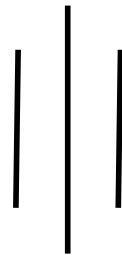


**Treeline Ecotonal Dynamics: A Case Study from *Pinus wallichiana*
Forest in Ngawal, Manang, North-Central Nepal**



A Dissertation

**for the partial fulfillment of the requirement for the Master Degree in
Environmental Science**



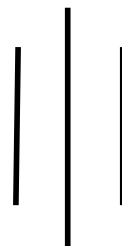
Submitted to

Central Department of Environmental Science

Institute of Science and Technology

Tribhuvan University

Kirtipur, Kathmandu, Nepal



Submitted by

Raju Bista

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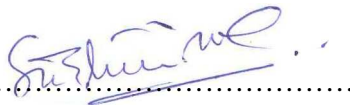
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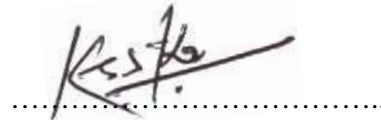
LETTER OF RECOMMENDATION

This is to certify that the dissertation entitled “**Treeline Ecotonal Dynamics: A Case Study from *Pinus wallichiana* Forest in Ngawal, Manang, North-Central Nepal**” prepared by **Mr. Raju Bista** for partial fulfillment of the requirements for the completion of Master’s Degree in Environmental Science (Mountain Environment) has been carried out under our supervision and guidance. To our knowledge, the results presented in this dissertation are original and have not been submitted to any other degree. We therefore recommend this work for the approval and acceptance.



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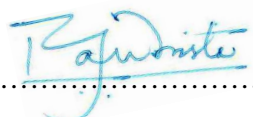


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DECLARATION

I, **Raju Bista**, hereby declare that the dissertation work entitled “**Treeline Ecotonal Dynamics: A Case Study from *Pinus wallichiana* Forest in Ngawal, Manang, North-Central Nepal**” presented herein is my own work, done originally by me and has not been submitted or published elsewhere and all sources of information used are duly acknowledged.



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Kirtipur
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Date: Dec 29, 2011

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LETTER OF APPROVAL

The dissertation presented by **Mr. Raju Bista** entitled “**Treeline Ecotonal Dynamics: A Case Study from *Pinus wallichiana* Forest in Ngawal, Manang, North-Central Nepal**” has been approved as a partial fulfillment of the requirement for the completion of the Master’s Degree in Environmental Science.

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Raju Bista

ABSTRACT

Global warming is now a scientifically established fact and this is also known to influence treeline structure. This study tried to have a glance and inkling through size, age structure and regeneration of Himalayan Blue Pine (*Pinus wallichiana*) on the treeline ecotone of Ngawal, Manang in south facing slope of the trans-Himalayan dry valley. Three vertical transects (20 m width) were laid across the treeline ecotone from forest line to treeline. Age of individual trees within the transects was determined based on the number of annual rings counted from increment cores whereas age of juveniles saplings and seedlings was estimated by counting branch whorls and scars left on stem. Almost reverse J-shaped size and age structure showed that the majority of the pine population was recruited from 1970s. The current timberline position is ca. 3930 m a.s.l. whereas the treeline position in the area is ca. 4020 m a.s.l. that with age-height regression model is estimated to be attained by early 1990s. Despite the absence of recent treeline advance, the progressive densification in the treeline ecotone as well as seedlings and saplings establishment above the treeline may indicate the future potential for the advance. Even under the current warming scenario of Nepal Himalaya, the ecotonal responses could not be predicted by climate warming alone but marked release in human pressure might have synchronous effect and for the disentangling pursuit, future studies incorporating both climate and anthropogenic aspects are proposed.

Key words: Age structure, Climate change, *Pinus wallichiana*, Population dynamics, Treeline, Treeline ecotone

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ACRONYMS AND ABBREVIATIONS

AD	: of the Christian era (from the Latin <i>anno domini</i>)
BD	: Basal Diameter
ca.	: about, approximately (from the Latin <i>circa</i>)
CDES	: Central Department of Environmental Science
cm	: Centimeter
°C	: Degree Celsius
DBH	: Diameter at Breast Height
DHM	: Department of Hydrology and Meteorology, Nepal
<i>et al.</i>	: and others (from the Latin <i>et alii</i>)
etc.	: and so forth (from the Latin <i>et cetera</i>)
Fig.	: figure
GHGs	: Green House Gases
GLOF	: Glacier Lake Outburst Flood
ha.	: Hectare(s)
IPCC	: Intergovernmental Panel on Climate Change
i.e.	: that is to say, in other words (from the Latin <i>id est</i>)
Km	: Kilometer(s)
Km²	: Square kilometer
m	: Meter
m²	: Square meter
mm	: Millimeter
m a.s.l.	: Meter above sea level
NAST	: Nepal Academy of Science and Technology
TU	: Tribhuvan University
VDC	: Village Development Committee
WWF	: World Wide Fund

Chapter: I

INTRODUCTION

1.1 General Background

High altitude treeline ecotone, forming sharp transition between the closed forest and the treeless alpine shrub land, (Hofgaard, 1997; Fagre, 2009) is one of the most conspicuous ecosystem boundaries on the earth (Paulsen *et al.*, 2000; Holtmeier, 2003; Moen *et al.*, 2004; Autio, 2006). The conspicuousness of this boundary and the clear links to climate makes treeline a promising and reliable proxy for studying ecosystem responses to ongoing climate change (Dullinger *et al.*, 2004; Esper *et al.*, 2006; Fagre, 2009). Thus, treeline ecotones are considered as sensitive biomonitors of past and recent climate change and variability (Kullman, 1998; Camarero and Gutiérrez, 2004; Wang *et al.*, 2006). As the treeline is a result of many factors that are unfavorable for tree regeneration and growth, with approaching the climatic limit, tree stature decreases and tree individuals are increasingly deformed by adverse climatic effects (Holtmeier and Broll, 2005). Upper part of the treeline ecotone is characterized by the dwarf, crooked, prostrate, stunted structures of the trees. There is a strong thermal advantage of being short, which is why dwarfed/shrubby form succeed at high elevation whilst trees do not (Grace *et al.*, 2002).

Vegetation patterns along altitudinal gradients change markedly in treeline ecotones. Therefore, altitudinal ecotones are the most dynamic sites for investigating the altitudinal distributions of plant species under the influence of climatic conditions (Takahashi *et al.*, 2003). There are steep thresholds of climate sensitivity at treeline (Lloyd and Fastie, 2002). In the treeline ecotone, the flora in its distributional margin occurs at its autecological limit (Brubaker, 1986). This is the area where limits of tree adaptation to various abiotic constraints, such as harsher climate, rocky substrates; interactions with biological processes, such as competition, facilitation of seedling establishment (Fagre, 2009) and anthropogenic activities (Holtmeier, 2003) produce a complex mosaic of surviving trees i.e. many abiotic, biotic and anthropogenic influences on the flora are interrelated in a complex way (Holtmeier, 2003). However, climate is the main abiotic factor having significant influence in the position of treeline and timberlines (Grace *et al.*, 2002; Körner and Paulsen, 2004; Holtmeier and Broll, 2005). The primary climatic limitation on tree establishment is the combined

effects of growing-season temperatures, and duration of snowpack (Brubaker, 1986). Air temperature is the prominent climatic factor which affects the altitudinal limit of vegetation (Tranquillini, 1979; Daniels and Veblen, 2004; Körner and Paulsen, 2004).

As alpine treelines are determined mainly by heat deficiency, they are considered particularly sensitive to altered temperature regimes. Global warming of the air may have a more significant effect (Rolland *et al.*, 1998). The sensitivity of treelines to environmental change implies a certain state of readiness of the trees to respond to changing conditions and the response can be the changes on growth, in growth forms, in regeneration, in treeline structures (Holtmeier and Broll, 2005), in composition and position of treeline (Grace *et al.*, 2002). Trees respond to climatic warming with advance to more northerly latitude (towards pole) and to higher elevations (Innes, 1991; Grace *et al.*, 2002; Dullinger *et al.*, 2004; Holtmeier and Broll, 2005) and also with increase in tree density (Szeicz and MacDonald, 1995; Camarero and Gutiérrez, 2004; Moen *et al.*, 2004). Currently, there is much interest in the rate at which the treeline may advance in response to environmental change, especially global warming. Migration of treeline species to higher positions, increase in growth rate and rise in treeline position in response to recent climate change (over the last 20th century) have been documented in several treelines in the northern hemisphere (Brubaker, 1986; Rochefort *et al.*, 1994; Meshinev *et al.*, 2000; Camarero and Gutiérrez, 2004; Kullman, 2002, 2005; Motta and Nola, 2001; Paulsen *et al.*, 2000; Kirdeyanov *et al.*, 2011) and the trend have been particularly visible in the last decades (Szeicz and MacDonald, 1995; Paulsen *et al.*, 2000; Lloyd and Fastie, 2002). The trend and changes in treeline structure and position is generally attributed to recent warming (Innes, 1991), as summer temperatures are generally the main limiting factor for tree radial growth (Tranquillini, 1979).

The treeline species are at the threshold of their climatic limit. Any change in climate which perturbs the vegetation-climate equilibrium, will lead to significant changes in demographic patterns of these species (Dubey *et al.*, 2003). Global warming will facilitate treeline advance to greater altitude and latitudes. However, the sensitivity of treelines to environmental change, particularly to climate warming, varies with local and regional topographical conditions and thus differs as to its extent, intensity and the process of change (Holtmeier and Broll, 2005). To some extent, archived climate

information on various timescales can be gathered from fluctuations of treelines (Kullman, 1996). The position of the tree limit has been suggested as a sensitive indicator of climate change (Kullman, 1998) and regeneration success also is probably a better indicator of the sensitivity of the treeline ecotone to environmental change (Holtmeier and Broll, 2005). Recruitment of seedlings above the treeline apparently reflects improved climatic conditions. Hence, treeline ecotones are ideally suited for climate change monitoring (Becker *et al.*, 2007) and the treeline is considered as a key to understanding ecosystem responses to climate change. The changes in the vegetation dynamics around the treeline ecotones can be attributed mainly to climate, especially climate warming in the recent decades but the changes are associated with many other local and regional environmental factors.

