Shift Assessment of Upper Tree Species Limit and Tree Line Recruitments in Manaslu Area, Nepal

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requirements for M.Sc. in Environment Science

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Declaration

I hereby declare that this M.Sc. dissertation entitled **"Shift Assessment of Upper Tree Species Limit and Tree Line Recruitments in Manaslu Area, Nepal"** is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged.

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Letter of Recommendation

This is to certify that Mr. Rabin Shakya has prepared and completed this dissertation work entitled **Shift Assessment of Upper Tree Species Limit and Tree Line Recruitments in Manaslu Area, Nepal** for partial fulfillment of the requirement for the completion of Master's Degree in Environmental Science and has worked sufficiently well under my supervision and guidance.

This dissertation work contains his original work and fulfills the requirements of Golden Gate International College, Tribhuvan University, Nepal. To the best of my knowledge, this dissertation work has not been submitted for any other degree. I recommend this dissertation to be accepted for the partial fulfillment of Master Degrees in Environmental Science from Tribhuvan University, Nepal.

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Letter of Approval

This dissertation paper submitted by Mr. Rabin Shakya entitled **"Shift Assessment of Upper Tree Species Limit and Tree Line Recruitments in Manaslu Area, Nepal "** has been accepted for a partial fulfillment of M.Sc. in Environmental Science.

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Rabin Shakya

Abstract

The upper species limit shift of *Abies spectabilis* and its tree line dynamics under climatic stress was studied in *A. spectabilis* forest of Lho village in Manaslu Conservation Area, central Nepal. The census of *A. spectabilis* was carried by belt transect laid covering tree line as well as tree species limit and the sample belt was located by purposive sampling method. Total number of tree individuals, basal diameter, diameter at breast height (DBH), and crown diameter, number of seedlings and saplings of *A. spectabilis* were recorded. Tree age was estimated by tree-ring counts and the count of branch whorls and bud scars in sapling and seedlings. Two LANDSAT MSS imageries of year 1976 and 2001 were used to delineate the change in vegetation. The area of interest of altitudinal belt of 3,700m to 4,200m was generated and the vegetation change was analyzed. The analysis of the precipitation and temperature data of 30 years (1971-2010) showed that there was an increase of mean temperature by 0.10^{o}C per year and decrease in precipitation by 1.777mm per year. The establishment of the species in the study area was dated back to 1900. Total 76 individuals of tree, 112 saplings and 77 seedlings were recorded. The recruitment of *A. spectabilis* was positively correlated with mean annual temperature ($r = 0.35$, $P = 0.04$) and negatively correlated with mean annual precipitation ($r = -0.36$, $P<0.5$). Between the periods of 1900 and 2012 *A. spectabilis* upper limit has shifted at a rate of 10.8m/year with the upslope shifting of 110m with 1911 tree line reference. Similarly, the NDVI analysis of the Landsat images has shown 9.06sq.km of non-vegetated area in 1976 have turned to vegetated area in 2001.

Key words: *Abies spectabilis,* tree line, climate change, upper species limit, tree line, remote sensing, belt transect

Abbreviations and Acronyms

A. spectabilis	*Abies spectabilis*
asl	Above sea level
ARVI	Atmospherically Resistant Vegetation Index
DBH	Diameter at breast height
DHM	Department of Hydrology and Meteorology
CO_2	Carbon dioxide
^oC	Degree centigrade
Fig	Figure
GEMI	Global Environment Monitoring Index
IITM	Indian Institute of Tropical Meteorology
IPCC	Intergovernmental Panel on Climate Change
m	meter
MCA	Manaslu Conservation Area
MSS	Multispectral scanner
NDVI	Normalized Difference Vegetation Index
NRVI	Normalized Ratio Vegetation Index
PC	Personal computer
SAVI	Soil Adjusted Vegetation Index
spp.	Species
QTP	Qinghai-Tibet Plateau
TM	Thematic mapper
VDC	Village Development Committee

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Chapter I

1. Introduction

1.1 Background

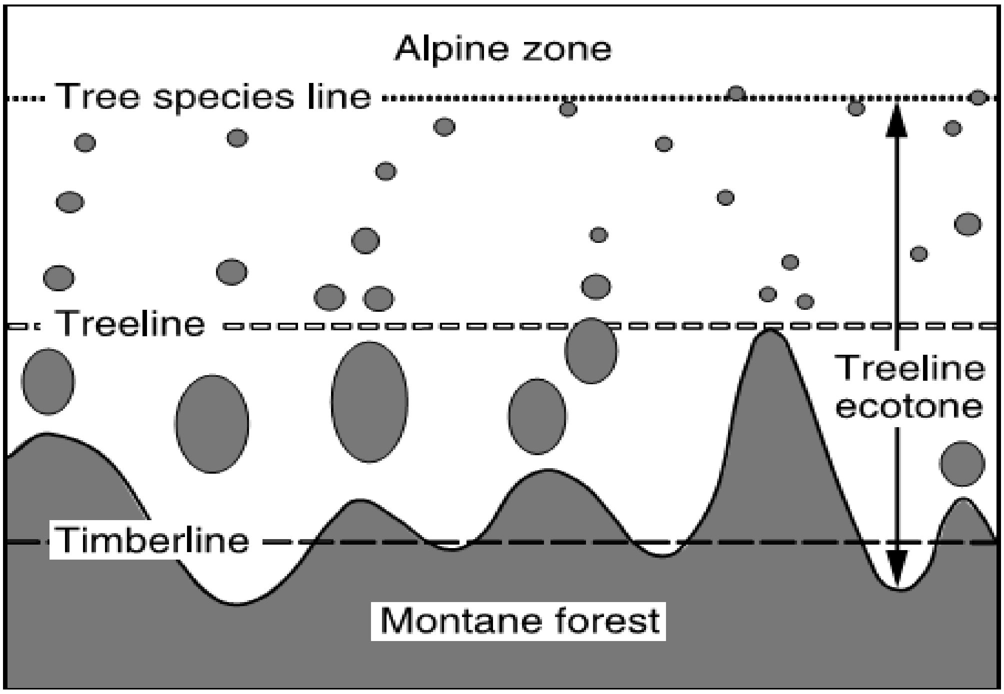
Global warming has been a widely discussed and studied topic in last decade. Among the study results, one of the most widely cited report is from the Inter-Governmental Panel on Climate Change (IPCC). According to IPCC Fifth Assessment Report (2013), the CO_2 has exceeded by 40% since the pre-industrial level; which has contributed average warming of earth by 0.85^{o}C since the beginning of the 20th century. The period 2001-2010 was the hottest decade on record (IPCC, 2013). In Europe's mainland temperature rise of about 1^{o}C since the 1980s is considerably larger than expected from anthropogenic greenhouse warming (Philipona et al., 2009). There is varying increase in average temperature over Hindu-Kush Himalayan region for the past 25 years showing least (0.01^{o}C per year) at Western Himalaya to highest (0.07^{o}C per year) for Tibet (Kulkarni et al., 2013) . The annual mean temperature in Nepal is increasing steadily at linear rate of about 0.039^{o}C per year for the period from 1975 to 2006 (Shrestha, 2008). The climate change that is a result of global warming has wide range of effects, one of which is on vegetation.

Evidence for world-wide ecological responses to recent climate change is supported by an ever increasing number of ecological 'fingerprints' and while plants in particular, may respond to the recent period of warmer climatic conditions by either adapting their life cycles or shifting their ranges to suitable habitats (Walther et al., 2005). Most likely the response of plants to recent warming are remarkably visible in the high mountain (Vijayaprakash and Ansari, 2009). In regard, to high elevation ecosystems of Himalayan region are the most vulnerable geographic regions besides the polar region to climate change (Tiwari, 2010). Subalpine forest represents the uppermost forest ecosystems along the elevation gradient in ecosystems. Alpine ecotones are excellent indicator of past and recent changes and considered to be sensitive to the effects of future global changes because growth and recruitment in these ecotones are mainly controlled by climate (Camarero and Gutierrez, 1999) coupled with local geographical and anthropogenic factors.

Most of the recent climate change response studies are focused on tree line (Roush, 2009, Szerencsits, 2012, Tiwari, 2010, Walther et al., 2005) a transition zone between subalpine and alpine vegetation zone as it assumes to depict the effect of vegetation response to climatic stress more than any other ecosystem (Korner, 1999, Kupfer and Cairns, 1996). In this research work, the upper species limit shifts under climatic stress in Himalaya from Manaslu Conservation Area, central Nepal, have been studied.

Climate, more than any other factor, controls the broad-scale distributions of plant species and vegetation. In general, temperature is the influencing predictor variable of tree line formation and maintenance (Harsch et al., 2009) as well as the species line determination (Korner, 2003). The above statement is valid for current environmental settings; while past climatic condition also influence on present day tree line or species line position (Singh et al., 2012) in a landscape level. Moving on to the finer scales, the local environmental conditions including microclimate, edaphic factors (soil, pH, water-holding capacity, nutrient content) and topographic factors (aspect, slope) has control over seedling establishment and growth resulting to effect on tree line position or species line position (Holtmeier, 2009).

The high altitude limit of forests, commonly referred to as tree line, timberline or forest line represents one of the most conspicuous vegetation boundaries (Holtmeier, 2009, Korner and Pualsen, 2004, Kullman, 1998). In reality the transition from uppermost closed montane forests to the treeless alpine vegetation is commonly not a line, but a steep gradient of increasing stand fragmentation and stuntedness, often called the tree line ecotone (Korner and Pualsen, 2004). In view of the great physiognomic variety and heterogeneity of mountain tree line, the tree line species also vary. In Northern America tree line species is characterized by the species like *Abies lasiocarpa, Larix lyallii, Picea engelmannii, Pinus albicaulis, Pinus longeaeva*, etc. Similarly, in South America it is *Nothofagus aantarctica*, *Nothofagus pumulio, Polylepsis tarapacana*, etc. In Europe, tree line species includes *Betula pubescens*, *Pinus sylvestris, Picea abies, Picea obovata, Larix sibirica*, etc. where as in Eurasia it is dominated by *Larix gamelinii, Pinus peuce, Pinus* *cembra, Pinus mugo* and *Betula pubescens*. In Northern Asia, the dominant species at tree line includes *Larix sibirica, Larix dahurica, Pinus sibirica, Pinus, pumula*, etc. In Nepal, dominant tree line species includes *Abies spectabilis, Betula utilis, Larix griffithiana,* etc.

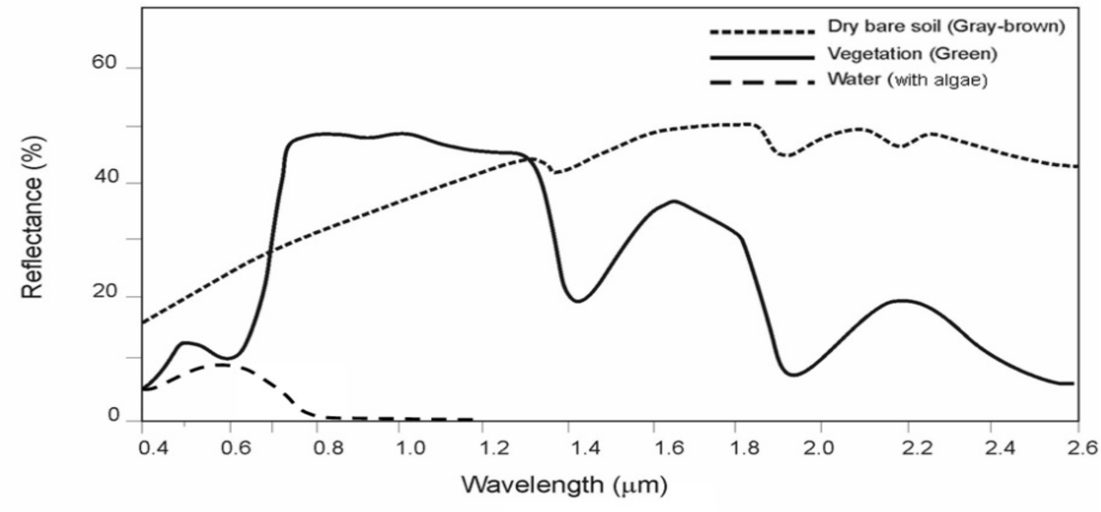


(Source: Korner and Paulsen, 2004)

Figure 1: A schematic representation of the high altitude tree line

Many studies around the tree line have focused on the effects of climate change response to temperature on the higher altitude regions (Pauli et al., 2003, Roush, 2009, Vijayaprakash and Ansari, 2009, Zhang et al., 2009). Tree line ecotone are at the physiological threshold between viability and non-viability of tree life form, and they are extremely sensitive to climate change in both arctic and alpine areas (Kittel et al., 2000). Natural tree line ecotones are sensitive biomonitors of past and recent climate change and variability (Kullman, 1998), and are well-suited for monitoring climate change impact (Becker et al., 2007). Previous tree line studies have typically been conducted at local or landscape scales (Holtmeier and Broll, 2007). The reality for tree line research is that historical data recorded over a long period are very rare, especially in alpine areas (Zhang et al., 2009). This started discussion on the use of remote sensing images and its techniques. For over two decades, the detection and monitoring of vegetation change using satellite multispectral image data has been a topic of interest in remote sensing. The use of remotely sensed data gives more widespread and systematic sampling, enabling firmer conclusions about changes to tree line forests (Zhang et al., 2009) provided that they are of good resolution.

Spectral vegetation index is normally used in monitoring vegetation density (Zhang et al., 2009). Green vegetation has a very distinctive interaction with energy in the visible and near-infrared regions of the electromagnetic spectrum. In the visible regions, plant pigments (most notably chlorophyll) cause strong absorption of energy, primarily for the purpose of photosynthesis. This absorption peaks in the red and blue areas of the visible spectrum, thus leading to the characteristic green appearance of most leaves (Thiam and Eastman, 2001). The near-infrared radiation, is not used in photosynthesis, and it is strongly scattered by the internal structure of most leaves, leading to a very high apparent reflectance in the near-infrared (Thiam and Eastman, 2001).



Source: (Baker et al., 2009)

Figure 2: Reflectance curve for different land cover types

Owing to this strong contrast, most particularly between the amount of reflected energy in the red and near-infrared regions of the electromagnetic spectrum, large variety of quantitative indices of vegetation condition using remotely sensed imagery has been developed. Major includes Simple Ratio, Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Normalized Ratio Vegetation Index (NRVI), Atmospherically Resistant Vegetation Index (ARVI), Global Environmental Monitoring Index (GEMI) , and green NDVI (Thiam and Eastman, 2001, Zhang et al., 2009). Among them NDVI is widely used, as NDVI has good correlation with canopy cover and leaf area index, better performance than single band or combined use of other bands in estimating crown closure, advantage of quantifying continuous changes to vegetation within each pixel and distinguish between bare ground areas and partially forested areas, or densely forested areas (Harsch et al., 2009, Singh et al., 2011). It has been broadly used in estimating tree productivity (Wang, 2004), species richness (Parviainen et al., 2010), environmental quality (Fung, 2000), phenological pattern (Lee et al., 2002), etc.

