	1928-2011	84	3	0	0.579
9	ABSB027A	1892-2011	120	5	1	0.394
10	ABSB031A	1918-2011	94	4	2	0.33
11	ABSB033A	1820-2010	191	8	1	0.419
12	ABSB035A	1869-2010	142	6	2	0.393
13	ABSB039A	1853-2011	159	6	1	0.427
14	ABSB040A	1777-2011	235	8	0	0.54
15	ABSB041B	1926-2011	86	3	1	0.325
16	ABSB044A	1876-2011	136	5	0	0.494
17	ABSB045B	1920-2011	92	4	0	0.479
18	ABSB049A	1855-2011	157	6	2	0.327
19	ABSB051A	1927-2011	85	3	0	0.497
20	ABSB053B	1868-2011	144	6	3	0.324
21	ABSB054A	1861-2009	149	6	3	0.381
22	ABSB057B	1923-2011	89	4	0	0.402
23	ABSB058B	1928-2011	84	3	0	0.611
24	ABSB060A	1942-2011	70	3	0	0.371
25	ABSB061A	1939-2011	73	3	0	0.467
26	ABSB062A	1960-2011	52	2	0	0.49

27	ABSB063A	1961-2011	51	2	0	0.523
28	ABSB066C	1959-2011	53	2	0	0.51
29	ABSB067A	1940-2011	72	3	0	0.476
30	ABSB071A	1952-2011	60	2	0	0.44
31	ABSB072A	1937-2011	75	3	0	0.389
32	ABSB072B	1937-2011	75	3	2	0.347
33	ABSB073A	1930-2011	82	3	1	0.449
34	ABSB078A	1963-2011	49	1	1	0.327
35	ABSB079B	1911-2010	100	4	1	0.269
36	ABSB082A	1948-2011	64	3	0	0.462
37	ABSB083B	1920-2011	92	4	0	0.517
38	ABSB085A	1960-2010	51	2	0	0.422
39	ABSB087A	1924-2011	88	4	2	0.355
40	ABSB087B	1924-2011	88	4	0	0.461
41	ABSB089A	1952-2011	60	2	2	0.236
42	ABSB090A	1960-2011	52	2	0	0.374
43	ABSB105A	1965-2011	47	1	0	0.452
44	ABSB107A	1963-2011	49	1	1	0.427
45	ABSB108A	1940-2011	72	3	0	0.452
Total of the mean			4353	170	28	0.423

A two hundred and thirty five (235) years long chronology was prepared from 45 core samples, which extends from 1777 to 2011 AD (Figure 4.5) . From 1777 onward the tree ring showed wider ring in the pointer years 1788, 1792, 1809, 1831, 1847, 1917 and 2003 whereas the tree ring was narrow in the pointer years 1797, 1805, 1836, 1842, 1870, 1891, 1999, 1984 and 1999. From 1846 onward the growth pattern of tree rings were fluctuating .