1.2 Rationale of the Study

Now a days, more interests have been arisen about treeline, treeline advance and treeline dynamics in response to environmental changes particularly global warming. The shift in the species ranges and movement of tree species to higher elevations is a well-documented biological response to climate warming (Rochefort *et al.*, 1994). It has been almost axiomatic and unequivocal that favorable climatic conditions are conducive to stand densification, new seedling establishment and recruitments within, above treeline, and as a whole to upslope shift of treeline. The climate-population dynamics at the treeline ecotone area can facilitate the understanding of the effects of global warming on tree regeneration and the recruitment at/by treeline ecotone. Age structure, among various parameters, is essential for reconstruction of the stand history. Population dynamics of tree species at treeline ecotones are considered as the most acceptable evidence of climate change (Payette and Fillion, 1985; Szeicz and MacDonald, 1995) where climatic warming may cause increase in growth rate, tree density, tree establishment there and treeline shift. The static age structure of living trees expresses the change in the rate of tree recruitment and mortality over time (Harcombe, 1987). Because the long lifespan of trees precludes the direct observation of population growth and decline, the age structure is an indirect source of information to infer population responses.

For monitoring pursuits and to understand the consequences of palaeo-climatic variability on treeline dynamics in the trans-Himalayan dry region, this study has been

carried out. In this study, it was hypothesized that recent environmental changes have affected dynamics of the treeline in the study area with some influence in the species densification, age and size distribution, altitudinal migration of treeline forming species in the treeline ecotone. Moreover, the age of trees would be found to decline with increasing altitude and the age structure would be inverse J-shaped which suggests gradual upward recruitment. In the current scenario of global warming, this study corroborates assumptions that warming climate regime might facilitate densification and the upslope migration of the treeline species.

1.3 Objectives

The broad objective of this study was to examine the treeline dynamics of *Pinus wallichiana* at Ngawal, Manang.

Specific:

- 1) To analyze age structure pattern across the treeline ecotone through the observations of the regeneration, recruitment, stand densification and enhancement of treeline forming species.
- 2) To develop age vs. height regression model to understand patterns of age and height distribution within the ecotone.
- 3) To estimate the present altitudinal position of treeline/forest line, the stability of the limits during recent decades.
- 4) To estimate the potential for the pine treeline advance.

1.4 Limitations of the Study

- 1) Study was carried out in Ngawal which is not representative of whole trans-Himalayan region.
- 2) Climate data of the nearby site was not available. The nearest climate station Chame is about 18 km away from the study site.
- 3) This study was focused only on treeline forming tree and does not encompass the anthropozoogenic aspects.
- 4) Considering the sensitivity of such area, only one core was taken from a tree as far as possible. Age of saplings and seedlings were estimated from branch whorl and scars as cut samples were avoided. For this reason the significance of counting whorls as surrogate of ageing couldn't be tested.

Chapter: II

LITERATURE REVIEW

2.1 Climate Warming

Global warming is already happening and Climate change is now a scientifically established fact. Unprecedented and significant spurt in global population increase and widespread industrialization following a fossil fuel based economic developmental path have been considered the culprit resulting in an accelerated and exponential increase in Green House Gases (GHGs) concentration in the atmosphere and the unequivocal warming of the recent global climate system is very likely and predominantly due to increase in anthropogenic greenhouse gas concentrations in the atmosphere (IPCC, 2001). The GHGs have vital role in disturbing and changing the earth's energy balance with their increased emissions and increased radiating forcing that poses the earth and the earth's natural systems to an encumbering menace.

The global average surface temperature has been soaring all over the world especially in the 20th century during which global temperature increased by approximately $0.6 \pm 0.2^{\circ}\text{C}$ and the century was the warmest century since more than past 1000 years (IPCC, 2001; 2007) with strong effects and implications on global biomes, ecosystems and biodiversity, change in vegetation and species composition (Beniston, 2003), on altitudinal and polar ice covers, sea level, rainfall patterns, water stress and insecurity, various climate disasters, agricultural production and food security, treeline dynamics and many other aspects of ecosystems.

2.2 Alpine Ecosystem Responses to Global Warming

High mountain regions (rich repositories of biodiversity) are exceptionally sensitive to climatic variations and conspicuous interactions exist between these ecosystems and climate (Esper *et al.*, 2002). Impacts on high mountain systems including snow cover, permafrost, glaciers and glacial lakes are amongst the most directly discernible signals of global climate warming in the high altitude areas. Climate change has been linked to a cascade of disasters like increased incidence of avalanches, expansion of glacial lakes, retreat or disappearance of glaciers, proliferation of Glacial Lake Outburst Floods (GLOF) in the high mountain areas. In

the later half of the 20th century, an increased rate of retreat has been observed in most glaciers around the world including the Himalayas (Rao *et al.*, 2008). Visible impact of global warming is also found pronounced in the alpine species range. Invasion of lower elevation species into upward alpine zone (shift), increased growth rates and densification towards last decades (Paulsen *et al.*, 2000; Motta and Nola, 2001; Camarero and Gutiérrez, 2004; Moen *et al.*, 2004), shift of treeline position (Brubaker, 1986; Rochefort *et al.*, 1994; Meshinev *et al.*, 2000; Camarero and Gutiérrez, 2004; Kullman, 2002; 2005; Motta and Nola, 2001; Paulsen *et al.*, 2000) are pronounced vegetation response to climate warming.

Understanding dynamics at the upper limits is a key element in the investigation of global changes (Luckman, 1996). There exist conspicuous interactions between ecosystems and climate in high mountain region. High mountain ecosystems are considered particularly vulnerable to climate change (Beniston, 1994; 2003) that is why this region offers its important scope of climate change study. Along the altitudinal gradient, temperature decreases in the standard atmosphere by 0.65°C per 100 m (Gregg, 1949 cited in Autio, 2006). Low temperature is the most important factor limiting plant growth and development at higher elevations area whereas, short growth season, low incoming solar radiation, lack of sufficient water, and wind also play the role in physiological and morphological processes and changes. Near the edge of species ranges radial growth rates shift dramatically in response to climatic variations. In High altitude ecosystems, treeline area in particular, the component species survive, grow or sustain at the extreme limit of climatic tolerances. Due to climatic warming, species characterized by an inherent sensitivity to climate change will migrate upwards in future because the climatic threshold position also rises accordingly with temperature. Species have to cope the increasing temperature by two ways: 1) they have to adapt to the warmer temperature there or 2) should migrate towards cooler area upward in the mountain or pole ward. Hence, mountain ecosystems are the good indicator of global temperature change and depict the same by shifting the range towards colder region (Holtmeier and Broll, 2005; Körner and Paulsen, 2004) i.e. upslope. Global warming may cause forest damage through migration of forests towards the polar or high altitude region, change in their composition (WWF Nepal, 2006).

Various studies have reported that recent global warming is affecting terrestrial biological systems, leading to pole ward or upward shifts in ranges in plant and animal species (Parmesan *et al.*, 2000; Meshinev *et al.*, 2000; Gehrig-Fasel *et al.*, 2007; Grabherr *et al.*, 1994; Holtmeier and Broll, 2005; Kullman, 2002). For example, in a study in Austrian Alps, Dirnböck *et al.* (2003) discusses that alpine plant species on mountain ranges with restricted habitat availability above the treeline will experience severe fragmentation and habitat loss if the mean annual temperature increases by 2°C or more. The upward advance of the forest with the advent of prolonged and continued climate warming may result even more far-reaching transformation and diminution of the alpine landscape. Shifts in species ranges during past major global climate changes indicate that all species have climate limitations beyond which they cannot survive (Xu *et al.*, 2007). However the abilities of species to respond to a changing climate vary. In contrast, disagreement also persists with this mainstream. For example, Wang *et al.* (2006) concluded that a directional increase in temperature will not necessarily result in an upslope shift on the *Picea schrenkiana* forest growing at altitudinal treeline in the central Tianshan Mountains and the same has been concluded by Daniels and Veblen (2004) in Northern Patagonia. Ninot *et al.* (2008) argued that the recruitment and growth of existing *Pinus uncinata* seedlings and saplings, unlikely to produce pronounced infilling and thus perceptible changes in high altitude forest cover in the Catalian Pyrenees.

Particularly, the treeline ecotone is a most useful paleoclimatic indicator, and treeline ecology has emerged as one of the fundamentals on which predictive global change ecology develops. Different empirical effect studies demonstrate that the alpine treelines respond even to the relatively small climatic shift that characterizes the past century, by changes in structure and elevation of the treeline (Kullman, 2005). Various studies of high-altitude treelines (the marginal ecosystem sites) demonstrate that 20th century climate warming has caused an increase in treeline elevation. Many of the plant species at upper elevational limits in western Himalaya have been found shifting to higher elevations with species and site-specific rates (Dubey *et al.*, 2003).

2.3 Climate Change and Treeline Dynamics

In order detect early indications of treeline responses to global warming, the study of growth dynamics within the treeline ecotone appears most promising (Paulsen *et al.*,

2000). Global warming is expected to increase tree growth and survival at the treeline because summer temperatures and length of the growing season strongly influence carbon production and shoot hardening (Brubaker, 1986). The critical role that temperature plays in controlling the reproduction, establishment and growth of trees in this environment, the alpine tree line ecotones are dynamic zones whose location is correlated with the isotherm of the mean temperature for the warmest month (Tranquillini, 1979). Temperature being the most prominent and influencing limiting factors, tree regeneration and growth there and population dynamics are particularly sensitive ecological responses of climate warming regimes.

The position of the treeline is also affected by physical and physiological factors. Physical factors which have a strong influence in determining the position of treeline are wind and snow. Nutrient and carbon limitations are the main physiological effects which affect the high altitude areas. As trees grow, the proportion of their tissues those are photosynthetic declines. “Carbon balance” hypothesis states that treeline is situated where the annual carbon fixation of trees doesn’t balance the carbon lost to respiration. The case is when the proportion of non-photosynthetic but respiring tissues accumulates and the “seasonal compression” hypothesis also emphasizes the carbon limitation that puts trees at a competitive disadvantage. As cold treeline approaches, the growing season shortens and at a threshold point beyond which trees are unable to fix enough carbon during the growth season to support them through the entire year and treeline marks that point (Stevens and fox, 1991).