1.2 Statement of Problem

The climate change has now been scientifically validated and its footprints have been documented from most of the regions of the world. High elevation ecosystems of Himalayan region are one of the most vulnerable geographic regions of the world and are important regions for detecting the patterns of climatic change on regional scale (Xu et al., 2009). Under projected global warming scenarios, alpine tree line dynamics, as a core aspect of mountain landscape transformation, is a key subject in detecting climate-dependent ecological processes (Zhang et al., 2009, Kullman, 2007) and also the impact of climate change are more or less distinct on high mountainous ecosystem where tree lines are assumed to be sensitive to changes in the climate and thus useful as indicators of climate change (Dalen and Hofgaard, 2005, Grace et al., 2002). Alpine tree line can therefore be castoff to apprehend the response of alpine vegetation as a result of changing climatic conditions.

Some handful of studies made from Nepal Himalaya to have illustrated the impact of recent climate change (Bhattacharyya et al., 1992, Bhuju et al., 2010, Cook et al., 2003, Gaire et al., 2011, Sano et al., 2005), still the science need more research on this field. Similarly, more studies are needed to understand the response of tree line species limit like *A. spectabilis* due to changing climatic parameters. Some initiatives have been carried out to document the tree line dynamics in the high altitudes of Manaslu (Gaire et al., 2013b, Suwal, 2010); however, there is no such scientific attempt to check the vegetation dynamics using RS images in Manaslu. Field surveys accompanied by remote sensing images and techniques can serve as complimentary tools to verify the climatic stress on vegetation dynamics. Therefore, this study in the Manaslu Conservation Area pertaining to *A. spectabilis* would be important to understand upper tree line species limit change in response to climatic stress and detecting change of forests in past four decades using NDVI of multispectral remote sensing data in the study area.

1.3 Research Questions

The study aims to answer the following research questions:

- Is there any change in upper species limit of *A. spectabilis*? What is the rate of change?
- Does climatic stress results the change in NDVI value in the area? What is the rate?

1.4 Objectives

The general objective of the research was to study response of species limit and tree line ecotone in recent climatic stress. The specific objectives of the study are:

- To study tree line dynamics in Manaslu Conservation Area
- To analyze the rate of upward shift of *A. spectabilis* in tree line ecotone, and
- To analyze the change of tree line ecotone by NDVI in Manaslu Conservation Area

Chapter II

2. Literature Review

2.1 Climate and Vegetation

Climate-vegetation interactions are two-way phenomenon. On the one hand, climate determines the structure of vegetation; whereas on the other hand, vegetation exercises effects of climate by converting short wave energy into long wave energy, sensible heat or by driving evapotranspiration (Grace et al., 2002). Over the past three decades most of the researches are focused on analyzing the response of vegetation owing to climatic stress. Therefore, the response of plants to temperature and precipitation are widely studied climatic parameters (Grace et al., 2002, Korner and Pualsen, 2004, Kullman, 2002, Kullman, 2007, Wang et al., 2006, Smith et al., 2003) in response with tree line. The sensitivity and response of northern hemisphere altitudinal and polar tree lines to environmental change are increasingly discussed in terms of climate change, often forgetting that climate is only one aspect of environmental variation (Holtmeier and Broll, 2005). Climate is moreover assumed to control the growth, survival and reproduction in the tree line (Grace et al., 2002). Apart from changes in tree physiognomy, the spontaneous advance of young growth of forest-forming tree species into present treeless areas within the tree line ecotone and beyond the tree limit is considered to be the best indicator of tree line sensitivity to climate (Holtmeier and Broll, 2005). Moreover, inter-annual temperature in highly variable areas, the probability of successive favourable summers that would enhance tree recruitment and trigger tree line advance is unlikely (Camarero and Gutierrez, 2004).

2.2 Climate Change and Tree Line

The high mountain vegetation are generally considered to be more vulnerable to climate change and can be studied as an "ecological indicator" of climate change effects (Pauli et al., 2003) provided that sample are taken from larger area. In montane ecosystems it has been projected that a 1^{o}C increase in mean annual temperature will result in a shift in isotherms about 160 m in elevation or 150 km in latitude. As it is evident to trace the effect of climate change on mountain vegetation the researcher focuses the study in determining the response with respect to tree line. Numerous studies have focused on correlative relationships between tree line altitudes and specific environmental parameters such as mean annual minimum temperatures (Smith et al., 2003). Moreover, the varying topographic site condition, moisture and nutrient condition of soil, wind and after-effects of historical disturbance by natural and anthropogenic factors may also determine the shift in vegetation (Holtmeier and Broll, 2007). The dynamics of tree line basically depends on its colonization by the species in tree line ecotone.

The advance of tree line is highly associated with the colonization of tree forming seedling and sapling growth in treeless areas. The mechanisms involved in the upward migration of tree line to higher altitude or latitude initially depend on new seedling establishment above the existing timberline, into the tree line ecotone. Increased seedling establishment and abundance is followed by even greater facilitation, leading to greater seedling establishment and sapling growth leading to the same sheltering effect that is necessary for the formation of the forest (Smith et al., 2003).

In response to the changing environmental conditions it has been seen that there occurs a progressive replacement of the existing dominant vegetation by a more temperature resistant one. Studies in the European Alps have shown that certain plants have already started responding in changing environmental conditions (Keller et al., 2000). The distribution and population pattern of many of the tree line species are affected by changes in climate and most of these tree line species are on the threshold of their climatic limits. The study of in Bernina area of southeastern Swiss Alps observed the rapid response of alpine vegetation to the conditions in the warmest decade of the 1990s and also confirmed the accelerating trend in the upward shift of alpine plants (Walther et al., 2005). Another study in the Swiss Alps shows a dramatic increase in the growth of *Picea* and *Pinus* at the tree line (Paulsen et al., 2000). In Swedish Scandes the range-margins of *Betula pubescens* ssp. *tortuosa* (mountain birch), *Picea abies* (Norway spruce), *Pinus sylvestris* (Scots pine), *Sorbus aucuparia* (rowan) and *Salix* spp. (willows) have advanced by 120 – 375 m to colonize moderate snow-bed communities since the early 1950s, (Kullman, 2002).

Similarly, another study conducted by Shiyatov et al. (2007), in the Polar Urals, Russia; the upper boundaries of open and closed forests have ascended 26 and 35 m and shifted horizontally 290 and 520 m, respectively between periods of 1910 and 2000 attributing the casual factor to climatic warming (Shiyatov et al., 2007). Furthermore, in northwest Yunnan comparison of repeat photographs taken in 1923 and 2003 indicate tree line rose by 67 m and tree limits rose by 45 m (Baker and Moseley, 2007).

2.3 Climate Change and Associated Vegetation Shift in the Himalaya

The Himalaya cover about 3 percent of the earth surface and are home to 10,000 species of plants, which makes the alpine ecosystem among the most diverse and unique in the world (Korner, 1999 cited in Vijayaprakash and Ansari, 2009). Study by (Yao et al., 2006) shows that, there exists a consistent overall trend in warming over the Himalayan region during the past 100 years. This climatic warming results increase in recruitment or tree-density, as well as upward advances in the vegetation at tree line (Bradley and Jones, 1993, Camarero and Gutierrez, 2004). Tree line in the Himalayan region varies from site to site depending on the position of the snow line. Its location in the western part of the Himalayas is at about 3,600 m. It descends as low as 2,550 m in Gilgit or is as high as 5,000 m at Thalle La in the Karokoram ranges (Singh et al., 2012) . This altitudinal variation in the tree line over the Himalayan shows different responses by tree line vegetation.

Studies in the upper tree line areas of western Himalaya showed that the Himalayan Pine (*Pinus wallichiana*) is sensitive to climate change. Similarly, the study conducted in the upper tree line areas of Gwang kharqa region in Sankhuwasabha district of eastern Nepal observed that *Abies spectabilis* is shifting at a faster rate i.e. 23m per decade in the southern aspect while, it is 17m in ten years in the north aspect because of climate change (Vijayaprakash and Ansari, 2009).

Tree-ring analysis of *Betula utilis*, a broadleaved tree in the central Himalayan tree line, showed correlation of increased tree growth with retreat of glaciers. Upward shift of pine in the Saram, Parabati Valley, Himachal Pradesh (Dubey et al., 2003), and greening and recruitment of tree line in Nanda Devi Biosphere Reserve (NDBR) Central Indian Himalaya based on a study of sapling recruitment pattern at higher altitude slopes have also been reported (Singh et al., 2012). Similarly, the stand character and age distribution of the *Abies spectabilis* showed a high level of recruitment in the recent decades, with decreased in average age along with increased altitude in the study carried out in the Langtang National Park (Gaire et al., 2011).

2.4 Use of NDVI in Vegetation Analysis

Normalized Difference Vegetative Index (NDVI) is widely used spectral index to determine the productivity (Wang, 2004), tree line dynamics (Zhang et al., 2009), greening trends (Xiao and Moddy, 2005), heterogeneity (Parviainen et al., 2010), changing environmental quality (Fung, 2000), etc. of remotely sensed images. Various studies have shown that NDVI are strongly correlated with the precipitation (Xiao and Moddy, 2005, Wang et al., 2001). Estimates of annual production and net carbon dioxide flux are generally assumed to relate directly to NDVI integrated over the growing season (Wang, 2004). NDVI is also used to study changes in the fractional ground cover (Krujis, 2009).

NDVI is use to detect the vegetation changes of a site, landscape, regionally and also globally. The study in the eastern Kansas landscape observed that the NDVI is strongly correlated with tree production (Wang, 2004). Over the past 18 year terrestrial vegetation activity NDVI has increased in most parts of China (81% of the area). The same study has observed that NDVI increase was closely related to increases in temperature on the national scale, while regional variations in NDVI trend were related to variation in precipitation (Shilong et al., 2004). Vegetation greening trends were observed in the northern high latitudes, the northern middle latitudes, and parts of the tropics and subtropics from 1982 to 1998 in conjunction with a gridded global climate dataset at a global scale using satellite-based NDVI (Xiao and Moddy, 2005). Similarly, another global study conducted by Kawabata et al. (2001) found that vegetation activities has been increased in north middle high latitudes due to gradual rise in temperature and in the tropical regions, such as western Africa and south-eastern Asia where increase in NDVI has also been detected (Kawabata et al., 2001).

NDVI is also applied in detecting the altitudinal tree line shift. In Changbai mountain of northeast China, NDVI ratio between the tree line and referenced old-growth forest has increased from 0.9 to 1.2 between the period of 1977 to 1999 indicating that growth of the tree line forest apparently exceeded that of the reference coniferous forest and had grown denser (Zhang et al., 2009). The study of satellite image of Uttarakhand from 1970 to 2006 indicates that there is an upward shift of tree line. The shift of tree line fluctuates in different districts between being minimum at Uttarkashi and Bageshwar (360m) and highest at Chamoli (430m). Similarly, the mean upward shift of tree line in Pithoragarh, Rudraprayag and Tehri Garhwal are 390m, 390m and 400m respectively based on threshold approach of NDVI values (Singh et al., 2012). The another analysis of satellite imagery of vegetation ecotone dynamics in Gangotri catchment reveals that the tree line has moved up about 327±80m and other vegetation line has moved up about 401±77m in three decades with reference to 1976 (Singh et al., 2011).

Chapter III

3. Methodology

3.1 Study Area

The Manaslu Conservation Area (MCA) lies in Gorkha district of central Nepal, about 200km from capital city Kathmandu. MCA is categorized into three geographical areas based upon natural setting and ethnicity i) Nubri Valley in the 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 Chhekampar VDCs. At the lowest altitude in MCA is Sirdibas VDC. The present study site was Lho village which is located at an altitude of 3200m asl. Total households of Lho village is 256 with the total population of 711 (male =320 and female = 391) (CBS, 2011). The study site lies in the south of the village which is north facing slope.

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The study area experiences the sub-alpine zone which may be further divided into an upper zone (3500-4000m) and a lower zone (3000-3500m) (TISC, 2002). As reported by TISC (2000) the mean temperature of the coldest month ranges from -3°C to -6°C and the hottest month July has mean temperatures which ranges from 3°C to 6°C. The frost period varies from six to eight months. The lower sub-alpine zone is little warmer. Mean temperatures of the coldest month ranges from -3°C to 0°C and the frost period is of four to six months.

The major vegetation found at sub-alpine zone are invariably associated with the occurrence of birch (*Betula utilis*) and fir (*Abies spectabilis*). This zone is rich in a number of *Rhododendron* species however, *Rhododendron campanulatum* is consistent throughout. Above 3,000m it is mainly dominated by *Juniperus macropoda* and from an altitude of 3,400m *Abies spectabilis* forms are dominant species vegetation with sub-canopy Rhododendron. According to TISC (2002), a number of forest types characterize this zone which includes Fir-Blue Pine forest, Birch-Rhododendron forest, Fir forest, Larch forest, Fir-Oak Rhododendron forest, Fir-Hemlock-Oak forest and Sub-alpine Mountain Oak Forest.

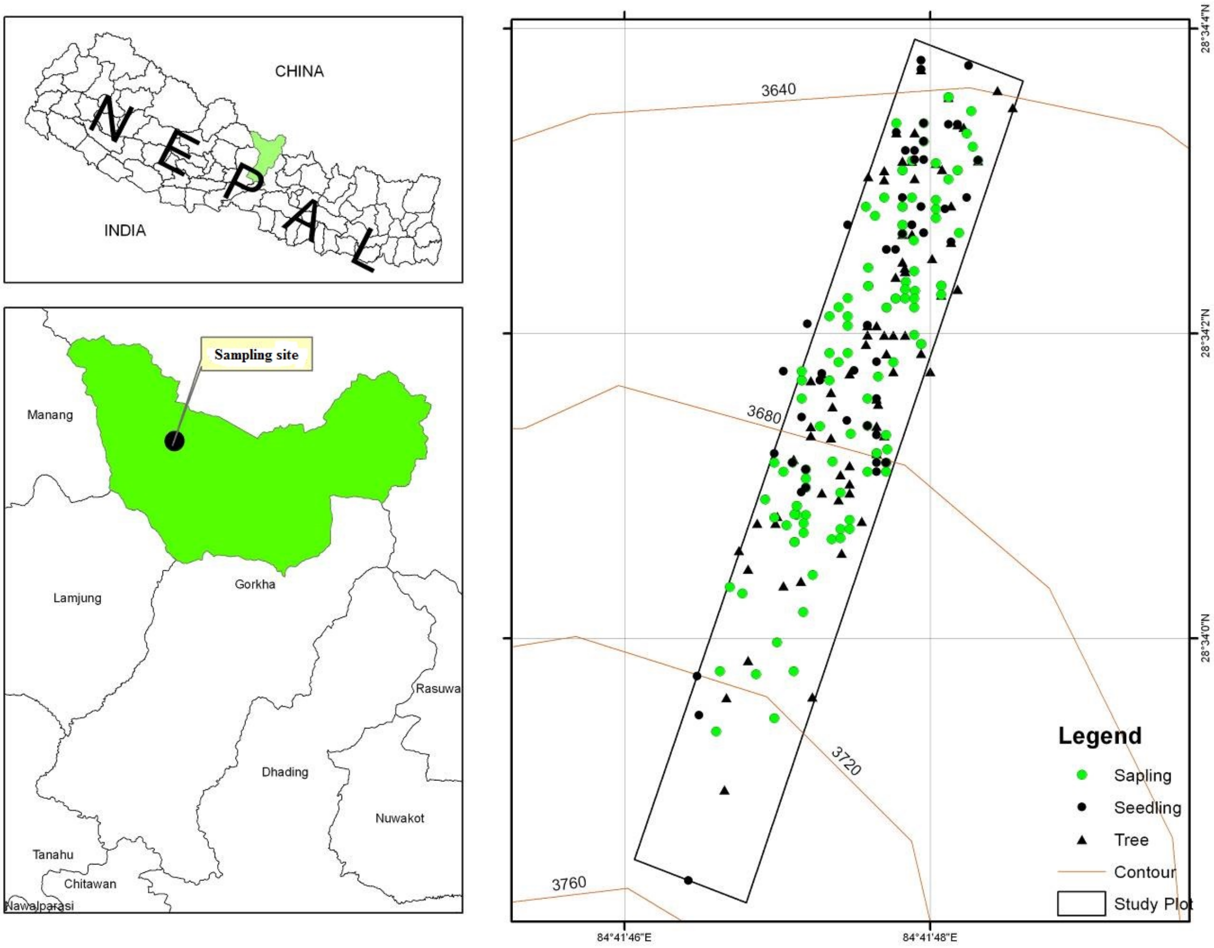


Figure 3 : Map showing study site with enumeration of seedling, sapling and tree

3.2 Research Design

The primary data was collected from Lho village of Manaslu Conservation Area which tends to explore the tree line ecotone dynamics due to climate stress. The data was collected at autumn season using belt transect where DBH, height, crown diameter, tree core and age of seedling and saplings, their location and altitude were recorded.