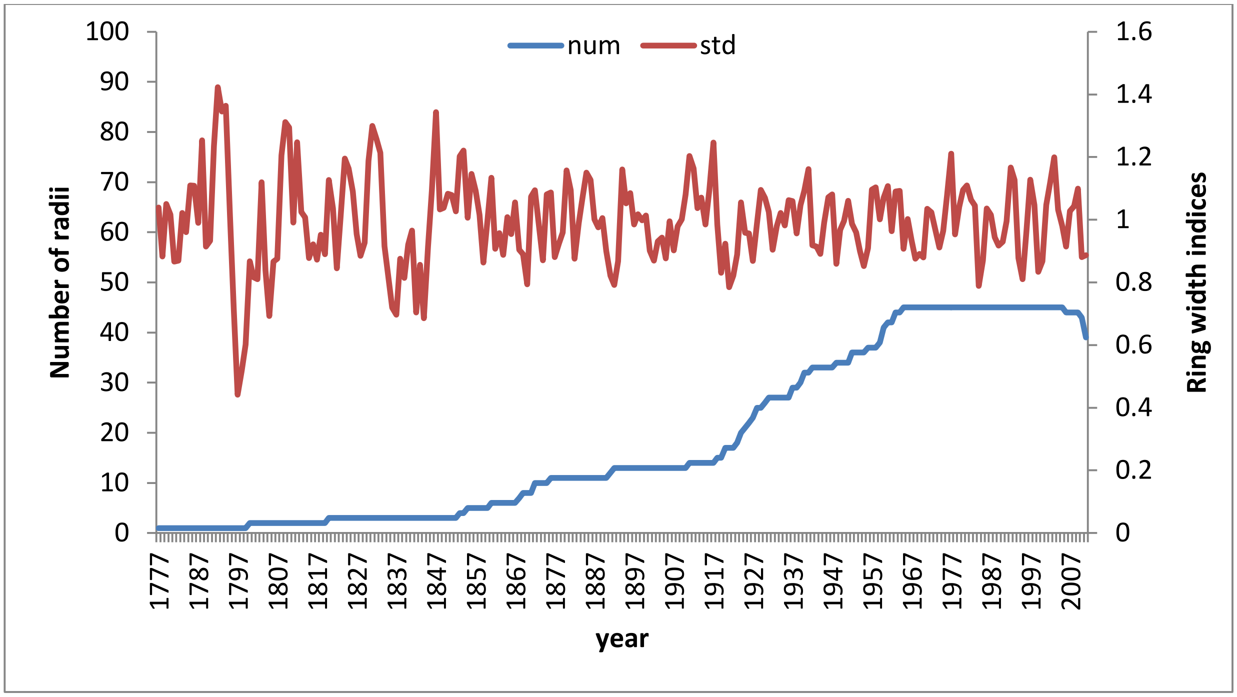


Figure: 4.5：Tree ring chronology of *Abies spectabilis.*

The primary axis (left) represents the number of series (samples) whereas the secondary axis (right) represents the annual increment in radius in the form of indices.The mean annual radial growth was 0.993 mm with a standard deviation of 0.141 and a mean sensitivity 0.109. The selected statistics of the site chronology of *Abies spectabilis* are illustrated in the following Table 4.3. The details of the statistics calculated for the site chronology are presented in table 4.3 and discussed below.

The value of mean sensitivity was 0.109 and 0.125 for standard and residual chronology, respectively (Table 4.3).Standard deviation for standard and the residual chronology were 0.141 and 0.116 respectively (Table 4.3).In the present chronology the value of first order autocorrelation in standard chronology was 0.542 and the autocorrelation for residual chronology decreased to 0.124 after applying AR modeling (Table 4.3). The statistics of common period (1950-2010) for both the standard and the residual chronology includes mean series correlation (among all radii, between tree and within tree), signal to noise ratio, expressed population signal and percentage of variance explained by first eigenvector. The values of mean correlation within tree in both standard and residual chronology were high (0.750and 0.628 respectively) as compare to mean correlation between tree and among all radii (Table 4.3).

The EPS value of 0.85 (i.e., 85%) is suggested as threshold limit (Wigley *et. al.* 1984) and it exceeds here in both standard and residual chronology (0.906 and 0.892 respectively) (Table 4.3). The EPS threshold value in the standard chronology was reached with sample size of 19. Both the residual and standard chronologies of ring width constructed since early 1777 satisfied the minimum threshold value of EPS. Signal to noise ratio in standard chronology is 9.672. The value of residual chronology is (8.287) (Table 4.3).

Table 4.3: Tree-ring chronology statistics of *Abies spectabilis*

Chronology statistics	**Standard**	**Residual**
Chronology period (Years)	1777-2011	1777-2011
Numbers of trees	90	90
Number of radii	45	45
Mean index	0.993	0.996
Standard deviation	0.141	0.116
Mean sensitivity	0.109	0.125
Serial correlation	0.542	0.124
1st lag auto correlation	1	2
Common period (1950-2010) parameters		
Numbers of trees	30	30
Number of radii	32	32
Correlation between trees	0.230	0.204
Correlation within trees	0.750	0.628
Expressed population signal (EPS)	0.906	0.892
Effective number of cores(Ceff)	1.304	1.304
Effective chronology signal (reff)	0.244	0.223
Signal to noise ratio (snr)	9.672	8.287
Minimum sample size for the EPS 85%	19	13

4.4 Climate and tree growth relationship

The correlation analysis showed that radial growth of tree ring was statistically significant and negatively correlated with mean maximum temperatures for May (r = 0.544, P < 0.01) and March (r = 0.396, P < 0.05) of current year. A significant and negative correlation was found with mean temperature during May (r = 0.431, P<0.05). But the precipitation data does not shows significant relationship. The result showed that the radial growth of *Abies spectabilis* in this region is mainly affected by temperature. Due to low correlation between climatic data and site chronology, the climatic reconstruction was not proceeded.