Several other factors such as variation in the slope, aspect, latitudes, topography, prevalent winds, ground moisture and other anthropozoogenic factors like land use, deforestation also seen to influence the position of the treeline. Altitude of treeline generally decreases from equator towards poles. (Miehe *et al.*, 2007). The influence of light and moisture availability on the composition and structure of treeline species becomes evident when compared among slope aspects. For example: compared to treelines at the northern slope (where evapotranspiration is lower and soil water availability is relatively higher) treelines at the western or southern slopes of Changbai mountain occur at a lower altitude with lower stem density and larger gaps within stands (Liu, 1989). Holtmeier and Broll (2005) found treeline sensitivity to be

different for various time-scales: the medium-term response (some years to a few decades) is mirrored by increasing tree coverage in contrast to forest and tree-limit advance or retreat in the long term response (several decades to hundreds of years).

Apart from changes in the tree physiognomy, the spontaneous upsurge in tree recruitment and establishment coupled with increased tree density within the treeline ecotone and beyond the tree limit is considered to be the best indicator of treeline sensitivity to environmental changes (Harcombe, 1987; Motta and Nola, 2001). The sensitivity of the treeline to changing environments varies among different types of treeline. Response of treelines to changing environmental conditions varies among orographic, anthropogenic or climatically determined treeline. Orographic treelines occur commonly in mountainous areas where steep rock walls, slope debris, boulder screes, talus cones and avalanche chutes may limit the forest at relatively low elevation, whereas, solitary trees and tree groves may occur far above at sites protected from wasting and avalanches. Warmer climate will not cause an advance to a greater elevation as long as mass wasting, debris slides, etc. occur. But greatest sensitivity can be expected in anthropogenic treelines after cessation of human activities. Climatic limits of growth will occur only if no other factors, such as orography or human impact prevent tree growth from reaching its climatically caused altitudinal or northern limit (Holtmeier and Broll, 2005).

There is already a general trend toward increased growth in high altitude areas. Several reports show an increased growth of established trees and saplings above the treeline, which, in places, has increased the tree limit i.e. both treeline shift and stand densification have been evidenced. There are several evidences of widespread upward or northward advancement of timberlines and treelines in Europe. A meta-analysis of a global data set of 166 treeline sites showed treeline advance at 52% of sites since 1900 AD, stable in 47% sites and treeline recession only in 1% of the sites (Harsch *et al.*, 2009). A recent upward movement of treelines has been observed in the Swedish Scandes Mountain (Kullman, 2000; 2001) since the 1950s and a new phase of tree limit advance with the mild winters of the 1990s. Moen *et al.* (2004) studied simulated changes in the position of the upper treeline in the Swedish mountains in response to predicted climate change and they suggested that the drastic change would influence all aspects of mountain ecosystems, including biodiversity patterns and the

potential for reindeer husbandry and tourism development there. The advancing tree line has many implications like disrupting the alpine plant communities and possible replacement of rare species (Grace *et al.*, 2002). Juntunen *et al.* (2002) in a study of Scot pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) found increased tree density and basal area. Despite greater heterogeneity among localities, new regeneration and tree establishment during the study period indicate a potential for the tree line to advance.

Szeicz and MacDonald (1995) analyzed the white spruce dynamics at the alpine treeline in northwestern Canada over 100-150 years and found only minor changes in the upper limits of trees, but an increasing population density within the forest stands. Takahashi *et al.* (2003) studied altitudinal distributions of species in the altitudinal ecotone (Japan) and found *Abies veitchii* responded to climatic conditions in the previous year and *Betula ermanii* and *B. platyphylla* responded to conditions in the current year. It was discussed that the responses to climatic conditions in radial growth might differ among plant species. A corresponding displacement of the treeline of about 12 km towards Hudson Bay occurred since the late 1800s, most likely as a result of recent warming (Lescop-Sinclair and Payette, 1995). Most pronouncedly, the recent treeline shift resulted from the development of vertical stems from pre-established krummholz, suggesting that the stem growth was a direct response to favorable climate. And the absence of treeline trees originating from seeds indicates that recent warming in spite of favoring sexual reproduction, had favored development from krummholz, with conspicuous treeline shift.

Land abandonment was the most dominant driver for the establishment of new forest areas even at the European treeline ecotone. Land use change comes to be apparent for that to occur rather than due to climate warming although they undoubtedly speed it up. However, some fraction of upward shifts can be attributed to the recent climate warming. The tree establishment, and more in general the forest dynamic, has been mainly controlled by human land-use whereas the tree growth has been mainly climatically controlled and browsing activity is the main driving force in controlling the forest dynamics in the western Italian Alps (Motta *et al.*, 2006). Both climate and land-use change have influenced treeline dynamics in the Alps. At the end of the Little Ice Age, *Pinus cembra* establishment and radial growth in the Swiss Alps

treeline ecotone were simultaneously favored by warmer climate. This ecotone quickly shifted upslope in a natural treeline, while a 60-year delay was observed in an anthropogenic treeline, and only after a decrease of cattle activity (Vittoz *et al.*, 2008). In a study in Swiss Alps, Gehrig-Fasel *et al.* (2007) found a significant increase of forest cover and upward shifts within a band of 300 m below the potential regional treeline with both land use and climate change as likely drivers, the former one (land abandonment) being the most likely dominant driver for both forest ingrowths and a majority of the upward treeline shifts. It is argued that human activities if present can place the treeline position lower than the potential (regional or climatic) position due to sole climate warming.

Batllori & Gutiérrez (2008) argued in favor of fact that the recent synchronous trend of ecotone densification since the 1950s occurred in the context of climatic warming and substantial land use abandonment and found a progressive decline in tree age and size (height and basal diameter) through the altitudinal gradient and presence of step-like treeline transition patterns in tree age as the most common pattern in the treeline ecotones studied in Iberian eastern range of the Pyrenees, Spain. Hofgaard (1997) from the study of treeline in the central Scandes Mountains of Norway concludes that future vegetation responses to diminished grazing pressure are likely to override responses forced by changing climate. Such responses could easily be misinterpreted as being governed by climate change, rather than by changes in land use. It is emphasized that the inter-relationship between vegetation responses to climate change and changed land use practice in high latitudinal and altitudinal areas may be of vital importance in developing reliable predictions of vegetation changes.

In contrast to the general trend that the climatic warming cause increased growth rate, establishment, stand densification and ultimately the treeline shift, some study have depicted no response to the warming. A directional increase in temperature, as predicted by current global climate scenarios, will not necessarily result in an upslope expansion of forests growing at altitudinal treeline and does not support the general predictions about treeline response to warmer climate (Daniels and Veblen, 2004; Wang *et al.*, 2006). The study on *Nothofagus pumilio* treeline in Northern Patagonia (Daniels and Veblen, 2004) doesn't support the general predictions of increased seedling establishment, tree growth rates, and, ultimately, an upslope advance of the

treeline under the influence of warmer climate. In a similar study carried out by Wang *et al.* (2006) on the *Picea schrenkiana* treeline in central Tianshan Mountains, China, despite strong associations between climatic change and ring-width patterns, and with recruitments, the treeline did not show an obvious upward shift and new recruitment was rare over the last several decades.

Dullinger *et al.* (2004) suggested that patterns and rates of transient treeline dynamics that are driven by climate change may be idiosyncratic. Ambiguous transient responses of individual treeline systems may thus originate not only from variation in regional climatic trends but also from differences in species dispersal and recruitment behavior and in the intensity and pattern of resistance of resident alpine vegetation to invasion. Species will not only vary in their response to increasing temperatures in terms of their growth rates, as they may also possess different dispersal capacities and competitive abilities during their recruitment phase. Their study demonstrates that these species-specific traits may affect future range dynamics as much as, if not more than, variation in regional climatic trends. Moreover, they interact with each other and with spatial vegetation patterns. This further complicates the task of accurately predicting transient treeline dynamics driven by climate change.

2.4 Age Structure and Population Dynamics

The static age structure i.e. the range and distribution of tree ages of tree populations depicts population dynamics and stand history thus gives a fairly accurate picture of temporal variations in tree establishment rate (Kullman, 1991 cited in Wang *et al.*, 2006), recruitment and mortality history (Harcombe, 1987) in the treeline ecotone. Age and size structure and regeneration dynamics of treeline forming plant population may act as an indicator of environmental changes across the distributional range (treeline ecotone). Aging trees for stand reconstruction, allows the investigation to examine historical changes dating back to the age of the earliest tree cohort (Lescop-Sinclair & Payette, 1995; Szeicz & Macdonald, 1995). Since the environmental gradients exist along the altitudinal gradients, the distribution of plant species and Age structure studies along an altitude gradient of a mountain would be helpful in understanding the influences of environmental factors on the regeneration of natural forests and adaptability of the species to the environment. Many scholars have studied

treeline ecotone through age structure. Motta and Nola (2001) and Motta *et al.* (2006) in their study in Italian Alps analyzed age structure to reveal the current sub-alpine forest stands. Analyzing age structure and population dynamics, Kullman (2005) derived stand history of Scots pine in Handölan valley, Swedish Scandes, west central Sweden. Seedling establishment, recruitment rate and Stand density seem to increase in later half of the 20th century and a clearly discernible process of conspicuous infilling (scattered young trees and saplings spreading out into previously treeless areas) since the mid 1980s is reported. Gamache & Payette (2005) also describe an important increase in seedling establishment since the late 1970s in the tree lines of the southernmost tundra of Northern Québec, Canada.

Dang *et al.* (2010) studied age structure and regeneration dynamics of subalpine fir (*Abies fargesii*) forest across the altitudinal range in both the north and south aspects of the Qinling Mountains, China. Age structure and regeneration dynamics were similar in both the north and south aspects. Wang *et al.* (2004) studied size distribution and age structure of Schrenk spruce (*Picea schrenkiana* Fisch. et Mey.) forest along the altitudinal gradient on the central Tianshan Mountains. A reverse-J shape age structure was found in the mid-altitude transect whereas the transect of high altitude lack of young seedlings and saplings. It was proposed that limiting environmental factors like temperature and precipitation play important roles in determining the age structure of *P. schrenkiana* population. Fang *et al.* (2009) analyzed the tree-ring width and age structure of *Juniperus przewalskii* (Qilian juniper) forests for four tree-line sites in Qilian and Anyemaqen Mountains, North-Eastern Tibetan Plateau, to investigate their relationships to climate change. The number of surviving trees in the tree-line ecotone was not clearly correlated with temperature before the 1900s. However, an unprecedented rise in the number of trees coincided well with the rapid global warming after the 1900s.