The secondary data sources included in this study includes the meteorological data obtained from DHM, and satellite imageries downloaded Global Land Cover Facility web site. For the data analysis and interpretation various journal articles, books, thesis, etc. have been thoroughly reviewed. The flow chart of the research design is shown in Figure 4.

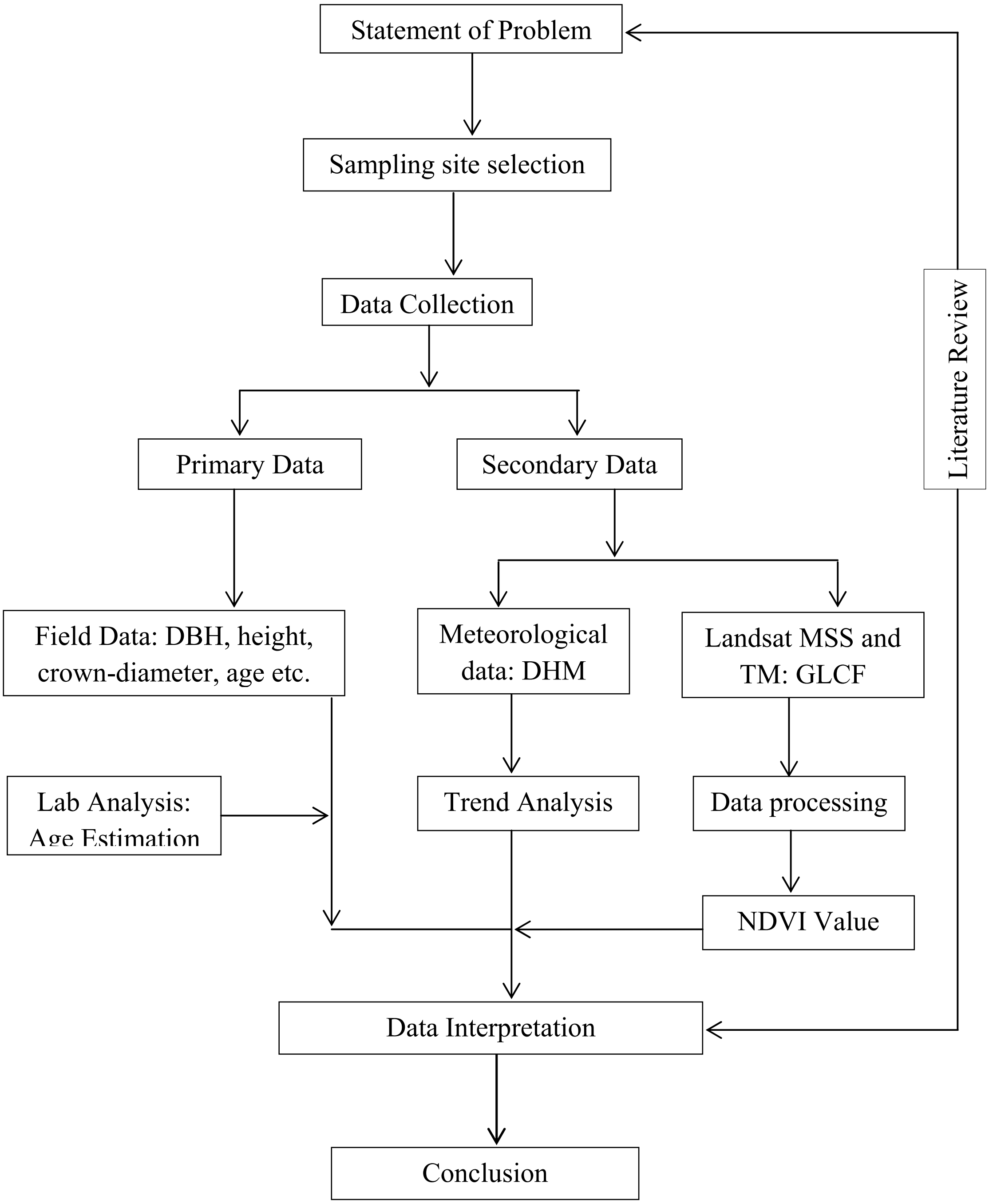


Figure 4: Flow chart of research design

3.3 Methods

3.3.1 Sampling

The study was carried out from 20th - 24th September 2012, at Lho village, Manaslu Conservation Area. The transect walk was carried out at alpine region (upslope) toward tree line (downslope) which was located at 3701m asl, above which no seedling or sapling of *A. spectabilis* was observed. Taking this point as a reference, the vertical walk was carried out till the first individual was found, which was the upper species limit of *A. spectabilis* in that slope. Then sampling was carried out on a belt transect. The transect of length 245m started from the upper limit and came down slope (with 20m width) toward the tree line and further down to the forest of *A. spectabilis.*

On this study, growth stages of *Abies spectabilis* were categorized into three height based classes namely; trees (>2m) (Wang et al., 2006), saplings (0.2-2m) (Baier et al., 2007, Brang et al., 2003) and other as seedlings (<0.2m). Census of tree, seedling and sapling classes of *A. spectabilis* was carried out above and below the tree line in approximation of equal distance to tree line (above and below).

3.3.2 Age of Trees, Saplings and Seedlings

Tree cores of *A. spectabilis* were collected from the sampling plots by using the increment borer (Haglof, Sweden). The increment borer was directed in such a way to retrieve exact pith. Occasionally, when the borer went out of the center, the coring procedure was repeated in order to get the pith. Fifty eight cores out of 76 trees encountered (due to the greater possibility of breaking down of small sized DBH of tree) were bored at the basal height from the ground and GPS (e-Trex 10) record was kept for the references. Collected cores were brought to Nepal Academy of Science and Technology lab and were air dried at room temperature and glued into grooved sticks with the transverse surface facing up. The surface of cores were polished with different grade of sand paper ranging from 120 to 400 grits until optimal surface resolution allowed annual rings to be visible under the microscope. Each ring of the cores was counted and cross dated using skeleton method (Fritts, 1976) and age of a tree was estimated. In addition, the age of seedlings and saplings was determined by counting the number of branch whorls and bud scars on the main stem (Gaire et al., 2011, Wang et al., 2006).

3.3.3 Age Structure and Establishment Analysis

A regression model of tree DBH and age was developed. Altogether 76 sampled trees were used to form the age–DBH regression model at tree line. However, this ageing method, as well as the methodology used to determine the age of seedlings and saplings, may underestimate age by 0–5 years, which can be removed partially by showing the age structure in 5-year classes (Camarero and Gutierrez, 1999). To investigate the relationship between establishment and climate change, recruitment from 1971 to 2010 were summed across 5-year intervals and compared with seasonal climate records compiled into 5-year averages over the same time period (Camarero and Gutierrez, 1999). The climate parameters used in the analyses include mean temperatures and monthly total precipitation.

3.3.4 Stand Structure

To define the stand structure DBH, height and crown diameter of live *A. spectabilis* at the site were measured. DBH was measured with the help of diameter tape at 1.3m above the ground and height was measured by the Sunto clinometer and for the seeding and sapling directly with the help of measuring tape. Crown diameter was calculated by measuring and adding the radii of the crown projection areas in four directions and then by dividing into 2 the value obtained (Avsar, 2004).

3.3.5 Methods to Estimate the Rate of Upward Shift of Vegetation

The species limit advance of *Abies spectabilis* within study area was evaluated by subtraction using the equation given by (Gamache and Payette, 2005, Suwal, 2010). The total shift was divided by the number of years taken to reach the recent position from oldest position by the species and expressed in per decade shift.

$$\text{Rate of Shift} = \frac{\text{Recent position of species - Oldest position of species}}{\text{Number of years taken to reach the recent position}} \times 10 \text{ (m/decade)}$$

(Suwal, 2010, Gamache and Payette, 2005)

The rate of vegetation shift was related with the temperature and precipitation. The increase in temperature over these years was related with the rate of vegetation shift to higher altitudes. The rate of shift was expressed in terms of how many meters the vegetation has shifted during the past 10 years. The temperature rise during the time period was noted which then was related with the rate of shift (Dubey et al., 2003).

3.3.6 NDVI Analysis

The study involves data selection, pre-processing, tree line ecotone delineation, vegetation index calculation; and vegetation area delineation and change analysis. Orthorectified and cloud free (<10%) Landsat MSS imagery of 2001 (UTM/WSG84 projection) was used to delineate the current vegetated area with reference to Landsat-MSS imagery 1976. Landsat MSS image recorded in December 1976 and a TM image recorded in January 2001 were downloaded from the Global Land Cover Facility web site (http://glcf.umiacs.umd.edu/data/). Each pixel of Landsat MSS and TM has a spatial resolution of approximately 79m and 30m respectively (Chander et al., 2009). Thematic mapper (TM) has 7 bands blue-green (band 1), green (band 2), red (band 3), near-infrared (band 4), mid-infrared (bands 5 and 7), and the far-infrared (band 6) in comparison to Multispectral scanner (MSS) that has four bands - green (band 1), red (band 2), and near-infrared (bands 3 and 4) that simultaneously record reflected radiation from the earth's surface in the portions of the electromagnetic spectrum.

A continuous belt between the altitudes of 3700m to 4200m was generated for the study of change in vegetation between the period of 1976 and 2001. The limitation of this study is that only two images could be acquired for this research. Other images taken for the area were not applicable to this study owing to their low quality caused by more percentage of cloud coverage. The NDVI capture the contrast between the visible-red and near-infrared reflectance of vegetation canopies. It is defined as,

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED}) / (\mathrm{NIR} + \mathrm{RED})$$

Where, RED and NIR are the visible-red (0.58-0.68um) and near-infrared (0.725-1.1um) reflectance, respectively. The NDVI is scaled between -1 to +1 and typically varies from -0.2 to 0.1 for snow, inland water bodies, deserts and bare soils and increases from about

0.1 to 0.75 for progressively increasing amounts of vegetation (Xiao and Moddy, 2005). But, for this study NDVI value less than 0 (-1 to 0) is considered to be non-vegetated area and greater than 0 (0 to 1) as vegetated area.

Chapter IV

3. Results

4.1 Local Climatic Trends

Weather data from the Jagat meteorological station showed that the trends of summer (June–September) and winter (December–February) temperatures between 1971 and 2010 were different (Figure 5). The average winter mean temperature showed an average increase at a rate of 0.097°C per year (F=6.912, P<0.05), and average summer mean temperature showed an increase of 0.087°C per year (F=29.55, P<0.0001). The mean temperature also showed the increasing trend of temperature with an average increase of 0.10°C per year.

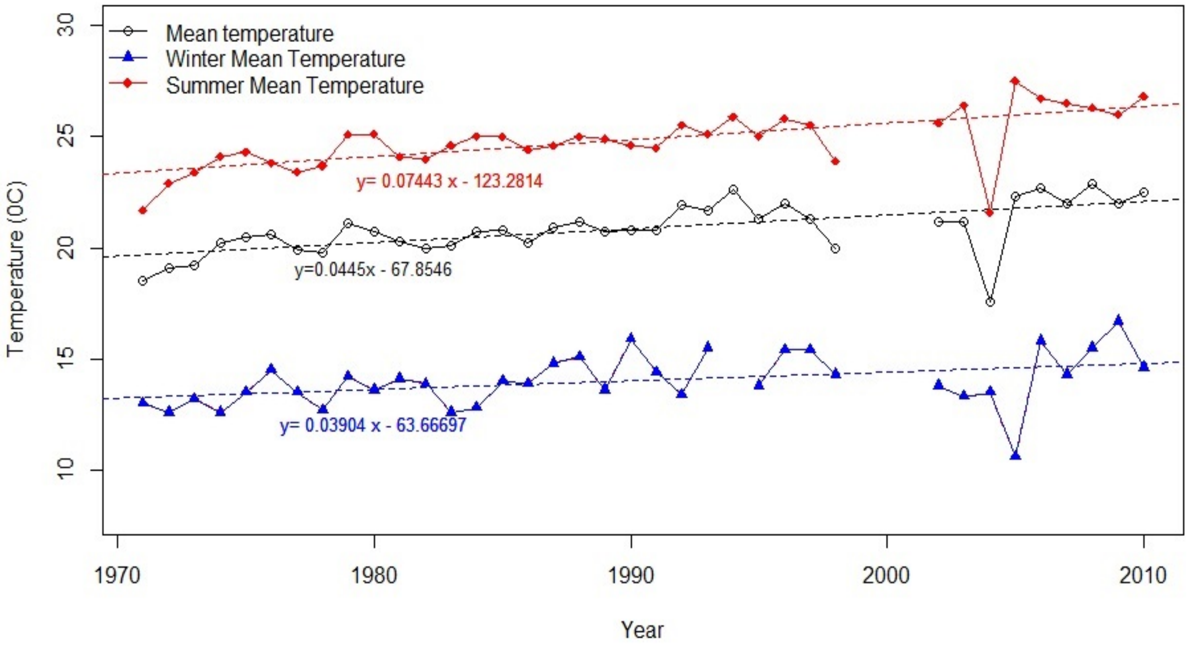


Figure 5 : Variation in mean temperature, winter mean temperatures (Dec–Feb) and summer mean temperatures (Jun–Sept) for the period 1971–2010 [data from the Jagat meteorological station]

Similarly, the total annual precipitation during the period from 1971 to 2010 showed that there is fluctuation in the rainfall pattern. In the span of 39 years there is slight decrease in average precipitation at a rate of 1.777mm per year (F=6.745, P < 0.05) (Figure 6).