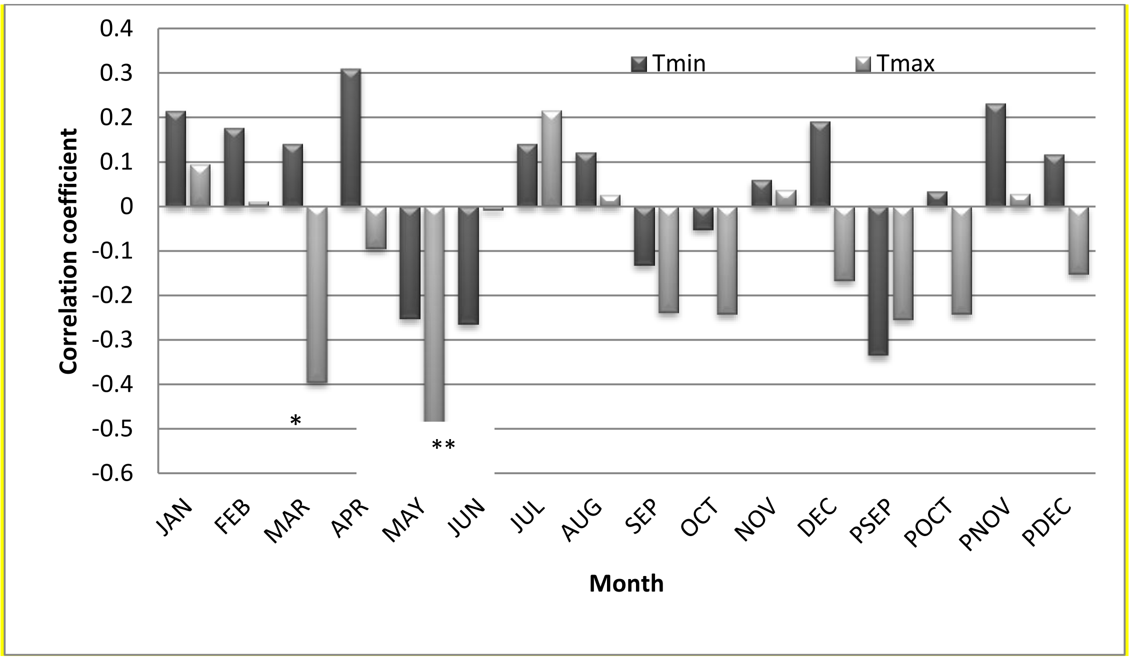


Figure 4.6: Correlation between standard chronology and monthly minimum and maximum temperature. Note: ** Significant at p<0.01, * Significant at p<0.05. The months with 'P' represents the months of previous years, for e.g. PSEP = Previous September……, JAN: January, FEB: February………DEC: December).

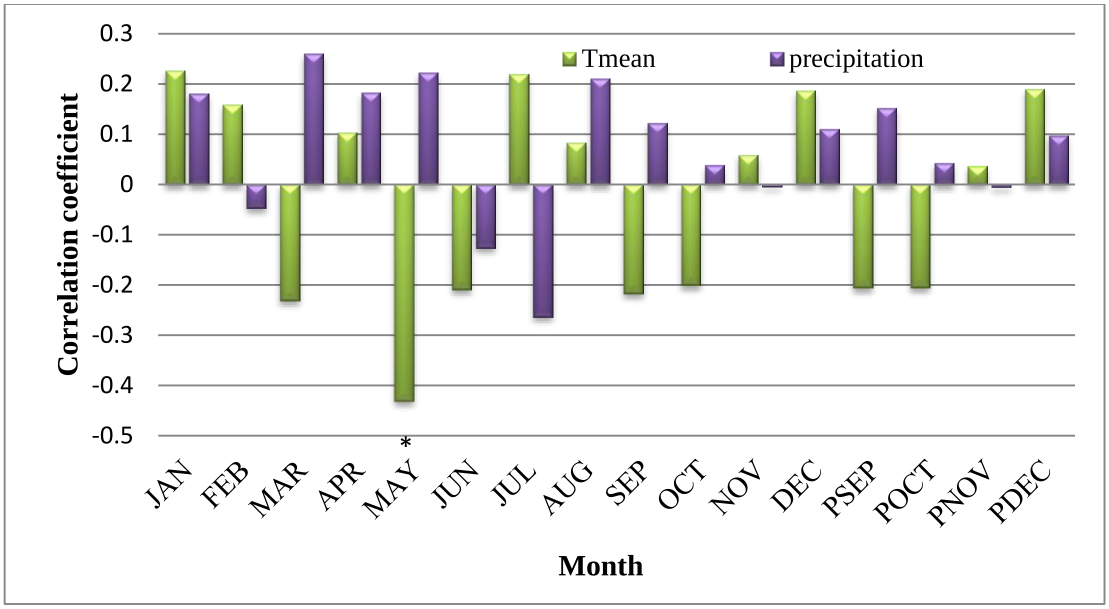


Figure 4.7: Correlation between standard chronology and monthly mean temperature and precipitation.