In a study in the Catalan Pyrenees carried out by Ninot *et al.* (2008), the age structure included the bell-shaped maximum of individuals recruited during 1989–1993 showing a real decrease in the establishment of seedlings during the period 1994–2003. Batllori and Gutiérrez (2008) state that population age structures in the Pyrenees could indicate the importance of feedback mechanisms for treeline

recruitment dynamics. In 50% of the surveyed treelines, ecotone densification has been coupled to tree limit shifts in the recent past. This indicates both great tree limit sensitivity to short-term climatic changes and the presence of differential tree line dynamics at a regional scale. They suggest that the presence of step-like treeline transitions in tree age can be considered an evidence of recent human induced disturbances when no other major natural disturbances affect the tree line dynamics.

2.5 Treeline Study in Nepal

The treeline is the most prominent ecological boundary in the Himalaya where the sub-alpine forests terminate (Champion and Seth, 1968 cited in Kharkwal *et al.*, 2007). So the treeline may offer an important proxy for climate change study. There is not a long history of climate change study in Nepal. What to speaking of having proxy studies in Nepal, even there is very short instrumental records. Towards recent, proxies like glacier dynamics, tree rings and treeline dynamics have been studied. Dendrochronological study began in Nepal mainly during late 1970s after collection of tree ring samples made from different habitat by Rudolf Zuber during 1979-80 (Bhattacharyya *et al.*, 1992). Then after, many scholars (Suzuki, 1990; Bhattacharyya *et al.*, 1992; Regmi, 1998; Schmidit *et al.*, 1999; Yadav and Singh, 2002; Khanal and Rijal, 2002; Cook *et al.*, 2003; Sano *et al.*, 2002; 2005 etc.) have carried out such dendro-researches. Suzuki (1990) and Bhattacharyya *et al.* (1992) have indicated several species in Nepal were promising for dendrochronological studies.

Tree-ring studies carried out so far in the Himalayan region are mainly restricted to the lower temperate and sub alpine forests (Gaire, 2008). There are not sufficient tree ring studies from high altitudinal treeline of Nepal despite its importance as bio-indicator of climate change. At a coarse scale, the timberline is estimated to be approximately 4000 m a.s.l. in eastern Nepal, while it goes down decreasing to approximately 3800 m a.s.l. in central and 3650 m a.s.l. in western Nepal (Chaudhary, 1998). Species richness decreases towards higher altitudes in Nepali Himalaya and highest limit of a tree species recorded in Nepal is 4000-4500 m a.s.l. (Kharkwal *et al.*, 2007). Gaire (2008) carried out the ecological and dendrochronological study in the treeline ecotone of *Abies spectabilis* in Langtang National Park to monitor treeline dynamics (treeline: 3850 m a.s.l.). The stand character and age distribution showed high level of recruitment in recent decades with decrease in average age of trees with

increasing altitude and he has also reported upward shifting of treeline in recent decades was suspicious because of high level of heterogeneity in sapling and seedling distribution and lack of studies in recruitment and climatic relation.

Vijayaprakash (2009) estimated the rate of upward shift of *Abies spectabilis* in the north and south aspects of Gwang Kharqa region in Sankhuwasava District of Eastern Nepal. The result showed the treeline vegetation shifting at a faster rate i.e. 23m per decade in the south aspect and 17m per decade in the north aspect. The different growth parameters like age, dbh and height of the dominant trees were found to be decreasing with an increase in altitude in both the aspects and uniform age groups were seen in different altitudes but growth was more in south facing slope than in the north facing slope.

In Manang area, a trans-Himalayan zone, research interests have been grown these days but there is not much study encompassing treeline dynamics. Schmidt *et al.* (1999) had collected some *Pinus wallichiana* samples from Mustang and Manang (North Manang, South Manang, Pisang I and Ngawal) sites. The longest site chronology spanning 300 years (from AD 1697 to 1996) was obtained from *Pinus wallichiana* in Ngawal, the present study area. Cook *et al.* (2003) had also included site chronologies from Manang (Pisang and Ngawal) among 32 tree-ring chronologies network. 20 cores of *Pinus wallichiana* were collected from Ngawal with period of the chronologies 1698-1996. Shrestha *et al.* (2007) assessed regeneration of treeline birch forest in Manang by density-diameter curve. The species was found regenerating, as from reverse J-shaped density-diameter curve, however, the distribution of seedlings and saplings was spatially heterogeneous and appeared to depend on canopy cover. And it was noteworthy that the treeline formed by the birch was abrupt (the anthropozoogenic type) without the krummholz zone. Shrestha and Vetaas (2009) studied the forest ecotone effect on species richness in the trans-Himalayan area. Detrended correspondence analysis revealed a continuous change in species composition across the forest border ecotone. The low species turnover and low variation in species richness between the forest and open landscapes were attributed to the grazing and browsing pressure in the area in recent past decades.

Chapter: III

STUDY AREA

3.1 Site Description

Ngawal, the study site is situated in the south facing slope of Manang valley, central north part of Manang district (Fig. 1). Manang is a part of the trans-Himalayan arid region of Nepal between the Tibetan plateau to the north and the main Himalayan axis to the south (Annapurna range). Ngawal is a part of the Annapurna Conservation Area (ACA) and is about one and half hours' walk toward north from Humde airport.

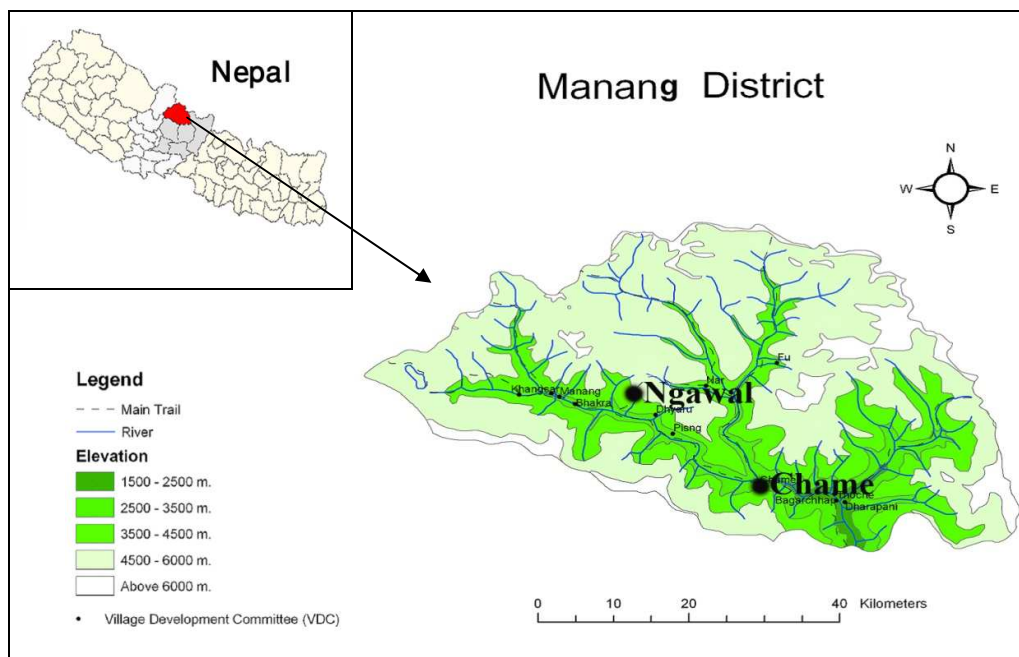


Fig 1: Study area (Ngawal)

This area is located in trans-Himalayan narrow valley traversed by the Marsyangdi River which is trending from northwest to southeast. The south-west facing study area ($28^{\circ}39'N$; $84^{\circ}06'E$; 3900-4025m a.s.l.) lies in the north and in the rain shadow of the massive trans-Annapurna range (elevation of 8091m a.s.l.). This arid area is the extension of the Tibetan plateau. The climatic condition of Manang is akin to the plateau and receives very little rainfall as the south-west monsoons are unable to cross the high mountains (Negi, 1994). Hence, topographic conditions are the vital

influencing and controlling factors conducive to prevalence of overall locality factors like deficient rainfall (as the monsoons are unable to reach here due to presence of Annapurna massif south of this area). The shallow soil of the area is poor in organic matter having low water holding capacity (Negi, 1994). The region is characterized by its rugged topography with sharp and large altitudinal differences within short distances. The study site lies on a horst which is not permanently covered by snow round the year but only in winter and occasional in summer.

3.2 Climate

There is no meteorological station in the Ngawal and the nearest meteorological station to the site lies in Chame ($28^{\circ}33'06.51''\text{N}$, $84^{\circ}14'27.57''\text{E}$, 2705 m a.s.l.), the district headquarter of Manang which is about 18 km from the study site. The meteorological data of the near most Chame station was obtained from Department of Hydrology and Meteorology (DHM). The average annual maximum temperature in Chame is 16.8°C ; average annual minimum temperature is 5.2°C . With the available temperature data from 1977-2007 AD, May, June, July and August maximum temperature seem to exceed 20°C while the minimum temperature falls below 0°C in December and January (Fig 2a). There is not remarkable change in temperature trends. But some decrease in summer minimum temperature and increase in winter maximum temperature seem to initiate from 2000 AD (Fig 2b).