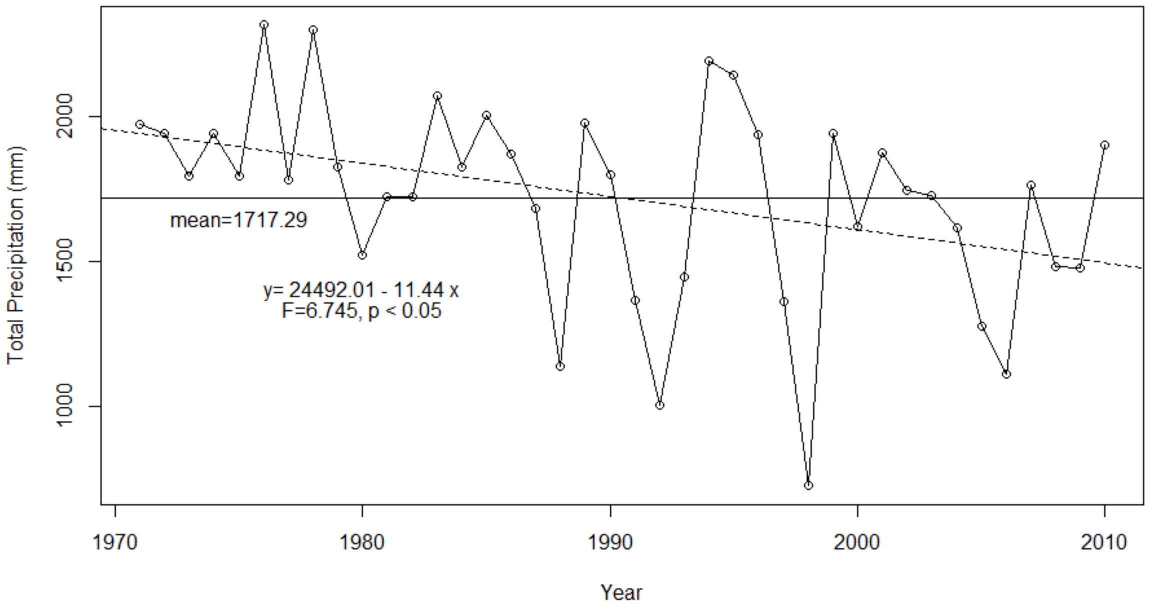


Figure 6 : Trend in precipitation of Jagat meteorological station, Gorkha

4.2 Stand Characteristics

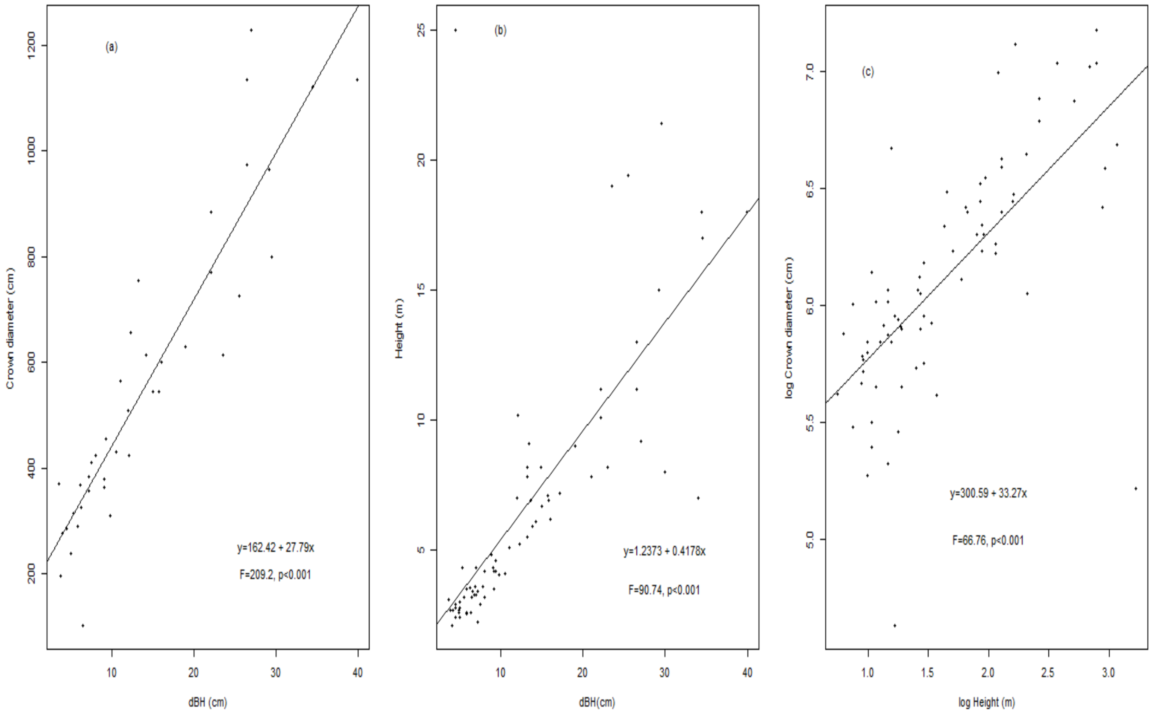


Figure 7 : Relationship between (a) crown diameter and DBH (b) height and DBH (c) crown diameter and height of *Abies spectabilis*

In the relationship between crown diameter, DBH and height of *Abies spectabilis*, crown diameter is taken as the response variable and DBH and height both as the predictor variables. In both the cases of crown diameter and DBH (F=209.2, P<0.001) and logarithm of crown diameter and logarithm of height (F=66.76, P<0.001)) the relationship is statistically significant. In the relationship between height and DBH, former taken as response and later as predictor the relation is statistically significant (F=90.74, P<0.001) (Figure 7). When the K/d ratio is plotted (Figure 8) the variation is apparent, particularly at smaller stem diameters. As the stem diameters approaches to 30–40 cm the ratios begin to stabilize, with the decline becoming less rapid.

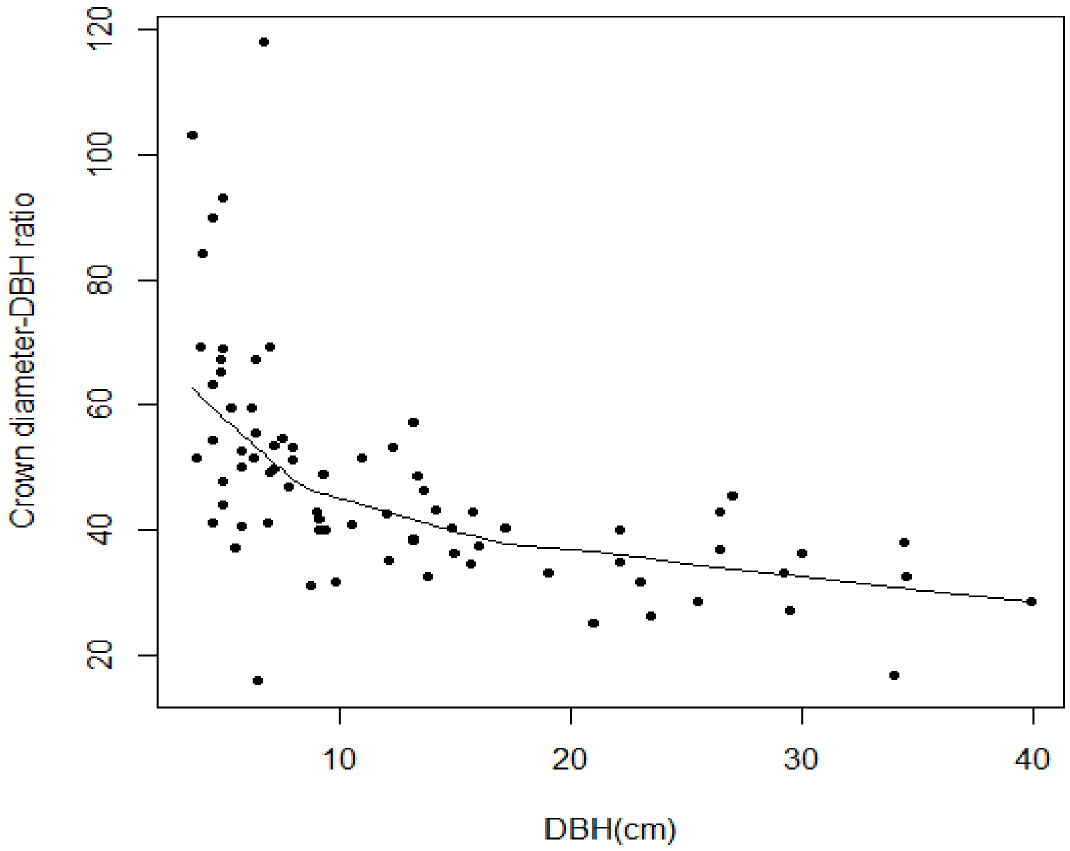


Figure 8 : Crown diameter–stem diameter ratios at different DBH for *Abies spectabilis*

4.3 Relation of DBH and Age

At the initial phase of establishment the DBH of *A. spectabilis* increases with increase in age and as the species tends to mature, the increase in DBH is likely to slow down. The relation between age and DBH of *A. spectabilis* was statistically significant (n= 76, F= 37.73, P< 0.001) (Figure 9).

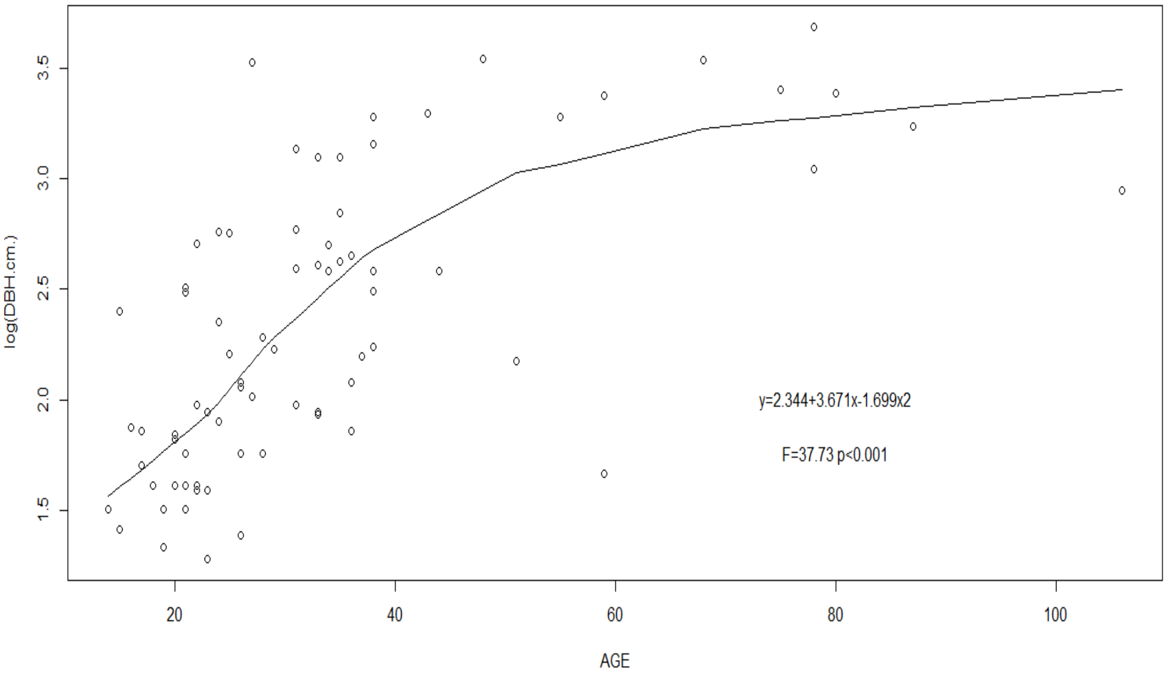


Figure 9 : Relationship between age and DBH of *Abies spectabilis* population using LOWESS smoother in polynomial second degree equation

The age–frequency of *A. spectabilis* displayed inverse J-shaped distribution (10-year intervals). The 21-32 year-old age class (trees that established in the 1980s) accounted for the largest age class (25 stems). The majority of trees (65 stems) were between 42 and 12 years established between 1970s and the 2000s. Before 1970s, establishment has been very poor with mature individuals (>50 years) accounting for only 5 stems of the total population (Figure 10).

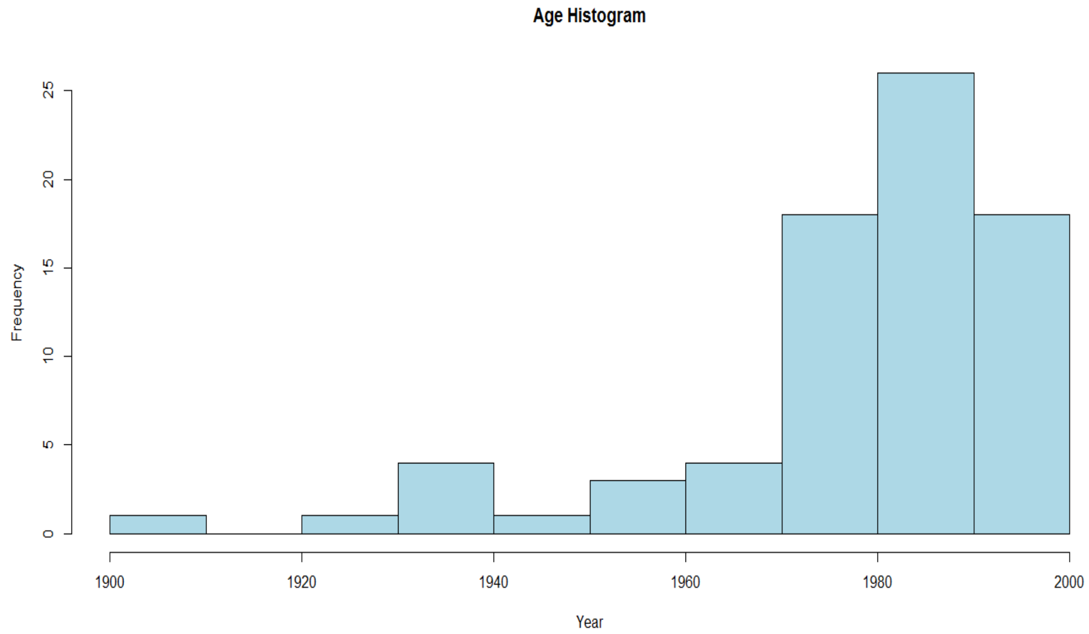


Figure 10 : Age frequency of tree of *Abies spectabilis* in Lho village, Manaslu

4.4 Recent Regeneration and Climate

Age-class histograms for *A. spectabilis* showed that trees could be dated back to the early 19th century. Establishment in this population occurred at low levels before 1900, at moderate levels from 1970 to 1980, and at high levels between 1996 and 2002s and recent regeneration has increase substantially after 1970s (Figure 10). During the last 40 years, there have been significant and positive correlations between recruitment and mean annual temperature (5-year average) ($r = 0.35$, $P = 0.04$). There is significant negative correlations between recruitment and mean annual precipitation ($r = –0.36$, $P<0.5$) and recruitment and autumn precipitation ($r = -0.72$, $P<0.000001$). All of the seasonal temperature facilitate seedling recruitment with the highly significant positive correlations between recruitment and mean autumn temperature ($r = 0.71$, $P < 0.000001$) (Figure 11).