5. DISCUSSION

5.1 Age- DBH relationship

The correlation between age and DBH of trees was positive and statistically significant (n=37, r = 0.878, P <0.0001 (Figure 4.3). Many studies have demonstrated considerable increases in tree-line population density during the 20th century in both high latitude and high-elevation sites in the Northern Hemisphere (Camarero & Gutierrez 2004, Esper & Schweingruber 2004, Kullman 2007). The synchronous recruitment trends at the tree line sites suggest that regeneration of *A. spectabilis* has been caused by a common external factor such as climate. The most severe restriction for tree enrollment at tree lines tends to be seed production, seedling emergence and survival (Korner 2003). Kullman (2007) found a strong and positive link between winter temperatures and survival rates of *Pinus sylvestris at* tree line populations in the Swedish Scandes.

5.2 Tree ring chronology

The tree ring chronology of *Abies spectabilis* developed in the present study was extended back to 1777 (235 years) (Figure 4.5). The length of core was limited by the small size of the corer (12 inch). However, in Nepal longer chronologies from *A. spectabilis* have been developed by various researchers; from 1700-1980 by Bhattacharya (1992); from 1395-1997 by Cook *et al*. (2003); from 1717-2000 by Sano *et al. (*2005) etc. Since we sampled only at tree line ecotone, there could be older trees spanning longer age in the middle and lower part of the forest.

The statistical analysis of standard chronologies from the *Abies spectabilis* at tree line revealed relatively low mean sensitivity (<0.2), low standard deviation values (0.2) but high first order autocorrelation values (>0.5). The value of mean sensitivity ranges from Zero (0) to two (2) whereas the lower mean sensitivity indicates lowest variance of frequency (Fritts 1976). The Expressed Population Signal (EPS) was clearly above the 0.85 threshold (Wigley *et al*. 1984) in the site chronologies since 1892s. Hence, the high value of EPS confirmed that the chronologies developed for *A. spectabilis* in the study site showed a common signal and were thus generally suitable for studying climate growth relationships.

Table 5.2: Comparison of chronology statistics of *Abies* species in the Himalaya (Cook *et al.* 2003, Chhetri 2010, Dhakal 2009, Gaire *et al*. 2011, Udas 2009).

Location	Mean sensitivity	Standard deviation	Autocorrelation
Lete	0.195	0.278	0.634
Marshyangdi Khola	0.18	0.2	0.4
Ghorepani	0.2	0.26	0.56
Pisang	0.13	0.18	0.55
Chandanbari	0.084	0.105	0.31
Gurchie lekh	0.10	0.17	0.70
Humla district	0.09	0.13	0.62
Present study(Dolpa)	0.109	0.141	0.542
Kalingchowk	0.12	0.21	0.65
Gonga Danda	0.16	0.2	0.44
Laurivinayak	0.086	0.105	0.310
Cholangpati	0.223	1.39	0.828

Udas (2009) developed chronology of *Abies spectabilies* of 107 years and 149 years at forest site and tree line site of Mustang with 46 series (26 trees). That study found mean sensitivity at forest site and tree line site as 0.191 and 0.195, respectively which is similar to the present study. On the other hand, Gaire *et al*. (2011) reported 218 years long chronology with mean sensitivity of 0.084. A study of *Abies spectabilis* at Humla district, (Sano *et al.* 2005) revealed that the value of mean sensitivity and standard deviations were low whereas the value of autocorrelation and EPS were high. Thus, the chronology statistic results of *Abies spectabilis* in the present study site were found to be consistence with other dendroclimatic studies done in the western and central part of the country. But the correlation value at Cholangpati shows quite unusual. Cook et al. (2003) reported 603 years long chronology of *Abies spectabilis* at Deorali which is probably a longest chronology from Nepal.