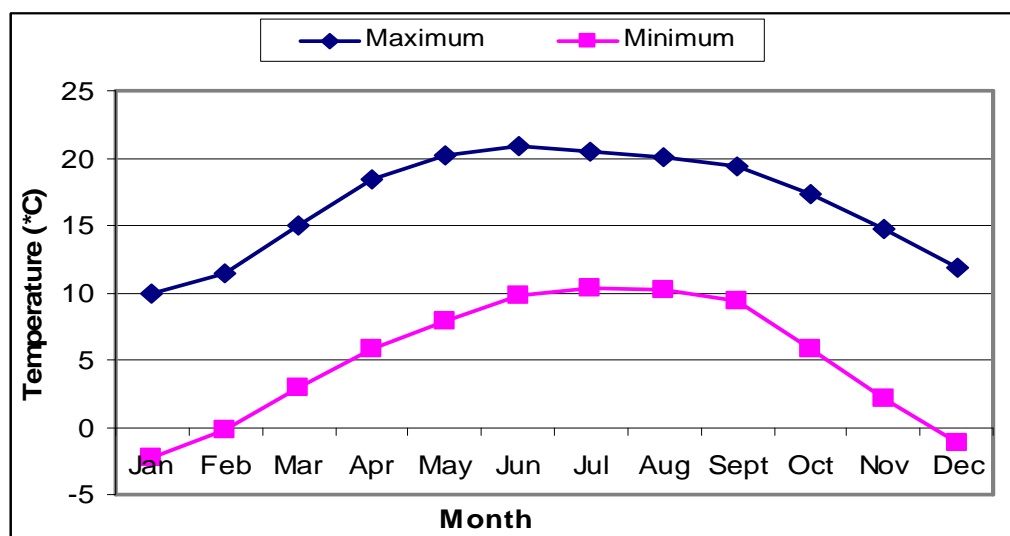


Fig 2a: Average maximum and minimum temperature in Chame

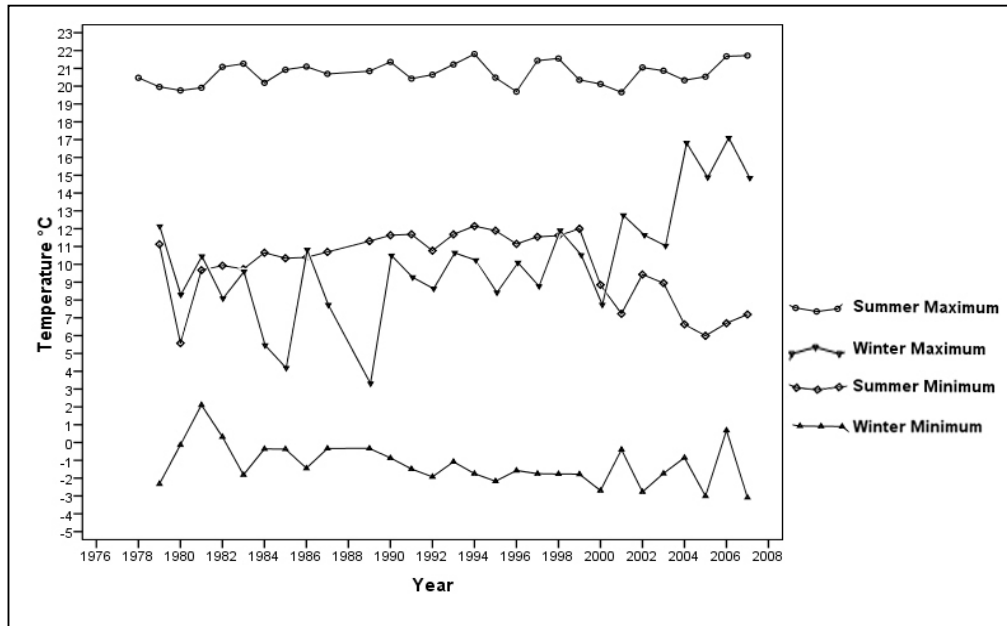


Fig 2b: Temperature trend in Chame

The mean annual total precipitation in Chame is 922 mm (1977-2007 AD). Precipitation occurs in the form of rainfall and snowing. Lion share of the precipitation occurs in the summer months June, July, August and September and July being the month with maximum precipitation.

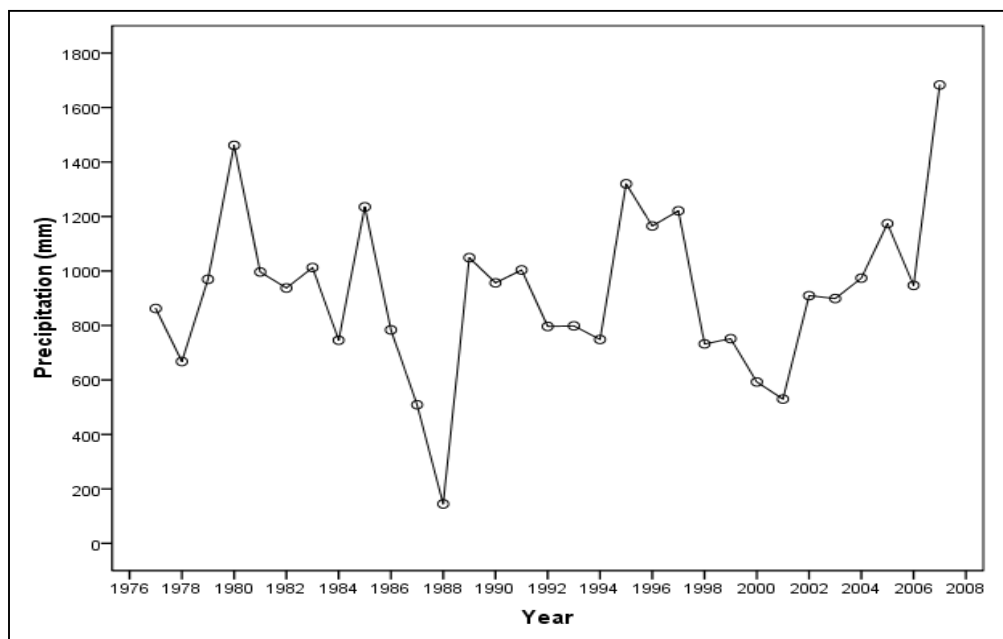


Fig. 2c: Total annual precipitation in Chame

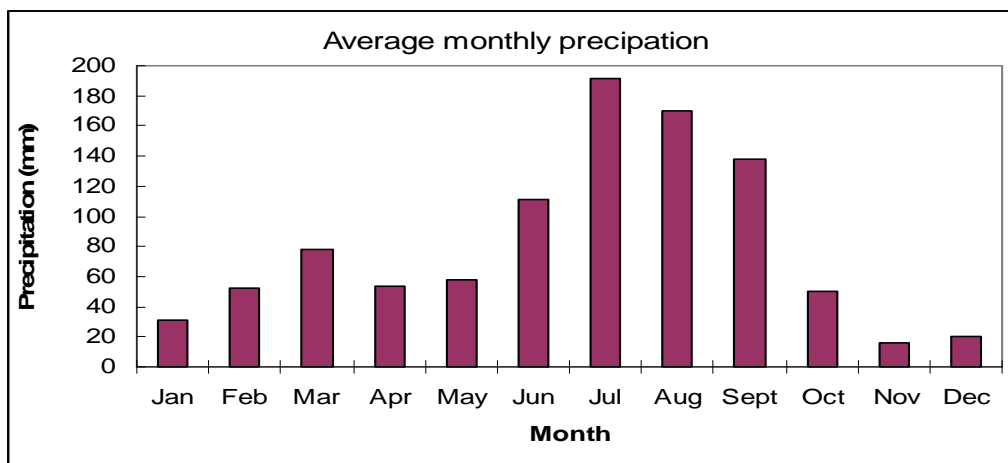


Fig 2d: Average precipitation in Chame

3.3 Vegetation

Phytogeographically, south facing slope in the trans-Himalayan valley is comparatively and significantly drier than the north facing slopes (Bhattarai *et al.*, 2004) may be owing to the direct exposure to sunlight and is dominated by pine stand. The structure of the vegetation and forest formation is different on south and north facing slopes. Vegetation status also differs with micro topography of the aspect and site. It is noticeable that the east facing slopes are devoid of vegetation possibly due to stronger east-west wind that usually becomes stronger in afternoon whereas west and south-west facing slopes seem to be vegetated.

The Himalayan blue pine, *Pinus wallichiana*, a common upper ecotonal species in western Himalaya grows pure or in association with Himalayan birch and juniper (Dubey *et al.*, 2003). Its forests are found from Afghanistan to Bhutan. Generally, it occurs between an elevation of 2200-4500 m a.s.l. the pine is a colonizer of abandoned fields, grazing grounds and freshly laid down alluvium (Negi, 1994). There can be seen the treeline ecotone, a conspicuous feature in Ngawal between the forest predominantly formed by almost pure *P. wallichiana* stand and treeless alpine meadow. The *P. wallichiana* forms extensive pure forest on south and south western facing slopes between 2200-3200 m a.s.l. in Humla-Jumla areas in Nepal and are scarce in the east forest (Chaudhary, 1998). The species stand is found pure in 2200-2900, and in northerly slope not pure but in association with *Picea smithiana*, *Betula*

utilis, *Abies pindrow*, *Juniperus indica*, *Cupressus torulosa* (Shrestha, 1982). The species has its upper limit upto about 4700 m a.s.l. in the inner dry valleys and outer arid areas (Negi, 1994). The tree individuals tend to be of a short stature towards the upper elevational limit.

Pinus wallichiana is dominant in treeline ecotone of Ngawal. In the closed forest in this site, there exist few and scattered standing individuals of *Betulla utilis*. In the treeline ecotone, *Juniperus indica* is the associated tree species (relatively few in number, compared to *P. wallichiana*). Krummholz form and bushes of *J. squamata* forms thickets in the ecotone. The ground layer consists of scattered patches of thorny cushion plant species such as *Caragana*, *Astragalus*, *Berberis*, etc. with species of *Primula*, *Saxifraga*, *Androsace*, *Anemone*, *Lonicera*, *Ephedra gerardiana*, *Cotoneaster microphyllus* etc. along with prostrate *Juniperus squamata*, *J. indica* and *J. communis* etc.

3.4 Land Use and Human Disturbances

Pastoralism and agriculture have been being prevalent on south-facing slopes in the Manang valley. Agriculture is confined in lower flat valley bottom. Towards the recent decades human population and agricultural dependency have been decreasing and people have turned to alternative professions (Shrestha and Vetas, 2009). Now a days, some people have horses but there are not seen herds of *Yaks/Chauris* and mules. Practices of keeping *Chauris* have been declined to very few in numbers and in limited families only. The village is about one and half hours' distance from the forest. The forest is thought of religious significance and direct human influences are not pronounced these days. However, the dilapidated *chauri*-hut seen above the forest line suggest that there was grazing pressure in the past.