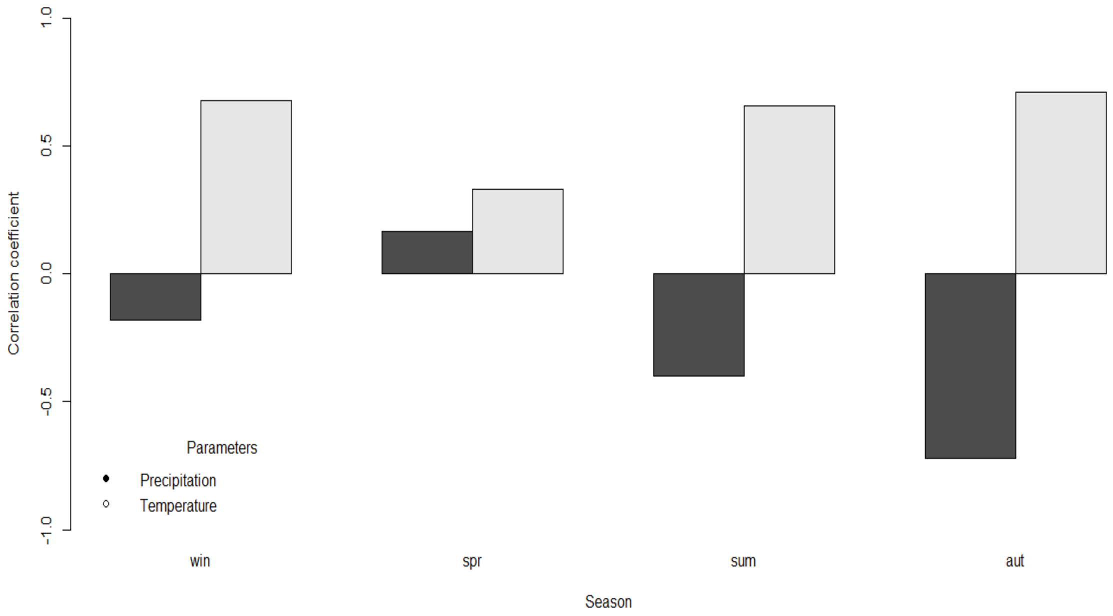


Figure 11 : Correlation coefficients of recruitment with seasonal mean temperatures and mean total precipitation (1971–2000). (Winter: Dec-Feb, Spring: Mar-May, Summer: Jun-Sept, Autumn: Oct-Nov)

4.5 Rate of Shift

Altogether 77 seedlings, 112 saplings and 76 trees of *Abies spectabilis* were encountered. The age difference between the uppermost age of seedling at highest altitude and tree of *A. spectablis* at lower altitude (within the belt transect) and the altitude difference between them was used for calculating the average rate of shift, which is expressed in terms of shift per decade. Figure 11 shows the frequency of age distribution of *A. spectabilis*. The age histogram shows the age gaps between different age classes of the species. The greatest frequency of the species is present at the age between 0-5 years and decreases rapidly thereafter. The lowest frequency of the trees is present in higher age class.

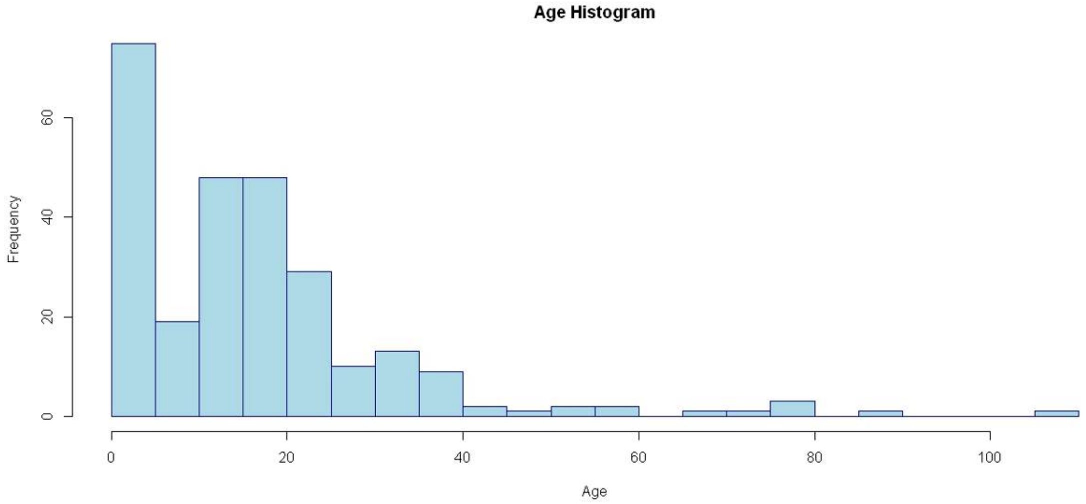
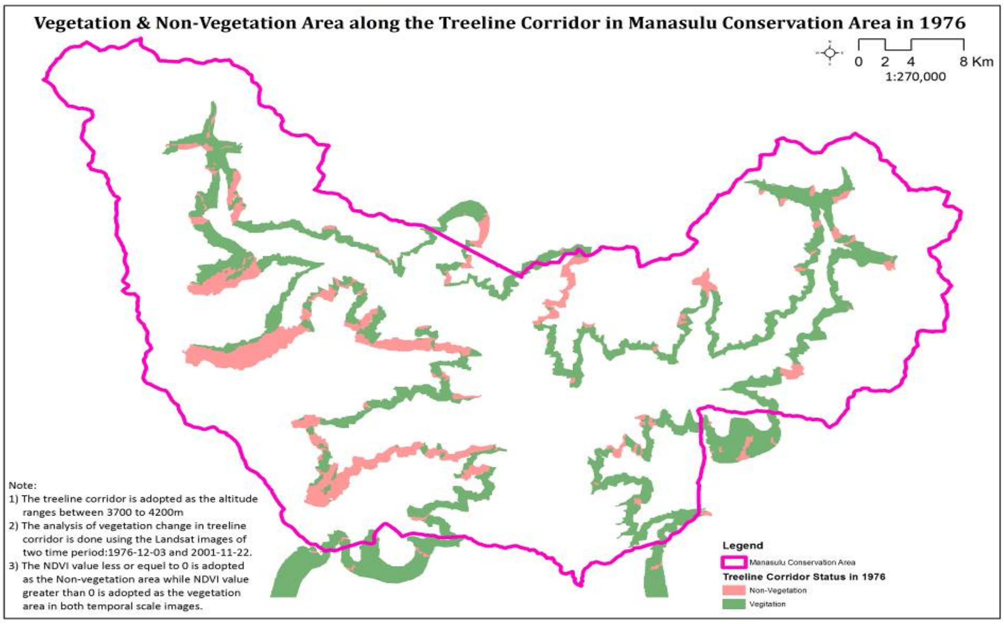


Figure 12 : Age histogram of *Abies spectabilis* (seedling, sapling and tree)

The youngest individual of *A. spectabilis* was encountered at an altitude of 3,752m whereas the oldest tree was at an altitude of 3,642m asl (Figure 13). The youngest individual was found to be of 5 years and the oldest with an age of 106 years. This indicates that it took 101 years to shift to the highest altitude by 110m (1.08m/year). Thus, vertical rate of tree line shift is found to be 10.8m/decade with reference to 1911 tree line.

Figure 13 : Establishment of seedlings of *Abies spectabilis* from 1907 to 2012

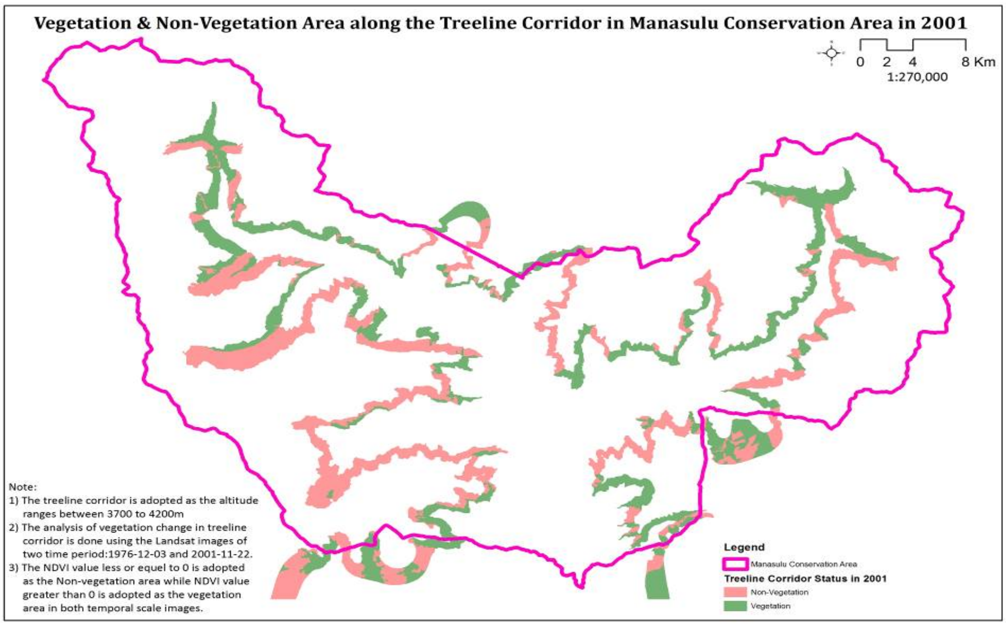
4.6 Change in Tree Line Ecotone



Vegetation & Non-Vegetation Area along the Treeline Corridor in Manasulu Conservation Area in 1976

Note:
1) The treeline corridor is adopted as the altitude ranges between 3700 to 4200m
2) The analysis of vegetation change in treeline corridor is done using the Landsat images of two time period:1976-12-03 and 2001-11-22.
3) The NDVI value less or equel to 0 is adopted as the Non-vegetation area while NDVI value greater than 0 is adopted as the vegetation area in both temporal scale images.

a.

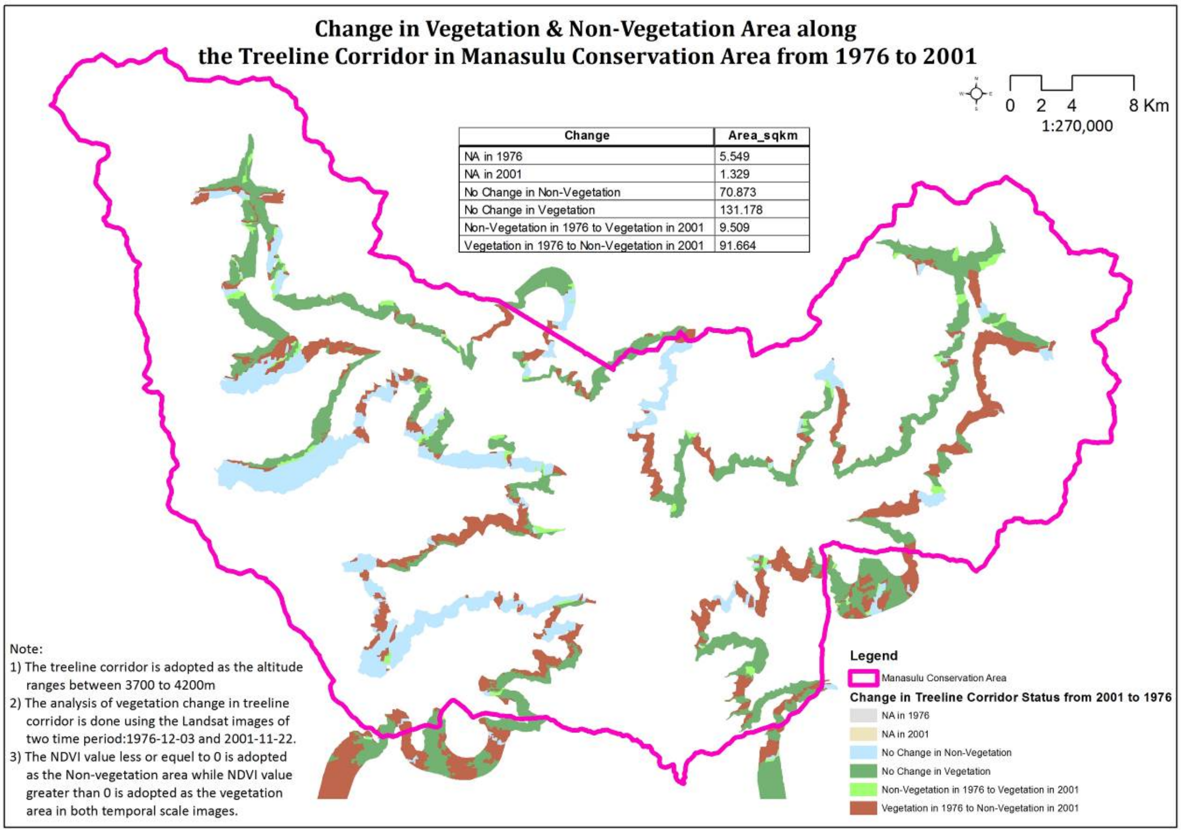


Vegetation & Non-Vegetation Area along the Treeline Corridor in Manasulu Conservation Area in 2001

Note:
1) The treeline corridor is adopted as the altitude ranges between 3700 to 4200m
2) The analysis of vegetation change in treeline corridor is done using the Landsat images of two time period:1976-12-03 and 2001-11-22.
3) The NDVI value less or equel to 0 is adopted as the Non-vegetation area while NDVI value greater than 0 is adopted as the vegetation area in both temporal scale images.

b.

Figure 14: NDVI for vegetation and non-vegetation area for a. 1976 and b. 2001 along tree line corridor in Manaslu conservation area



Change	Area_sqkm
NA in 1976	5.549
NA in 2001	1.329
No Change in Non-Vegetation	70.873
No Change in Vegetation	131.178
Non-Vegetation in 1976 to Vegetation in 2001	9.509
Vegetation in 1976 to Non-Vegetation in 2001	91.664

Note:
1) The treeline corridor is adopted as the altitude ranges between 3700 to 4200m
2) The analysis of vegetation change in treeline corridor is done using the Landsat images of two time period:1976-12-03 and 2001-11-22.
3) The NDVI value less or equel to 0 is adopted as the Non-vegetation area while NDVI value greater than 0 is adopted as the vegetation area in both temporal scale images.

Figure 15: Change in tree line vegetation from 1976 to 2001

The digital comparison of tree line ecotone between year 1976 and 2001 found that it has changed in the past three decades (Figure 14). Most of the vegetated zone along the past tree line ecotone are still forested in 2001 with same or increased NDVI while certain non-forested area in 1976 are converted to forest in 2006 (Figure 15). The analysis had shown that area of vegetation in 1976 to non-vegetation area in 2001 (91.662sq.km) is far more than the non-vegetation area in 1976 to vegetation in 2001 (9.509sq.km). This might be due to the error in data acquisition and processing techniques, especially during atmospheric correction to the calculated NDVI. Similarly, large area of the vegetation remained unchanged during the period of 25 years (131.178sq.km) and 70.873sq.km of area are still remained non-vegetated (Figure 15).

Chapter V

3. Discussion

5.1 Local Climate

The result of the climate data analysis showed that there was a significant increase in atmospheric maximum temperature around Manaslu area during the past 40 years. The mean maximum temperature in the area has increased from 23.93°C during the year 1971 to 27.05°C in the year 2010. Similarly, the average winter and summer minimum temperature increased at a rate of 0.097°C and 0.087°C per year respectively (Figure 2). The result of this study, thus, is in conformity with the studies done all over the Nepal by analyzing the temperature data during the period from 1971-1994 which showed a warming trend (Shrestha et al., 1999). The study showed a warming trend in Nepal after 1977 which ranges from 0.068°C per year in the middle mountains to 0.128°C in the Himalaya. The Siwalik and southern lowland Tarai plains showed a much lesser warming trend, which is less than 0.038°C per year. The high warming rate in the Himalaya and the middle mountains is attributed to the sensitivity of such regions to changes in climate (Shrestha et al., 1999). Shrestha (2008) has calculated the mean winter and summer temperature is increasing at a rate of 0.037°C and 0.043°C per year respectively.