One or more environmental factors are strong enough to cause the ring widths to vary in the same way (Fritts 1976, 2001); therefore, it was evident that the presence of strong common signals at tree line and forest sites might largely be due to climate (e.g. temperature and precipitation). Smaller scale responses of tree ring widths might be due to high competition and other tree species present in the study area therefore, it lowers the EPS rates.

Generally, human disturbances and other natural calamities which vary from site to site may dilute the macro climatic signal, which is common to the present study site such as grazing, firewood and forest product collection and selective logging etc. Trees at dry sites usually show higher inter annual growth variability than the trees from temperature limited sites (Fritts 1976, Braeuning 2001). But this is a typical for conifers which are growing in humid environments (Fan *et al.* 2009). In subalpine temperate region, conifers have low mean sensitivity under mesic climatic conditions rather than in arid sites (Bhattacharya and Chaudhary 2003).

The chronology which has a low autocorrelation, a high mean sensitivity and a high standard deviation has been considered suitable for dendroclimatic analysis (Fritts 1976). Multi-site chronologies will help in developing robust climatic reconstructions and such long-term climate records reconstructed from tree-ring would provide records insight into the understanding of the long-term glacier dynamics and estimate the impact and magnitude of anthropogenic warming on glacier fluctuation (Singh and Yadav 2000). Likewise, Bhattacharya and Yadav (1996) developed chronology of *Pinus wallichiana* tree ranging from 1621 to 1990 to study glacial behavior in the western Himalaya and concluded that these tree growing in the subalpine Himalayan regions would be an excellent candidate for the tree ring study to understand past glacier behavior in the region. Thus, the northeast facing slope in the present study site could have a well-balanced supply of moisture. Such low values of mean sensitivity have been reported from trees growing in the western Himalaya (Borgaonkar *et al*. 1996, Bhattacharya *et al*. 1998) and the central Himalaya (Bhattacharya *et al.* 1992). Similarly, the high value of first order autocorrelation in the site chronologies revealed that the tree ring widths of the previous year had influence on tree ring widths of the current year. The high autocorrelation values reflected significant impact of previous year's climate on the current year's ring width, which could be due to carry-over effects of carbohydrates used for early wood formation (Fritts 1976). The serial correlation values for the site chronologies were also high (> 0.5) revealing a strong persistence from one year to the next.

In the present study there was no clear increasing tree growth in the recent years. However, the higher growth in the high altitude tree-ring chronologies has been observed during the past few decades in the other region of Himalaya which is strongly associated with the increasing temperature pattern over the region (Borgaonkar *et al*. 2011). Similarly the increasing trend in temperature was also observed over the entire Indian region (Kothawale and Rupa Kumar 2005).

5.3 Relationship between tree ring and climatic variables

Correlation coefficients indicated that tree rings widths of *Abies spectabilis* were negatively correlated and controlled by previous year's late monsoon (September) and current year's pre-monsoon (March–May) temperature. The summer months in the study area starts from March and reach its peak at July then ends in September. Thus hot summer months and monsoon rainfall periods coincides with each other. During the pre-monsoon season, the precipitation is low and it coincides with the early growing season of the Himalayan conifers (Borgaonkar *et al*. 1996, 1999). Due to high temperatures and low precipitation during pre-monsoon periods, it accelerates evaporation and evapo-transpiration resulting in moisture stress condition for tree growth even in mesic sites (Bhattacharya and Chaudhary 2003). Similar results has been also shown by Sano *et al*. (2005) and Suzuki (1990) in their studies from western Nepal and Gaire *et al*. (2011) from central Nepal. This relationship suggests that moisture availability during pre-monsoon limits tree growth of this site. The cool and wet conditions during these months recharge the soil moisture, from which trees can take benefit for the next growing season.

Tree growth is influenced in one way or another by the climate of growing season, i.e., of March to September, but not by that of winter. More specifically, the ring width is influenced by the climate of only pre-monsoon seasons. Tree-ring width is controlled by pre-monsoon climate which was correlated negatively with temperature and positively with precipitation also observed by Sano *et al* (2005). Thus, reduced water availability during the beginning of growing season is restrictive for tree growth. Some reports mentioned that the rainfall pattern during the monsoon season in Southeast Asia is shifting and the peak of July rain has been shifted to August.