Chapter: IV

METHODOLOGY

4.1 Field Survey and Sampling Designs

This study was carried out in the treeline ecotone (elevational range between 3900-4025 m a.s.l.) in the south-west facing slope of Ngawal VDC of Manang district during May 20-June 2, 2009. For the sampling convenience, the operational definition of treeline in the study was the elevational line connecting the outermost erect trees with a height of at least 2 m, growing at the highest altitudes (Brubaker, 1986; Hofgaard, 1997; Kavanagh, 2000; Motta and Nola, 2001; Juntunen *et al.*, 2002; Camarero and Gutiérrez, 2002; 2004) where the distance between solitary trees (≥ 2 m) doesn't exceed 100 m (Juntunen *et al.*, 2002). Forest line (timberline) was defined as the uppermost delimitation of the closed stands of trees with at least 2 m stature (Juntunen *et al.*, 2002). Species limit is a highest elevation at which any individual of the species is found (Moen *et al.*, 2004). And the transition zone between the forest line and the tree species limit was considered as the treeline ecotone. In reality, the transition from uppermost closed montane forests to the treeless alpine area is commonly not a line but a steep gradient of increasing stand fragmentation and stuntedness, often called the treeline ecotone or the treeline parkland (Körner and Paulsen, 2004). Forest is defined as having a cover of at least 30 % and a surface area of at least 500 m², the minimum conditions for the existence of a forest microclimate (Motta and Nola, 2001). In this study, forest is considered as having at least 50% coverage in 1 ha area (Shrestha and Vetaas, 2009).

Three vertical transects (across treeline ecotone) were laid at three different locations of the study area encompassing the upper altitudinal limits of the species i.e. the tree species limit from the forest line. The width of each transects was 20 m. The Transect 'A' (28°39.12'N and 84°06.7'E) stretched from 3909 to 4019 m a.s.l., Transect 'B' (28°39.00'N and 84°06.8'E) from 3928 to 4015 m a.s.l. and Transect 'C' (28°38.9'N and 84°06.80'E) from 3930 to 4022 m a.s.l. (Transect C was located toward the ridge-edge to the east). All the pine individuals within those transect were studied. On the basis of height, every plant individuals was categorized as: tree (height (H) ≥ 2 m), sapling (50cm \geq H < 2 m), and seedling (H < 50cm) (Wang *et al.*, 2004; 2006).

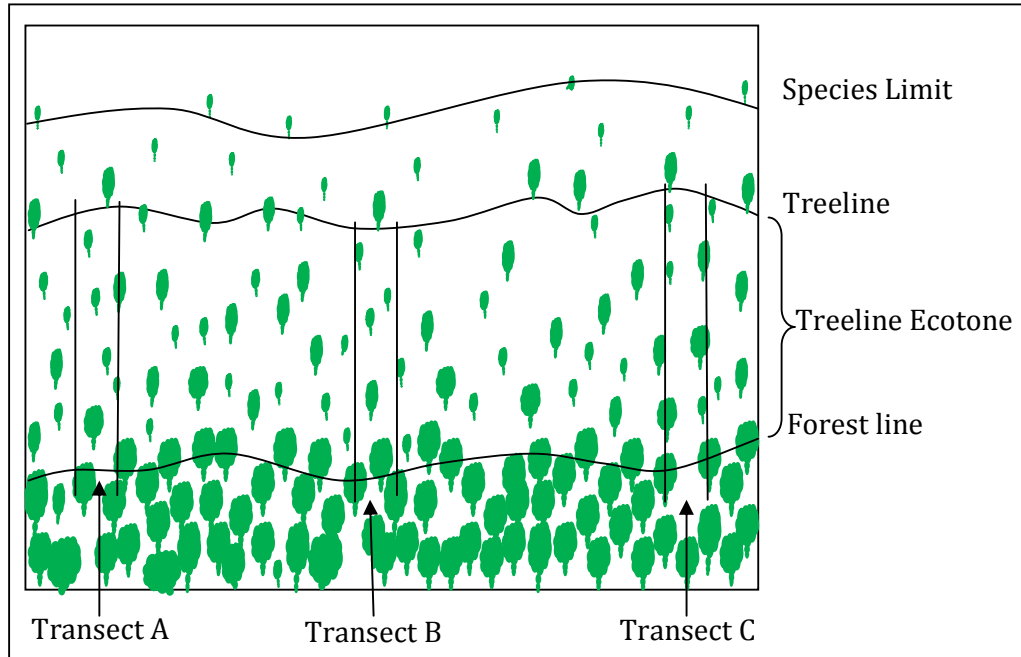


Fig 3: Schematic sampling design showing treeline ecotone

Disturbances in the Treeline Ecotone

Anthropogenic pressures in the study site were studied by observing whether trampling/foot trails, cut stumps/lopping/logging, grazing, fire etc. were present or not. The disturbances have not been quantified and based simply on the personal observations. The near most village is about one and half hours' distance from the forest which is thought of religious significance and hence direct human influence is not pronounced these days. There were seen narrow foot trails. Some dilapidated cattle *Goth* above the forest line indicated intense grazing pressure in past, however, grazing diminution has happened these days. The evidences of tree-logging, lopping, firing were not seen. The complete absence of cut stumps means that no trees have been logged in the recent years. In sum, it is indicated that there were intense pressure in the past but the pressure have been reduced in recent decades.

4.2 Basic Biometric Measurements

Height (H), basal diameter (BD) and diameter at breast height (dbh at 1.37m) for all individuals within the transects were measured. Heights of seedlings, saplings and smaller trees were measured with wooden ruler. Heights of taller trees were measured with clinometers. In the case of multiple trunks, the trunks with the largest dbh and

height were supposed to be the main. Basal diameter and diameter at breast height (dbh) were measured with a dbh tape. Canopy was measured in two diagonal directions. The canopy diameter measured parallel to the contour was recorded as 'A' and that perpendicular to the 'A' i.e. along the slope was recorded as 'B'. The canopy diameters were measured with a measuring tape.

In case of small individuals (seedlings and saplings), height of each branch whorl and scars, inter-nodal lengths were recorded with the hard and straight ruler. Geographic position (latitude, longitude, elevation, slope gradient, aspect, and bearing) of each individual was taken with GPS (eTrex, Garmin). Also, the vitality status, availability of cones/catkins, vegetation layer, growth substrates etc. were also recorded. To avoid possible repetition, each individual were marked with a biodegradable ribbon.

4.3 Dendrochronological Analysis

Dendrochronological methods were used to reconstruct the age structures of tree populations. For acquiring age of specimens, all individuals with sufficient diameter were cored at the base; and in case of saplings and seedlings, age was obtained by counting branch whorls and bud scar remains left in the main stem (Camarero and Gutiérrez, 2004; Wang *et al.*, 2006; Ninot *et al.*, 2008). Branch whorl counting may be erroneous. Instead, a cross-section cut at the base/stem collar can be useful for determining the actual age. With the cut cross sections, errors in estimating age with branch whorl counts can be obtained. But this process was discarded considering the sensitivity in the treeline ecotone.

4.3.1 Taking Core Samples from Trees

An increment borer (5 mm diameter) was used to take cores from trees. An increment core was taken at base (as possible as at the root collar) of each tree (Fang *et al.*, 2009). The increment borer was directed towards the pith at the stem base in such a way as to retrieve the exact pith. Then pushing firmly against the bark, the borer handle was moved in clockwise direction. When the desired depth of penetration was reached (when the borer portion slightly longer than the trunk radius was inserted), an extractor spoon was pushed from back of the borer between the core and the inner wall until it was tightly wedged between the core and the top of the borer. The core

was broken off within the tree with an anticlockwise movement and then pulled out and the core was put in plastic tube and tagged. Occasionally when the borer went far off the centre, the coring procedure was repeated in order to get the exact pith of the stem. The incomplete cores with largely missing rings were discarded.

4.3.2 Mounting the Cores

Mounting was done in order to polish the core surface for ring counting. All the increment cores taken were air dried. Then, the cores were glued using water soluble glue into groove in pre-grooved wooden sticks (great care was taken to ensure that the pith was placed vertically to expose the transverse surface). The mounted cores were tied with paper tape and were then held together until they were fully dried out.

4.3.3 Core Processing and Counting the Annual Rings

The structure of the rings can be rendered visible by making the surface smoother and can be achieved by cutting, polishing, staining, micro-sectioning, etc. (Schweingruber, 1988) but here, polishing with sand paper of different grits was chosen as this is the easiest one. The mounted cores were smoothed by sanding with sequence of sand paper gradually from coarse to finer grits (from grit sizes no. 80, 120, 240, 400, and no. 600) until optimal surface resolution allowed rings to be counted (Stokes and Smiley, 1968). After achieving smoother surface rings were counted using stereomicroscope. The number of rings present in the perfect core (with both bark and pith) equals the age of the tree. The tree rings were counted in the Dendro-Lab of Nepal Academy of Science and Technology (NAST).

4.3.4 Determining the Tree Age from Cores

Altogether 156 samples were used to construct the age structure. With the core having pith, age was taken as the number of rings between pith and bark (age at the stem/root collar is the exact year of establishment). Frequently, core samples did not contain the innermost rings because of wood decay or imperfect coring. In case of imperfect cores falling short of the pith with strongly curved innermost rings, the position of the pith was estimated. Then number of missing rings in the estimated radius was added to the number of counted rings available in the incomplete core to obtain the correct tree age

(Motta and Nola, 2001). The rot cores and cores with apparently uncurved innermost rings were discarded for age structure study.

4.3.5 Determining the Age of Saplings and Seedlings

Since coring and taking cross-section cut at stem base is destructive so disc cutting was avoided. Instead, branch whorl and bud scars left in the main stem of saplings and seedlings were counted such that the first apical side whorl was produced in 2009, second in 2008 and so on (first whorl counts for two years, second for three years and so on). The process of counting was repeated until the same count was obtained. Height of the plant was recorded along with other biometric measurements, GPS position, etc. Counting branch whorls and scars do not give accurate age of the seedling and saplings (Camarero and Gutiérrez, 1999; 2004). Even from ring-count of tree core, accuracy cannot be assured due to various problems posed by those incomplete cores. To minimize this error age structure was analyzed in 5-year age classes (Ninot *et al.*, 2008).

4.3.6 Problems in Ageing

Counting branch whorls and scars do not give accurate age of the seedling and saplings. Even from ring-count of tree core, accuracy cannot be assured due to various problems posed by those incomplete cores.

Anomalous growth rings: Presence of anomalous growth rings (partial or false rings and locally absent or missing annual rings (Fritts, 1976) can complicate ring counts and failure to recognize false rings and locally absent rings can lead to substantial under/overestimation of tree-ages.