The precipitation (Fig. 3) showed that it followed a steady fluctuation (increase and decrease) between 728 and 2,312mm up to the year 1995. There has been a tremendous decrease in precipitation after the year 1995 the lowest during the year 1998. The five-year average precipitation also showed decreasing trend at a rate of 1.77mm per year. Precipitation data from Nepal over the past three decades show large inter-annual and decadal variability in the all-Nepal as well as regional (within Nepal) precipitation records but lacks a long-term increasing trend in the precipitation records, despite the fact that climatic models predict an increase in monsoon precipitation (Shrestha et al., 2000). According to Shrestha (2008), all Nepal annual precipitation is decreasing at a rate of 9.8mm per decade. A model prediction (Kulkarni et al., 2013) suggested that rainfall may increase by 20–40% in the HKH region and it may be 40–50% more variable in the Central

Himalaya and Eastern Himalaya at the end of the century. The rainfall pattern is highly variable in the region. It has been suggested that the precipitation climatology in the northern part of the subcontinent (including the Himalayan region) is different from the rest of the subcontinent (Shrestha et al., 2000). High variability in precipitation can be seen within a relatively short distance depending on the aspect, slope, and direction of the hills.

5.2 Stand Structure of *A. spectabilis*

Regression models established between DBH, height and crown diameter variables of *A. spectabilis* in the studied area were statistically significant ($P<0.001$). The relationship between height and DBH, crown diameter and DBH, height and crown diameter were investigated in many studies which determined a strong relationship between them (Avsar, 2004). The K/d ratio calculated by the relationship between crown diameter (K) and stem diameter (d) of trees have various applications including the application for decisions on spacing, basal areas per hectare, the prediction of desirable stocking levels for any mean stem diameter and thinning regimes and also be used for estimating basal area from crown diameters measured from aerial photographs or other methods of remote sensing (Hemery et al., 2005).

5.3 Establishment of *A. spectabilis* and Climate Relation

The age structure of a stand can provide a fairly accurate picture of temporal variations in the establishment rate (Kullman, 1991, Wang et al., 2006), with the dynamics of climate change (Zhao et al., 2013), because tree recruitment is more sensitive than tree mortality to climate variability (Camarero and Gutierrez, 2004). In the present study, the age structure of the *A. spectabilis* forest growing at the tree line showed that trees were dated back to the early 20th century (Fig. 6). The age histogram showed significant difference in the age class between lower age class and higher age class of *A. spectabilis* (Figs. 6 and 9). In the present study, the establishment of *A. spectabilis* was high in recent decades as compared to the previous decades, which is consistent to the findings of other studies (Gaire et al., 2011, Gaire et al., 2013b, Liang et al., 2011, Lv and Zhang, 2012). In the recent years more seedlings (0-5 age class) were established in the area. Seedling generally preferred high soil moisture, moderate pH and moderate canopy cover (Qi-Jing, 1997). As *A.*

spectabilis is shade tolerant species it can regenerate under a densely closed canopy (Tiwari, 2010, Qi-Jing, 1997). Establishment at the tree line ecotone may also be controlled by local micro-environmental factors and episodic climatic events, leading to years of either low or high mortality (Szeics and MacDonald, 1995, Wang et al., 2006). The age histogram also revealed the absence of higher age and girth class of *A. spectabilis* in the area. Human factors like transhumance and logging of trees for fuel wood and timber may also be the factor for seedling mortality. Logging of trees not only reduced tree density but also hamper regeneration directly by mechanical damage to recruits and indirectly by reducing the seed production (Tiwari, 2010).

A static age structure of living trees is the expression of change in the rate of tree recruitment and mortality over time (Wang et al., 2006). Successful recruitment and establishment is controlled mainly by favorable human condition and sustained climatic conditions leading to a lower mortality (Camarero and Gutierrez, 1999, Szeics and MacDonald, 1995). In the upper tree line of the MCA, significant and negative correlations were found between recruitment (5-year classed) and total precipitation during summer and autumn (5-year average), but positive correlations were found with rainfall in spring (5-year average). High precipitation could cause higher soil moistures but colder soil temperatures in the early and late summer and in autumn at the cold alpine tree line, which could be related to a shorter growing season and increased mortality due to cold (Camarero and Gutierrez, 1999). The significant positive correlations between summer temperatures and recruitment were also reported from conifer seedlings in alpine tree line ecotone of the Snowy Range in Wyoming USA and from *A. spectabilis* forest in the alpine timberline of the Mt. Everest in southern Qinghai-Tibet Plateau (QTP), China (Zhao et al., 2013)

Forests advance to higher elevations will in general not depend on increasing growth rates of mature trees and change in growth forms from ‘krummholz’ to erect stems but on successful regeneration and survival of young growth (Smith et al., 2003) . The survival rate of seedlings has been generally low in the tree line environment the first year after germination. The regeneration process in Spanish Central Pyrenees between 1960 to 1990 is positively correlated to favorable thermal condition of several sequential years (Camarero and Gutierrez, 1999, Holtmeier and Broll, 2007). Warmer summers are likely to favor production of viable seeds, seedling establishment and thereby tree recruitment in the present tree line ecotone provided that other factors do not interfere (Holtmeier and Broll, 2007).

5.4 Tree Line Advance and Climatic Warming

Climate can affect both tree recruitment and tree line advance rates (Wang et al., 2006). However, relationships between tree line shifts and changing climate may be much more complex. A tree line ascent implies several consecutive processes: production of viable seeds, dispersal, availability of adequate regeneration sites, germination, seedling establishment, vertical growth of tree line individuals and persistence until the individual reaches adulthood. Climate variability affects all these sequential stages, but the same climatic variable can enhance one of these processes while inhibiting another one (Camarero and Gutierrez, 2004, Wang et al., 2006). Furthermore, site history, including climatic changes, wildfires, human impact, insect infestations and plant diseases play a very important role at the landscape scale when discussing sensitivity of the tree line to changing climate (Holtmeier and Broll, 2005).

Regardless of the sites, the *A. spectabilis* tree line in the present study was found at 3701 m asl which is lower than the tree line observed at other sites of Nepal (Bhuju et al., 2010, Gaire et al., 2011). This can be attributed to the topographic constraints as the upper region of the study site was very steep and rocky. Bhuju et al. (2010) found the tree line at 4050m asl in Pangboche of Sagarmatha (Everest) region in eastern Nepal, while at the Lauribina of Langtang in central Nepal it was observed at about 3900m asl (Gaire et al., 2011). In this present study the rate of shift was found to be 10.8m in 10 years. The rate of shift seems to be slightly lower when compared to the studies done in Himalayan pine in the Western Himalaya (Dubey et al., 2003). From the study at Samagaun region of Manaslu area, Suwal (2010) reported an upward expansion of *A. spectabilis* by an average of 34m decade^{-1} and another study from Kalchuman lake region of Manaslu area, Gaire et al., (2013) reported the average upward movement of the upper distribution limit of *A. spectabilis* was 26.1m decade^{-1} which are higher than the average upward migration in the present study. It has been observed that, when compared to the other species reported in the Alps and other regions the rate of upward shift of pine in Himalaya is much higher 19m per decade in south facing slope and 14m per 10 years in north facing slope, but it is only 4m for 10 years in the Alps (Dubey et al., 2003). Hence, the results have supported the findings from other studies on alpine tree line which have documented an altitudinal shift during the first half of the twentieth century followed by tree-density increases within the ecotone during the last decades (Camarero and Gutierrez, 2004, Szeics and MacDonald, 1995, Vijayaprakash and Ansari, 2009). But, the continuous establishment of seedling in the study site has not occurred where recruitment continues to be episodic as ever (Holtmeier and Broll, 2007). However, there is the mixed response in the response of tree line with climatic warming in the alpine region (Harsch et al., 2009).

In the study site, the oldest trees established in the early 19th century, and many *A. spectabilis* individuals (57%) were established between 1940 and the 1970s, which probably form the current tree line zone. The presence of cut-off scars of matured *A. spectabilis* in the study site was supported by the gaps in the age class. This indicates that there occurred high disturbance affecting the dynamics of tree line. Disturbance legacies may further influence tree line position and its ability to respond to climate changes. Past disturbances can shape tree line structure and influence initial recruitment patterns but subsequent patterns of recruitment and spread may be more strongly controlled by climate (Harsch et al., 2009, Holtmeier and Broll, 2005, Vitasse et al., 2012). Recruits were detected at and above the adult tree limits, irrespective of the disturbance. Matured as well as young seedlings were mostly dominated in the lower elevation. However, both seedling and saplings were represented beyond adult tree limits, indicating that it was not just a few good years in the very recent past that contributed to tree establishment but takes a decades to persist from transition phase of seedling to sapling. This indicates both stand densification and upward migration as recorded in many other areas (Gaire et al., 2013b, Harsch et al., 2009). The Alps also has shown the similar results in tree line species demonstrating recruitment occurring above the current adult limit with the potential of upward migration tree in response of ongoing climatic warming (Vitasse et al., 2012).

5.5 Vegetation Change

Analysis of the satellite imagery exposed two perspectives of the vegetation ecotone dynamics in Manaslu Conservation Area. On one hand, there was evidence of a shift in the tree line in three decades, and on the other hand, the absolute NDVI value of the past tree line had also increased. Under the hypothesis that the climatic warming has changed the tree line dynamics, this is a reasonable assumption- the NDVI value have changed from 1976 to 2001. The occupancy of non-vegetation area in 1976 to vegetation area 2001 is the evidence of the response of tree line vegetation to climatic warming. Similar kind of study in Gangotri catchment in northern India has also shown the change in tree line area by 6.33sq.km and vegetation line area by 9.06sq.km. Same study has also shown the altitudinal shift of tree line by 327±80m and other vegetation line by 401±77m in the past 3 decades (Singh et al., 2011). Another case from Indian Himalaya studied the change in alpine tree line ecotone as a function of shift in altitude from the past (1970s) to the current (2006) with remote sensing. It was found that the tree line covered 2,250km surface distance with mean elevation of 3,554m in 2006 as compare to 1650km surface distance with average elevation of 3,166m in 1970 (Singh et al., 2012). Similarly, the greening trend was observed in northern India and south-eastern China with significant increases in annual NDVI of vegetation pixel between the study periods of 1982-1998 (Xiao and Moddy, 2005). The coverage of vegetated area has been decreased by 91.66sq.km between the periods of 25years.

Different data acquisition (Landsat MSS vs. TM) and processing techniques, especially atmospheric correction, can easily introduce errors to the calculated NDVI. In addition, NDVI is also biased by plant phenology, although the images were acquired at about the same time of the year (Zhang et al., 2009). For the mountainous countries like Nepal topographic shadowing significantly degrades the quality of reflectance data on slopes oriented away from the tangent of illumination where topographic normalization approaches generally take one of three forms: spectral band ratios which reduce differences in brightness values for surface materials due to topography, shadows and seasonal illumination geometry differences, slope and aspect modeling with DEM reduce terrain induced spectral variance in by 69%, or non-Lambertian normalization with a backwards radiance correction transformation (Millette et al., 1995). Furthermore, it might be due to increasing harsh micro-topography or probably due to the change in geomorphological condition of the area. The effects of micro-topography on solar radiation and wind and resulting consequences to the microenvironment would primarily control site conditions and the distribution pattern of the surviving young growth and also controls relocation of solid and suspended substances by surface runoff and seepage (Holtmeier, 2009). The tree line area is dominated by unconsolidated debris and rock faces. The geomorphological processes are more intense in the area (e.g. rockfalls) and unstable landforms (e.g. rock faces) are markedly and extensively distributed, becoming ‘disturbance factors’ able to slow down altitudinal shifts and maintain the tree line below the potential climatic tree line (Leonelli et al., 2011).

Chapter VI

6. Conclusion

This study has documented some notable response shown by tree line to the climatic stress faced by *Abies spectabilis* in north facing slope of Lho region in Manaslu Conservation Area of central Nepal. The analysis of climatic data indicated climatic warming in recent decades, favoring positive response in regeneration and recruitment. The tree recruitment was correlated positively with all four seasonal temperatures, whereas the population age structure indicated that successful establishment was much related to high summer and autumn temperatures and spring precipitation over several successive years. Recruitment analysis was helpful to understand and reconstruct tree line dynamics but for reconstructing past climatic conditions, dendroclimatology (Gaire et al., 2013a) and pollen analysis will provide better results provided that knowledge of the ecological indicator values of plants, the present vegetation and its dynamics (Miehe et al., 2009). The study results are similar to the findings by Camarero and Gutierrez (1999), Camarero and Gutierrez (2004), which showed that warmer summers over several successive years favored reproduction and establishment in tree line populations. It is concluded that a directional increase in temperature could be one of the factors that result in an upslope shift of the *A. spectablilis* with an average shift of 10.8m per decade. NDVI analysis has shown that the area converted from non-vegetation area in 1976 to vegetation in 2001 is only 9.509sq.km whereas area of vegetation in 1976 to non-vegetation area in 2001 is 91.662sq.km. This might be due to the error in data acquisition and processing techniques, especially during atmospheric correction to the calculated NDVI.

For understanding and predicting the ecological consequences of climatic stress on the dynamics of the uppermost distributional limits of tree line and forests located in high altitude remote sites more detailed studies on the relationships between climatic change and forest regeneration rates are needed. To study the change in tree line ecotone the analysis of satellite images is proving to be more beneficial at landscape level. Similarly, under the ongoing climatic trends, the role of geomorphological factors in controlling the tree line dynamics is also needed to be considered.