Therefore, it can be presumed that the early monsoon brings only little rain prolonging the moisture stress conditions until July and inversely affecting tree growth even in the early monsoon season.Temperature plays an important role during the growing season and low temperature can hamper tree growth due to reduced photosynthesis and thereby inhibiting regular physiological processes (Udas 2009). But sudden increase in temperature for a short period favours respiration over photosynthesis. As a result, there is loss of stored food. Therefore, this reasons seemed to be more supporting that the precipitation in the present study site has insignificant correlation with tree growth. While the temperature rises sharply from March through May, the rainfall lags behind by some months causing water deficit and suppressing tree growth. Similar response of ring width was also found in several coniferous species from the Indian Himalayans farther west (Borgaonkar *et al*. 1996, 1999, 2011). During March, temperature reaches fairly high for photosynthesis and the moisture induces rapid growth. The precipitation does not show significant relation on the growth of *Abies spectabilis* in the study area. As precipitation fluctuate sharply between different areas, the insignificant relationship might due to variation in precipitation data. The inverse relationship of tree–ring width with May temperature might be due to lower net photosynthetic rate, resulted from the water stress. During this month, precipitation is almost negligible but temperature is at its maximum level. Hence, it appears that the pre-monsoon temperature has a vital role in the growth of coniferous of this region.

A study carried out by Udas (2009) in Mustang on *Abies spectabilis* showed negative correlation with previous year December temperature and current year April-May-June temperatures in tree line whereas Fan *et al*. (2009) found that Abies *spectabilis* chronologies at high elevation of Hengduan Mountains in South West China were positively correlated with early winter temperatures (November-December) which is contradictory to the present study. If the trees ceased their annual growth prematurely, then the surplus photosynthate could be stored for immediate growth at the start of the next growing season (Henderson and Grissino-Mayer 2009).

Few studies in the Himalayan areas shown that tree growth is limited by moisture availability in the pre-monsoon season and can show negative relationship with temperature and positive with precipitation (Borgaonkar *et al*. 1996, 1999, 2011, and Sano *et al*. 2005). The correlation between tree ring width of *Abies spectabilis* is negatively significant with pre monsoon temperature (Suzuki 1990, Khanal and Rijal 2002, Sano *et al*. 2005, but the growth response of *Abies densa* in the eastern Himalaya, Arunachal Pradesh of India, revealed negative correlation with previous year's August-October and current year's July-September temperature; but positive correlation with current March-May temperature (Chaudhary *et al*. 1999, Bhattacharya and Chaudhary 2003).

6. CONCLUSION AND RECOMMENDATION

A 235 year tree ring chronology dating back to 1777 A.D was developed for *Abies spectabilis* at Dolpo District, Nepal. The present study of *Abies spectabilis's* tree ring and climatic relationship indicates that this species is suitable for dendroclimatic study due to its clear and datable tree-ring sequences and synchronistic growth pattern. The response function analysis revealed that the pre- monsoon temperature plays an important role in growth of the *Abies spectabilis* in this study site. The mean maximum temperature of May and March of the current year shows a significant negative relation with tree growth patterns. The precipitation of that region shows an insignificant relationship with tree growth. This could be due to the fact that higher temperatures have high desiccating effects on soil, and as a result increased evapo – transpiration makes a moisture deficiency in the coming growing seasons. Temperature also increases the activity of cells and cellular respiration which might cause the loss of the reserve food materials necessary to persuade fast growth.

However, the tree cores collected from Majhphal VDC of Dolpa district cannot be a complete representation for the whole Dolpa district although the area is relatively semi-arid. Therefore, further studies should be carried out at Dolpa district to understand the climate-growth relationship. In addition to that, more samples from older trees at different altitudinal ranges should be used to improve the strength of the response function and correlation. Therefore, long –term chronology at a regional scale with crucial statistic data is required for a better understanding of the current status of climate change. Similarly, contineous climatic data should be kept by Department of hydrology and Meteorology (DHM) for a reliable interpretation of climate change.

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ANNEXES 1- Information on sample site

PLOT	Latitude	Longitude	Elevation	Slope	Aspect
T1Q1	28.88828	82.79322	3728	32	E
T1Q2	28.88661	82.79109	3688	41	NE
T1Q3	28.88663	82.79256	3660	19	NE
T2Q1	28.89052	82.79012	3650	40	NE
T2Q3	28.89043	82.79082	3592	36	NE
T2Q2	28.89034	82.79169	3612	29	NE
T3Q3	28.889	82.7923	3618	55	E
T3Q2	28.88999	82.79262	3658	43	NE
T3Q1	28.89023	82.793	3689	53	E

ANNEX 2 - Some photo plates

2008/01/07 03:57


2008/01/07 23:47


2008/01/08 00:23


THE NORTH FACE
2008/01/08 03:21