Partial cores: If borer alignment while coring trees is incorrect, or the borer is too short to hit the pith, or pith region is rotten, exact pith cannot be obtained and then age estimation is problematic and erroneous.

Inability to find exact stem collar: Age of the tree is age at the stem collar. But it is difficult or in some case impossible to core at exact stem collar. Sometimes it is difficult to estimate, sometimes the collar region may be buried and sometimes it is impossible to core due to various obstruction.

Failure to identify real whorls and scars: When branches produced in same years are not easily identifiable and if scars left in stem can't be seen and in case shoots have been damaged, age estimation would be erroneous. This method generally yields an age underestimation of 0–5 years (Camarero and Gutiérrez, 1999; 2004).

Samples cored near the ground (as far as possible towards the root/stem collar) reasonably determine establishment year. Given the establishment year could be earlier than the ring record (in failure of acquiring cores at root collar, error in estimation of missing rings in incomplete cores, and unavoidable error in counting branch whorl and scars), age structure was then analyzed in 5-year age classes (as have done by Ninot *et al.*, 2008).

4.3.7 Age Structure and Establishment Analysis

Due to aforementioned problems in aging, age structure is shown in 5-year classes which can remove partially or minimize the differences in estimation (Camarero and Gutiérrez, 1999; Kullman, 1983 cited in Wang *et al.*, 2006; Ninot *et al.*, 2008) and the age structure was shown with Histogram. Altitudinal distribution of ages, establishment years also tried to depict to understand regeneration pattern and history.

4.4 Data Analysis and Statistical Approach

All statistical analyses were carried out using SPSS 16.0 and Microsoft Excel 2007. Correlation analysis (Karl Pearson correlation coefficient) was done for identifying the trend between different variables.

Linear regression analyses were performed to find out the associations between variables. Regression analyses of age vs. dbh, age vs. height, dbh vs. height, etc. were performed. The linear equation for regression is,

$$y = \alpha + \beta x$$

Where, y = dependent variable

x = predictor variable

α = y-intercept

β = regression coefficient i.e. rate of change of dependent variable with that of predictor variable in the regression.

Estimating periods when current treeline was attained

Using the regression model between age and height in upper elevational range, year to attain height of 2 m was estimated for saplings in the upper part of the ecotone. As the establishment years (age) of them were already obtained, the period during which the current treeline position was attained was estimated. With regression between established year and elevation can give some rough estimate about treeline dynamics.

4.5 Demographic Structure

Tree size and age were used to establish the demographic structure at the stand, and to characterize abrupt or smooth transition patterns along the tree line ecotone. Average age, average height, and average diameter distribution were shown in different elevational ranges (using Histogram). Demographic structure was also analyzed through density. Density of trees, saplings, and seedlings was calculated separately.

$$\text{Density (D) (No. / ha)} = \frac{\text{No. of individuals}}{\text{Area of the plot (sq. m)}} \times 10000 \quad (\text{Zobel } et \text{ al.}, 1987)$$

For stand structure, tree: sapling: seedling ratio was calculated with different elevational ranges.

Chapter: V

RESULT

5.1 Forest Stand Structure

Pinus wallichiana was present as continuous tree species from closed forest to the treeline on the south-west facing slope. Below the forest line, some scattered individuals of *Betula utilis* and *Juniperus indica* were present, whereas marked presence of *J. squamata* and some individuals of *J. indica* can be observed in the ecotone (zone between forest line to treeline).

P. wallichiana at the treeline ecotone constituted of about 54.5% of trees, 36.5% of saplings and only 9% of seedlings with the density of 94.44, 63.33 and 15.55 individuals/ha, respectively (total density in the ecotone was found to be about 173.33 individuals/ha). Total basal area of *P. wallichiana* in the ecotone was about 9.83 m²/ha. In the ecotone, frequency of *P. wallichiana* decreased with rising elevation (Table 1). Elevation-wise tree to sapling and seedling ratio showed that younger plants existed toward upper ranges (1:0.77, 1:0.44, 1:3 and 1:1 respectively in the ranges of 3910-3940, 3941-3970, 3971-4000 and 4001-4030 m a.s.l.). Seedlings predominated in upper ranges while trees were more abundant in lower altitudes.

Table 1: Elevation-wise distribution of trees, saplings and seedlings. Data shown represent number of tree, sapling and seedling at different altitude levels.

Elevation Range (m a.s.l.)	Tree	Sapling	Seedling	Total
3910 to 3940	31	17	7	55
3941 to 3970	36	20	4	60
3971 to 4000	10	13	2	25
4001 to 4030	8	7	1	16
Total	85	57	14	156

Almost all trees were flag-shaped with noticeable branching towards west and it is also to be marked that the crown diameter 'A' taken along the contour was relatively more than the crown diameter 'B' taken along the slope. The average ratio of the crown diameter 'A' to the 'B' was about 1.22 that may indicate that tree crowns are

stretched parallel to the contour and prevailing wind direction by about 20 percent more than that along the slope.

5.2 Size Structure

The diameter at breast height (dbh) showed step-like almost reverse J-shaped distribution in the ecotone (Fig. 4a) where the small individuals accounted more. Two youngest size classes (<5 cm and 5 to <10 cm dbh) accounted for 42.6%, 10-15 cm dbh class accounted for 8.5%, but 15-20 cm class accounted for 18.1%. All the individuals of dbh 20-40 cm accounted for 26.6% and individuals with dbh ≥ 40 cm accounted for only 4.2%. In general, dbh decreased with the increasing altitude (Fig. 5). The overall dbh (in all 156 individuals) in the ecotone was 15.75 cm; and it was

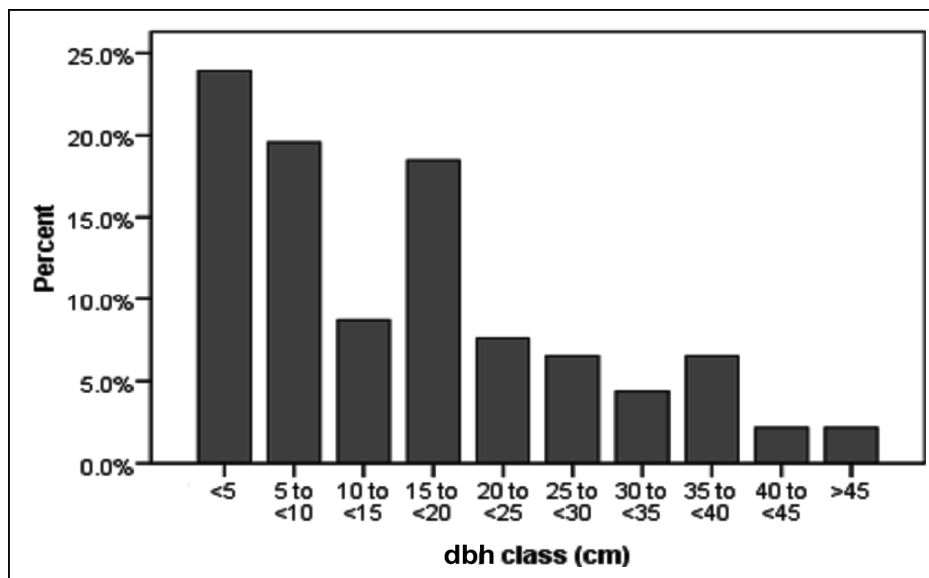


Fig. 4a: dbh distribution pattern in the ecotone

16.85, 16.0, 14.59 and 12.49 cm respectively in the elevational ranges of 3910-3940, 3941-3970, 3971-4000, and 4001-4030 m a.s.l. The mean value of dbh of *P. wallichiana* population was quite different in different altitudinal ranges in the ecotone (Fig. 4b). Altitude-wise distribution of size class revealed the domination of younger size class in all altitude levels (Fig. 4c). However, the contribution of younger size class increases with increasing altitudes. For example, contribution of young plants (<20 cm dbh) at 3910-3940, 3941-3971, 3971-4000 and 4001-4030 m a.s.l. was found to be 62.8%, 71.05%, 70% and 81.81% respectively within the

altitudinal ranges. Similarly, the mean tree height in the ecotone was found to decrease (insignificantly) with increasing altitude (Fig. 5, 8e).