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Appendix

Appendix I

Mean temperature for Jagat meteorological Station, Gorkha (1971-2010)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1971	12.4	14.3	19.0	19.4	20.8	22.5	22.8	22.1	21.9	19.4	15.5	12.7
1972	12.6	12.5	19.1	22.1	24.7	23.7	22.9	22.8	20.9	18.9	16.0	13.3
1973	12.2	15.1	18.3	24.4	22.0	22.8	23.5	22.9	21.7	19.2	16.1	12.7
1974	11.8	14.2	19.9	23.7	23.8	24.7	23.7	24.2	22.5	23.0	18.2	12.9
1975	12.6	15.3	20.1	25.0	24.4	24.7	23.4	24.3	22.8	22.6	17.3	14.2
1976	13.7	16.2	21.1	23.6	23.4	23.8	24.1	23.7	23.0	21.2	19.2	14.9
1977	12.5	15.5	21.4	20.6	21.7	24.5	24.5	24.2	23.4	20.1	17.6	13.6
1978	12.0	14.3	17.6	22.1	22.9	23.9	24.0	24.7	23.3	21.0	17.6	14.5
1979	14.1	14.5	20.6	24.4	26.6	26.1	25.1	24.7	23.5	21.0	19.1	13.6
1980	12.8	15.2	18.8	25.7	24.3	24.6	25.2	24.7	24.0	20.7	17.8	15.1
1981	13.0	16.2	19.1	20.9	23.2	25.6	24.9	25.0	23.9	21.3	16.9	13.6
1982	14.1	13.6	17.7	22.0	24.9	24.2	25.2	24.8	22.9	20.7	17.1	13.7
1983	11.7	14.5	19.1	21.8	22.2	25.6	25.6	25.3	24.0	21.4	17.2	13.0
1984	11.8	14.9	21.0	23.9	23.6	25.5	25.0	25.6	23.9	22.2	16.9	14.1
1985	13.2	15.6	21.7	24.4	23.4	25.2	25.0	25.7	23.9	20.6	16.7	14.0
1986	13.3	15.2	19.4	22.3	22.7	25.3	25.0	25.1	23.1	20.3	17.2	13.6
1987	14.2	16.0	18.9	22.8	23.4	25.4	24.9	25.2	24.9	21.9	17.9	15.6
1988	14.4	16.5	19.0	24.5	23.9	25.3	25.5	24.7	24.7	22.5	18.5	15.5
1989	12.8	15.2	18.3	23.6	24.7	25.6	25.4	24.9	24.6	22.3	16.5	14.8
1990	16.1	15.4	17.6	22.1	24.2	26.1	25.4	24.7	23.4	21.4	18.4	15.1
1991	13.2	16.7	19.3	22.7	25.5	25.1	25.5	24.6	24.5	22.2	17.1	14.0

1992	13.1	14.0	21.2	24.8	23.8	25.0	26.3	25.8	23.9	24.6	NA	18.7
1993	14.2	16.8	19.1	22.6	24.0	26.5	25.9	25.7	24.7	22.0	18.0	NA
1994	NA	NA	NA	NA	24.2	25.3	26.3	26.2	24.6	21.4	18.9	14.0
1995	12.9	15.7	18.2	24.5	26.8	25.6	25.3	24.6	25.7	23.5	18.6	14.7
1996	14.8	16.8	21.1	25.1	26.4	26.7	25.9	25.6	24.0	22.5	19.5	16.4
1997	14.8	16.5	22.4	24.3	NA	26.4	26.4	24.9	22.9	21.6	18.6	15.6
1998	14.0	15.0	17.0	18.2	20.8	25.2	26.5	25.7	24.2	22.2	17.8	13.7
2001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	13.5
2002	12.6	16.1	20.0	22.9	24.3	26.6	26.5	26.5	25.0	22.3	17.9	14.1
2003	12.4	15.3	19.1	24.0	NA	27.3	27.0	27.3	26.0	23.1	18.3	13.7
2004	12.4	15.9	21.2	NA	NA	21.6	21.1	22.2	21.0	17.0	12.6	10.9
2005	10.6	NA	NA	NA	26.1	27.8	27.3	27.4	27.2	22.9	17.8	13.8
2006	13.8	19.9	21.3	24.4	26.8	27.1	27.8	27.6	26.1	23.9	19.2	14.9
2007	13.6	15.7	20.2	25.1	26.8	27.0	26.8	27.2	25.9	23.6	18.4	14.0
2008	NA	15.5	21.6	24.3	25.2	26.6	27.3	26.9	26.2	23.4	19.3	16.0
2009	15.6	18.9	22.1	25.6	25.3	26.5	26.5	25.6	24.7	20.6	17.2	15.1
2010	13.9	16.2	22.9	25.9	25.9	27.4	27.3	26.8	25.9	24.0	19.9	14.5

Appendix II

Precipitation data of Jagat meteorological Station, Gorkha (1971-2010)

Year	Jan	Feb	Mar	Apr	May	Jun	JUL	AUG	SEP	OCT	NOV	DEC
1971	2	4.9	20.6	216.8	133.3	603.9	277	362.3	204.9	120.5	23.4	0
1972	2.3	59.9	37.3	35.8	250.6	477.9	464	220.4	286.2	91.6	14.5	0
1973	50.7	27.6	18.1	39.2	192.3	333.3	278.7	335.3	291.8	227.1	NA	NA
1974	28	12.8	42.4	71.5	150.7	233.9	628.7	368	325.2	72.1	0	5.8
1975	24.1	29.7	14.7	63	176.1	247.7	555.4	313.2	347.3	23.1	0	0
1976	25.2	1.7	0	21	298.5	812	451	422	264	16.6	0.2	0
1977	12.5	10.5	20.2	138.6	231.3	296.4	390.7	494.7	76.5	15.8	46.6	45.7
1978	2	16	89.6	76.5	359.2	376.5	431	517.9	359.5	56.4	4.5	9.3
1979	5.2	32.1	5.7	60	109.2	354.6	450.1	396.6	147.1	133.1	20.4	112.7
1980	0	32	55.4	2	113.4	332	497.9	264.9	171.7	51.3	0	2.2
1981	39.7	4.2	49.8	188.1	109	296.7	477.5	295	237.2	2.3	21.5	0
1982	26.4	40.4	97.4	53.1	79.6	219.8	556.9	435.3	172.1	16.1	22	1.5
1983	19	5.3	17.3	82	221.7	196.8	663	351.5	333.4	163	0	16.6
1984	23.1	7.4	22.1	85	240.7	300.9	416.7	382	320.3	24.7	0	3.9
1985	2.9	0	25.9	95.4	158	303.3	488	309.5	345.8	212.2	9.6	52.2
1986	0	17.6	60.1	67.6	196.4	361	531	287.1	227.3	44.2	0	78.1
1987	3.9	8.4	72.4	73.3	95.5	253.4	563.8	381	150.2	16	2	63.7
1988	0	0	36.2	65.1	229.9	42.5	226	251	192.2	44.2	7.7	44.8
1989	161	0	96.1	42.6	223.3	272.1	450.4	404.4	251.9	65.1	1	8.5
1990	6	62.1	116.8	128.7	129.6	331.4	544.4	270.1	157.9	41.3	0.2	9.4
1991	21	17.2	100.2	36.2	100.8	388.9	344.1	207.3	131.7	0	0	20.1
1992	2.8	0	0	0	97.5	309	146.5	396.6	31.5	20.6	NA	0
1993	8.5	13.1	51.6	50.1	349.2	249.1	243.2	242	240	1.1	0	0

1994	38.2	12.1	94.5	3.4	217.3	265.4	628.3	745.5	185.3	0	0	0
1995	7.6	41.7	20.2	NA	NA	886.2	591.3	211.7	250.7	66	57.7	5.5
1996	60.6	40.2	19.3	40.6	95	335.6	408	717.8	138.4	80.2	0	0
1997	24.7	14.4	32.8	315.6	NA	352.8	383.7	127.2	50.2	9.8	12.7	37.8
1998	8.1	12.2	21.3	9	73.2	181.4	326.2	60.8	18.9	2.2	0	14.8
1999	0.2	NA	NA	12.8	359	186.6	705.4	466.7	161.6	49.6	0	0
2000	14.4	14	NA	NA	250.9	432.3	281.9	473.7	153.7	0	0	0
2001	7.5	34.2	3	98.5	241.2	360.1	409.9	527.5	178.5	2.5	9	0
2002	48.3	33.7	13.3	190	213.9	205	497.6	332.9	174.8	16.2	17.5	0
2003	34.2	64.2	56.8	46.4	111	346.7	567	333.9	147.4	3	0	18.3
2004	27	2.5	0	143.4	132.7	363.8	411.4	275	216.3	39.3	2	0
2005	50.2	4.8	51.7	106.3	206.6	103.8	255.5	293.6	105.5	98.5	0	0
2006	0	0	20.6	67.6	125.1	227.9	293.7	216.7	129.3	1.8	2.8	28.5
2007	0	107.1	44.4	84.5	101.1	489.3	363.1	175.7	353	37.6	7.3	0
2008	NA	0	30	145	153.6	440.6	208.6	405.9	88	9.4	0	0
2009	0	0	24.3	65.4	141.3	208.4	383	492.3	52.8	107.9	1	0
2010	4	39.9	33.4	147.9	184.2	246.6	477.2	490.6	246.8	29.4	0.3	0

Appendix IIIa

Tree inventory and stand structure data of *Abies spectabilis* at Lho village

Code	Latitude	Longitude	Elevation(m)	Age	Type	Height(m)	CD (a_cm)	CD(b_cm)	BD(cm)	DBH(cm)
TR01	28.56647812310	84.69630412860	3727	20	Tree	3.57	260	217	9	6.18
TR02	28.56720319150	84.69649436820	3669	80	Tree	21.4	600	400	32	29.5
TR03	28.56655981350	84.69645241080	3718	15	Tree	5.11	401	329	14	11
TR04	28.56703624190	84.69658339260	3678	21	Tree	5.24	450	412	17.7	12.3
TR05	28.56715970240	84.69662149030	3669	87	Tree	19.4	500	450	30.5	25.5
TR06	28.56677048380	84.69643217790	3702	22	Tree	2.4	172	135	7	5
TR07	28.56676240230	84.69640029980	3704	26	Tree	2.57	195	190	7.5	5.8
TR08	28.56679314350	84.69633574080	3701	38	Tree	19	420	390	26.3	23.5
TR09	28.56682647350	84.69631908080	3701	21	Tree	7	360	300	16.2	12
TR10	28.56682210780	84.69650579240	3697	22	Tree	2.22	250	215	9	7.2
TR11	28.56688877780	84.69638913240	3693	59	Tree	4.3	220	190	6.1	5.3
TR12	28.56699314350	84.69641908080	3684	20	Tree	2.59	230	190	9	6.3
TR13	28.56709363720	84.69657202820	3675	48	Tree	17	806	630	40.6	34.5
TR14	28.56687647350	84.69635241080	3694	23	Tree	3.1	270	202	7	3.6
TR15	28.56687647350	84.69638574080	3693	26	Tree	2.11	207	140	5.8	4
TR16	28.56708877780	84.69648913240	3677	44	Tree	8.2	5.6	3.9	15.7	13.2
TR17	28.56723673560	84.69656968010	3665	24	Tree	4.1	300	260	12	10.5
TR18	28.56693187620	84.69652011430	3685	28	Tree	4.05	308	290	12.8	9.8
TR19	28.56693187620	84.69647011430	3687	29	Tree	4.17	305	300	12.2	9.3
TR20	28.56698187620	84.69652011430	3682	14	Tree	2.9	210	150	5.4	4.5
TR21	28.56696521620	84.69650344430	3687	19	Tree	2.7	133	125	5.6	3.8
TR22	28.56694854620	84.69652011430	3685	38	Tree	10.2	300	250	13.6	12.1
TR23	28.56700340560	84.69656968010	3680	25	Tree	3.5	260	240	10.4	9.1
TR24	28.56703187620	84.69648678430	3679	25	Tree	7.1	3.7	3.5	18.7	15.7
TR25	28.56691958190	84.69650006260	3690	33	Tree	11.2	6.2	5.3	27.5	22.1
TR26	28.56705340560	84.69656968010	3678	78	Tree	18	790	690	41.4	39.9
TR27	28.56705340560	84.69656968010	3678	38	Tree	11.2	680	590	28.8	26.5

TR28	28.56710340560	84.69656968010	3673	35	Tree	10.1	540	460	27	22.1
TR29	28.56714854620	84.69652011430	3671	22	Tree	6.7	370	350	18.1	15
TR30	28.56714854620	84.69647011430	3672	43	Tree	9.2	840	780	30.3	27
TR31	28.56711521620	84.69648678430	3674	36	Tree	6.1	420	390	16.5	14.2
TR32	28.56723673560	84.69655302010	3666	27	Tree	2.9	300	220	9	7.5
TR33	28.56722006560	84.69655302010	3669	55	Tree	13	7.8	7.1	30.9	26.5
TR34	28.56705291190	84.69645006260	3680	59	Tree	15	720	490	36.5	29.2
TR35	28.56703624190	84.69645006260	3680	16	Tree	3.4	78	50	8.2	6.5
TR36	28.56713624190	84.69645006260	3675	36	Tree	4.2	300	250	10	8
TR37	28.56729238440	84.69668709920	3661	25	Tree	4.2	320	90	11.4	9.1
TR38	28.56735905440	84.69667043920	3659	31	Tree	3.4	280	210	9.3	7.2
TR39	28.56715291190	84.69660006260	3670	31	Tree	6.2	420	360	18	16
TR40	28.56759783350	84.69672794810	3643	106	Tree	9	4.2	3.6	19.7	19
TR41	28.56718575490	84.69658760550	3670	34	Tree	8.2	420	360	18.3	14.9
TR42	28.56703624190	84.69658339260	3678	38	Tree	4.6	260	230	11.3	9.4
TR43	28.56649721890	84.69633123210	3727	31	Tree	9.1	460	380	15.2	13.4
TR44	28.56721908490	84.69662094550	3667	24	Tree	3.3	650	280	9.5	6.7
TR45	28.56718624190	84.69665006260	3669	37	Tree	4.3	280	210	10.8	9
TR46	28.56721958190	84.69660006260	3668	20	Tree	3	240	210	6.4	5
TR47	28.56720291190	84.69655006260	3669	36	Tree	3.2	310	240	8.5	6.4
TR48	28.56687990210	84.69654257510	3689	21	Tree	2.6	210	190	7.8	5.8
TR49	28.56721958190	84.69658339260	3668	38	Tree	5.5	350	320	15	13.2
TR50	28.56735291190	84.69661673260	3659	17	Tree	3.2	250	210	8	6.4
TR51	28.56753220110	84.69667724090	3649	35	Tree	7.2	490	410	20.3	17.2
TR52	28.56750826160	84.69655394130	3650	78	Tree	7.8	380	290	21.5	21
TR53	28.56732492160	84.69660394130	3663	24	Tree	6.9	460	440	17.2	15.8
TR54	28.56734159160	84.69662060130	3659	23	Tree	2.6	250	140	6.3	4.9
TR55	28.56751958190	84.69658339260	3650	33	Tree	6.9	450	360	16.5	13.6
TR56	28.56753624190	84.69661673260	3649	18	Tree	2.8	160	120	6	5
TR57	28.56740291190	84.69661673260	3657	15	Tree	2.7	250	190	6	4.1
TR58	28.56740291190	84.69663339260	3657	22	Tree	2.7	240	180	7.7	4.9
TR59	28.56730291190	84.69671673260	3661	28	Tree	3.5	160	150	9.1	5.8
TR60	28.56730291190	84.69671673260	3661	21	Tree	25	140	90	7.2	4.5
TR61	28.56733575490	84.69662094550	3659	21	Tree	2.8	320	290	7	5

TR62	28.56733575490	84.69662094550	3659	19	Tree	2.4	280	250	6.6	4.5
TR63	28.56738834370	84.69670508740	3656	68	Tree	18	920	780	44	34.4
TR64	28.56745501370	84.69670508740	3654	26	Tree	3.2	290	240	10.2	8
TR65	28.56750501370	84.69663841740	3652	26	Tree	3.6	270	190	11.5	7.8
TR66	28.56752167370	84.69668841740	3649	75	Tree	8	750	680	35.5	30
TR67	28.56763408630	84.69681650710	3642	33	Tree	3.6	210	150	8.4	6.9
TR68	28.56753743160	84.69675425800	3648	51	Tree	4.8	220	110	10.5	8.8
TR69	28.56758834370	84.69663841740	3647	21	Tree	2.8	170	150	5.5	4.5
TR70	28.56758834370	84.69660508740	3647	23	Tree	3.3	250	190	9.4	7
TR71	28.56750291190	84.69658339260	3653	35	Tree	5.9	310	280	16.7	13.8
TR72	28.56753624190	84.69663339260	3649	17	Tree	3.2	160	90	7.6	5.5
TR73	28.56760291190	84.69671673260	3643	31	Tree	8.2	500	460	26	23
TR74	28.56765291190	84.69670006260	3640	33	Tree	4.3	340	290	9	7
TR75	28.56770291190	84.69665006260	3636	27	Tree	7	390	360	39	34
TR76	28.56766521620	84.69678904820	3640	34	Tree	7.8	360	290	15	13.2

CD (a_cm): Crown diameter at longest section, CD (b_cm): crown diameter at shortest section, BD: Basal diameter, DBH: Diameter at breast height, cm: centimeter

Appendix IIIb

Saplings inventory and stand structure data of *Abies spectabilis* at Lho village

Code	Latitude	Longitude	Elevation(m)	Age	Type	Height(m)	CD (a_cm)	CD(b_cm)
SP01	28.56685	84.69649	3694	19	Sapling	1.97	151	81
SP02	28.56671	84.69644	3706	22	Sapling	1.18	90	51
SP03	28.56652	84.69638	3721	19	Sapling	1.04	64	34
SP04	28.56676	84.6963	3705	16	Sapling	0.83	32	19
SP05	28.56684	84.69642	3695	18	Sapling	1.14	140	135
SP06	28.56687	84.69641	3695	18	Sapling	1.31	168	145
SP07	28.56666	84.69639	3711	16	Sapling	0.61	69	68
SP08	28.56701	84.69659	3680	28	Sapling	0.69	34	10
SP09	28.56699	84.69649	3683	18	Sapling	0.72	67	59
SP10	28.56704	84.69652	3679	12	Sapling	0.31	43	33
SP11	28.56678	84.69645	3702	13	Sapling	0.95	46	39
SP12	28.56714	84.69657	3673	15	Sapling	0.76	44	40
SP13	28.5673	84.69664	3662	17	Sapling	1.17	160	100
SP14	28.56756	84.69674	3645	16	Sapling	0.73	98	97
SP15	28.56732	84.69662	3662	24	Sapling	1.27	140	135
SP16	28.56689	84.69638	3693	13	Sapling	0.33	30	23
SP17	28.56675	84.69633	3705	12	Sapling	0.35	35	30
SP18	28.56684	84.69642	3695	18	Sapling	0.45	48	45
SP19	28.56686	84.69644	3695	24	Sapling	1.32	153	149
SP20	28.56692	84.69637	3693	15	Sapling	0.6	101	51.5
SP21	28.56691	84.69642	3691	13	Sapling	0.38	25	18
SP22	28.56689	84.69644	3691	14	Sapling	0.45	52	47
SP23	28.56689	84.69642	3691	11	Sapling	0.28	28	22
SP24	28.56689	84.69642	3691	16	Sapling	0.99	93	91
SP25	28.56688	84.69644	3695	13	Sapling	0.91	157	117
SP26	28.56688	84.69652	3689	13	Sapling	0.35	54	38
SP27	28.56661	84.69628	3717	13	Sapling	0.36	67	56

SP28	28.56685	84.6965	3694	9	Sapling	0.32	39	29
SP29	28.56687	84.6965	3694	10	Sapling	0.22	24	18
SP30	28.56687	84.69652	3693	17	Sapling	1.4	88	76
SP31	28.56693	84.6965	3687	18	Sapling	1.79	131	120
SP32	28.56691	84.69642	3691	20	Sapling	1.18	102	48
SP33	28.56699	84.69659	3680	12	Sapling	0.36	49	31
SP34	28.56697	84.69655	3682	18	Sapling	0.87	91	83
SP35	28.56763	84.69674	3643	16	Sapling	1.35	105	90
SP36	28.5671	84.69655	3674	7	Sapling	0.2	18	16
SP37	28.56699	84.69638	3685	10	Sapling	0.53	17	5
SP38	28.56697	84.69644	3684	6	Sapling	0.2	25	5
SP39	28.567	84.69657	3680	15	Sapling	0.53	79	69
SP40	28.567	84.69657	3680	14	Sapling	0.57	79	69
SP41	28.56704	84.69659	3678	15	Sapling	0.49	47	39
SP42	28.56699	84.69659	3680	14	Sapling	0.63	29.5	5
SP43	28.56696	84.69644	3688	13	Sapling	0.35	46	24
SP44	28.56694	84.69644	3688	17	Sapling	0.49	65	45
SP45	28.56697	84.6964	3685	10	Sapling	0.42	61	29.2
SP46	28.56699	84.69642	3684	8	Sapling	0.25	25	5
SP47	28.56705	84.69655	3679	16	Sapling	0.77	123	92
SP48	28.5666	84.69635	3719	6	Sapling	0.3	33	24
SP49	28.56661	84.69642	3713	5	Sapling	0.22	11.6	6
SP50	28.56705	84.69647	3679	13	Sapling	0.374	54	31
SP51	28.5671	84.69643	3675	12	Sapling	0.42	50	46
SP52	28.56714	84.69643	3675	10	Sapling	0.28	33	23
SP53	28.56714	84.69643	3675	13	Sapling	0.434	60	48
SP54	28.56717	84.6965	3672	20	Sapling	1.03	125	90
SP55	28.56714	84.69648	3674	11	Sapling	0.48	40	32
SP56	28.56715	84.69643	3673	25	Sapling	1.89	131	60
SP57	28.56729	84.69669	3661	17	Sapling	0.98	130	60
SP58	28.56731	84.69669	3661	19	Sapling	0.995	54	45
SP59	28.56731	84.69669	3661	11	Sapling	0.342	42	24
SP60	28.5665	84.69628	3729	10	Sapling	0.901	96	90
SP61	28.56725	84.69648	3667	20	Sapling	1.726	160	140

SP62	28.56719	84.69652	3671	16	Sapling	0.44	61	52
SP63	28.56719	84.69648	3672	17	Sapling	1.723	120	90
SP64	28.56717	84.6966	3670	11	Sapling	0.362	57	54
SP65	28.56727	84.69659	3665	12	Sapling	0.532	102	65
SP66	28.56727	84.69659	3665	7	Sapling	0.219	28	18
SP67	28.5673	84.69662	3662	20	Sapling	0.826	126	105
SP68	28.56729	84.6966	3663	13	Sapling	0.384	52	37
SP69	28.56729	84.6966	3663	11	Sapling	0.302	24	10
SP70	28.56722	84.69664	3667	16	Sapling	0.508	64	41
SP71	28.56727	84.69664	3664	7	Sapling	0.204	15	5
SP72	28.56729	84.69662	3662	7	Sapling	0.202	29	21
SP73	28.56729	84.69664	3662	20	Sapling	1.196	210	190
SP74	28.5672	84.69665	3667	12	Sapling	0.414	39	37
SP75	28.5672	84.69665	3667	15	Sapling	0.643	104	63
SP76	28.56724	84.69652	3669	18	Sapling	1.396	180	160
SP77	28.56725	84.69652	3666	14	Sapling	0.559	39	28
SP78	28.56727	84.6965	3667	20	Sapling	1.722	174	149
SP79	28.5674	84.69672	3656	14	Sapling	0.48	91	41
SP80	28.56729	84.69652	3663	14	Sapling	0.52	89	50
SP81	28.56742	84.69662	3654	19	Sapling	0.43	92	60
SP82	28.56731	84.69655	3663	17	Sapling	0.5	68	51
SP83	28.56731	84.69655	3663	21	Sapling	0.61	62	42
SP84	28.56744	84.69657	3655	11	Sapling	0.37	28	25
SP85	28.56745	84.69655	3656	23	Sapling	1.28	155	97
SP86	28.56734	84.69655	3661	15	Sapling	0.53	48	26
SP87	28.56743	84.69668	3654	15	Sapling	0.54	63	49
SP88	28.56745	84.69668	3654	11	Sapling	0.38	57	42
SP89	28.56747	84.69668	3651	12	Sapling	0.27	50	48
SP90	28.56739	84.69664	3657	12	Sapling	0.3	36	25
SP91	28.56753	84.69668	3649	13	Sapling	0.31	49	30
SP92	28.56752	84.69662	3649	20	Sapling	1.1	105	94
SP93	28.56747	84.69658	3653	10	Sapling	0.29	19	12
SP94	28.56745	84.69662	3654	16	Sapling	0.65	91	79
SP95	28.56745	84.69662	3654	9	Sapling	0.25	27	8

SP96	28.56747	84.69663	3652	16	Sapling	0.84	105	76
SP97	28.5674	84.69662	3657	8	Sapling	0.19	19	3
SP98	28.56742	84.69662	3654	5	Sapling	0.22	23	15
SP99	28.56734	84.69664	3659	17	Sapling	0.9	132	114
SP100	28.56757	84.69666	3647	19	Sapling	1.31	106	88
SP101	28.56754	84.69675	3648	19	Sapling	1.44	120	80
SP102	28.56761	84.69661	3643	15	Sapling	1.02	130	90
SP103	28.56761	84.69666	3644	11	Sapling	0.27	20	12
SP104	28.56754	84.69663	3649	23	Sapling	1.31	95	62
SP105	28.5675	84.6967	3651	21	Sapling	1.02	96	75
SP106	28.56759	84.69673	3645	22	Sapling	1.08	73	50
SP107	28.56765	84.6967	3640	12	Sapling	0.31	37	5
SP108	28.56765	84.6967	3640	18	Sapling	0.88	97	41
SP109	28.56752	84.69662	3649	22	Sapling	1.1	75	61
SP110	28.56752	84.69672	3648	15	Sapling	0.69	23	4
SP111	28.56752	84.69672	3648	17	Sapling	0.78	44	21
SP112	28.56697	84.69659	3680	11	Sapling	0.26	13	7

Appendix IIIc

Seedlings inventory and stand structure data of *Abies spectabilis* at Lho village

Code	Latitude	Longitude	Elevation(m)	Age	Type	Height(m)
SD1	28.56653	84.69625	3726	1	Seedling	0.044
SD2	28.56724	84.69644	3668	12	Seedling	0.151
SD3	28.56622	84.69623	3753	5	Seedling	0.157
SD4	28.56693	84.69643	3688	6	Seedling	0.134
SD5	28.56706	84.69652	3676	1	Seedling	0.04
SD6	28.56697	84.69657	3680	1	Seedling	0.078
SD7	28.5666	84.69624	3722	1	Seedling	0.032
SD8	28.56699	84.69657	3680	1	Seedling	0.04
SD9	28.56699	84.69657	3680	1	Seedling	0.053
SD10	28.567	84.69638	3685	1	Seedling	0.06
SD11	28.5671	84.69657	3673	1	Seedling	0.049
SD12	28.56715	84.69653	3671	1	Seedling	0.049
SD13	28.56739	84.69671	3656	1	Seedling	0.05
SD14	28.56697	84.69644	3684	1	Seedling	0.06
SD15	28.56697	84.69644	3684	1	Seedling	0.09
SD16	28.56697	84.69644	3684	1	Seedling	0.032
SD17	28.56699	84.69659	3680	1	Seedling	0.05
SD18	28.56699	84.69659	3680	1	Seedling	0.021
SD19	28.56699	84.69659	3680	1	Seedling	0.039
SD20	28.56694	84.69644	3688	1	Seedling	0.078
SD21	28.56694	84.69644	3688	1	Seedling	0.055
SD22	28.56699	84.69642	3684	4	Seedling	0.102
SD23	28.56699	84.69642	3684	1	Seedling	0.033
SD24	28.56705	84.69655	3679	1	Seedling	0.06
SD25	28.56704	84.69657	3678	1	Seedling	0.049
SD26	28.56704	84.69657	3678	1	Seedling	0.05
SD27	28.56715	84.69647	3672	1	Seedling	0.043

SD28	28.56715	84.69647	3672	1	Seedling	0.041
SD29	28.56724	84.69655	3666	1	Seedling	0.05
SD30	28.56724	84.69655	3666	1	Seedling	0.04
SD31	28.56724	84.69655	3666	1	Seedling	0.042
SD32	28.56724	84.69655	3666	1	Seedling	0.031
SD33	28.56717	84.69657	3670	1	Seedling	0.046
SD34	28.56707	84.69643	3678	1	Seedling	0.046
SD35	28.56714	84.69647	3674	2	Seedling	0.078
SD36	28.56715	84.6964	3673	4	Seedling	0.141
SD37	28.56715	84.6964	3673	5	Seedling	0.167
SD38	28.5676	84.6967	3644	1	Seedling	0.06
SD39	28.5676	84.69672	3643	1	Seedling	0.045
SD40	28.56742	84.69652	3656	7	Seedling	0.145
SD41	28.56745	84.69669	3654	4	Seedling	0.093
SD42	28.56737	84.6966	3658	1	Seedling	0.052
SD43	28.56737	84.69659	3658	1	Seedling	0.061
SD44	28.56737	84.69659	3658	1	Seedling	0.05
SD45	28.56747	84.69662	3652	4	Seedling	0.135
SD46	28.5674	84.69662	3657	1	Seedling	0.05
SD47	28.56771	84.69674	3637	1	Seedling	0.06
SD48	28.56742	84.69663	3654	1	Seedling	0.045
SD49	28.56742	84.69663	3654	3	Seedling	0.123
SD50	28.56742	84.69663	3654	1	Seedling	0.05
SD51	28.56745	84.69665	3654	1	Seedling	0.115
SD52	28.56745	84.69665	3654	1	Seedling	0.056
SD53	28.56741	84.69666	3657	1	Seedling	0.05
SD54	28.56741	84.69666	3657	1	Seedling	0.05
SD55	28.56741	84.69666	3657	1	Seedling	0.051
SD56	28.56754	84.69666	3649	1	Seedling	0.035
SD57	28.56754	84.69666	3649	1	Seedling	0.051
SD58	28.56724	84.69655	3666	1	Seedling	0.03
SD59	28.56756	84.69662	3647	1	Seedling	0.037
SD60	28.56756	84.69664	3647	1	Seedling	0.034
SD61	28.56754	84.69664	3649	1	Seedling	0.055

SD62	28.56754	84.69664	3649	1	Seedling	0.06
SD63	28.56754	84.69664	3649	1	Seedling	0.054
SD64	28.56757	84.69666	3647	3	Seedling	0.126
SD65	28.56754	84.69675	3648	1	Seedling	0.05
SD66	28.56761	84.69666	3644	1	Seedling	0.07
SD67	28.56759	84.69661	3647	1	Seedling	0.06
SD68	28.56747	84.69673	3650	8	Seedling	0.142
SD69	28.5676	84.69672	3643	1	Seedling	0.045
SD70	28.5676	84.69672	3643	1	Seedling	0.06
SD71	28.5676	84.69672	3643	1	Seedling	0.054
SD72	28.5677	84.69665	3636	1	Seedling	0.025
SD73	28.5677	84.69665	3636	1	Seedling	0.031
SD74	28.5677	84.69665	3636	1	Seedling	0.034
SD75	28.56772	84.69665	3636	1	Seedling	0.035

Appendix IV

Photographs

Plate 1: Study site

Plate 2: Seedling at highest altitude

Plate 3: DBH measurement

Plate 4: Height measurement by Clinometer

Plate 5: Sapling of *A. spectabilis*

Plate 6: Coring of *A. spectabilis*