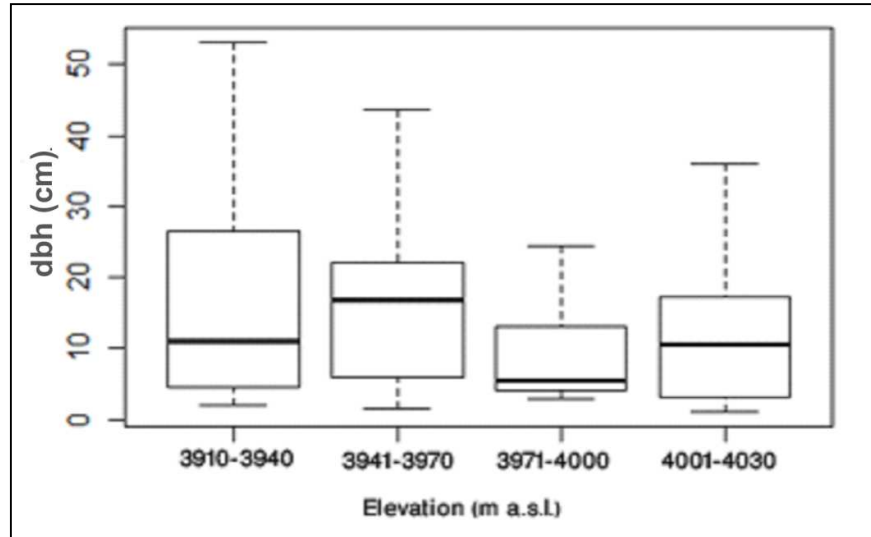


Fig. 4b: dbh distribution in altitudinal ranges

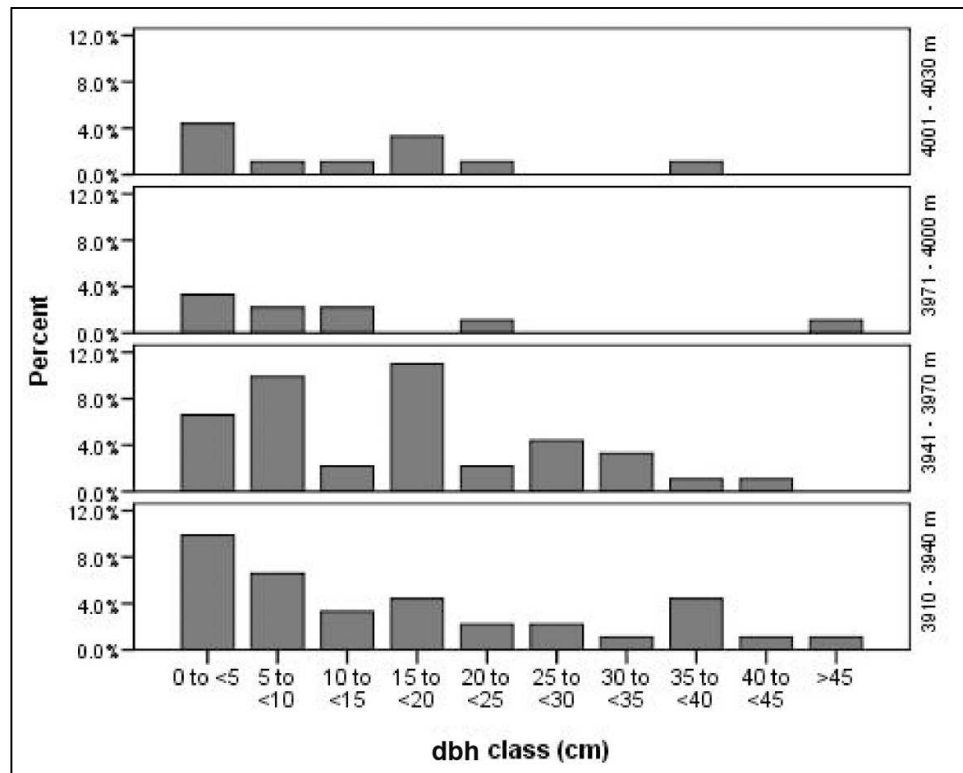


Fig 4c: dbh distribution in altitudinal ranges

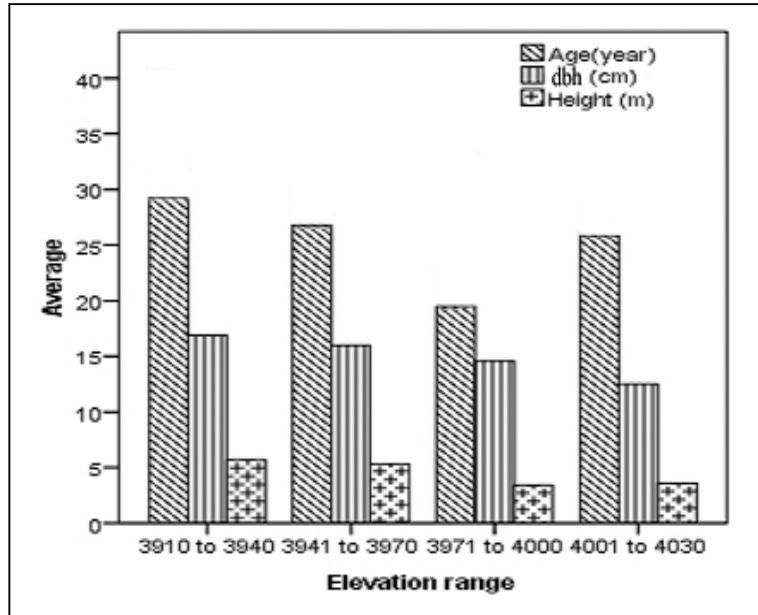


Fig 5: Age, dbh and Height patterns (mean) along altitudinal gradient in the ecotone.

5.3 Age Structure

Age-frequency of *P. wallichiana* also displayed the similar distribution trend with the dbh (Fig. 6). The age structure (5-year intervals) was also almost reverse J-shaped with remarkable exception of age classes 31-35 and 61-65 years (Fig. 6), the corresponding dbh classes of which also had the same pattern. The majority of individuals was ≤ 20 years and accounted for 52.6%. Among all classes, the age class 11-15 years (17.3%) had highest frequency. The age classes 6-10 years (14.1%) and 16-20 years (12.2%) were second and third in order of frequency respectively. Individuals with age ≤ 35 years accounted for 76.3% and only 14.7% individuals were older than 50 years. Among these, the oldest tree was found to be of 108 years. Only 2 trees (1.28%) were found to exceed 100 years of age. These findings suggest that population of *P. wallichiana* was established during the 20th century with the lion share of establishment after 1970s.

Age distribution also varies with respect to elevational ranges. The mean age decreases (insignificantly) towards upper ranges (Fig. 5). The mean age at the ecotone was 26.46 years and that in general decreases with altitude with an exception of uppermost elevational range. The mean age was 28.96, 27.02, 19.84 and 26.06 years in the elevational ranges 3910-3940, 3941-3970, 3971-4000 and

4001-4030 m a.s.l. respectively. The age structure also varies in different altitudinal ranges (Fig 7). The size structure and age structure of *P. wallichiana* at the ecotone suggest the almost early stage of colonization toward upper elevational ranges with presence of some tree individuals having more age and sizes.

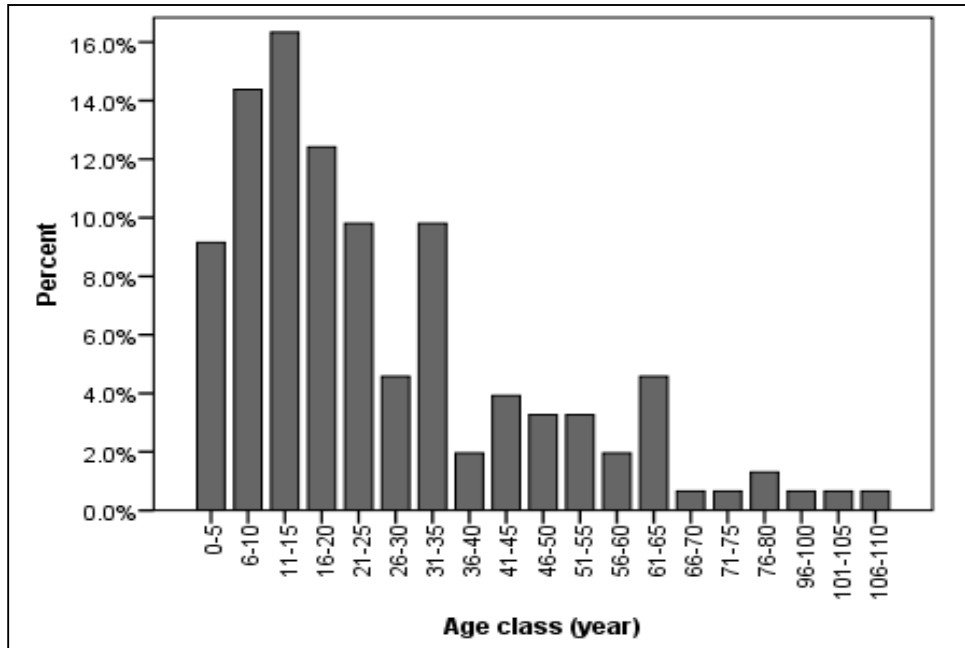


Fig. 6: Age structure at the treeline ecotone

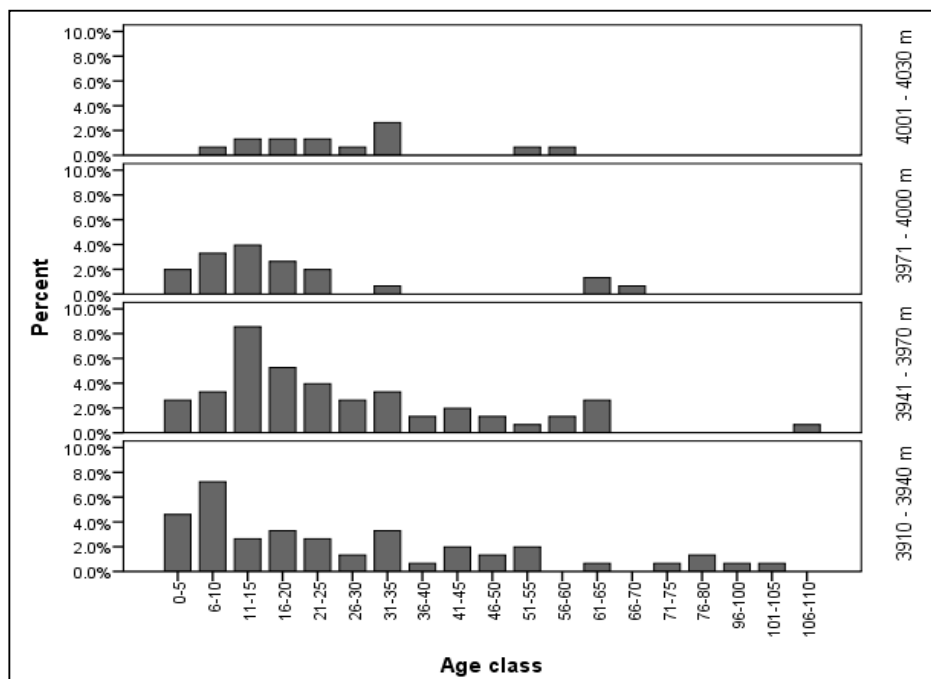


Fig. 7: Elevation wise age structure at the treeline ecotone

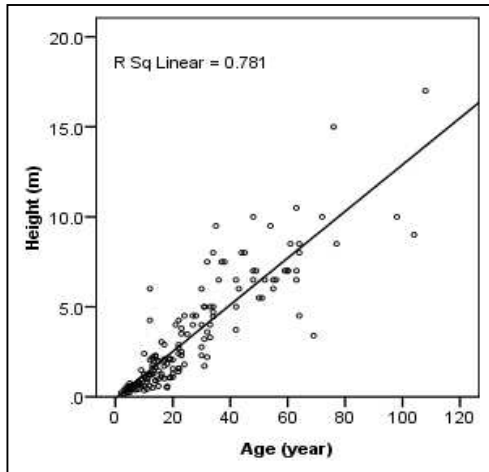
5.4 Relation among Sizes, Age and Elevation

The correlation analyses indicated that age and height of *P. wallichiana* was significantly correlated (correlation coefficient, $r = 0.883$, $p < 0.05$). Similarly, age and dbh ($r = 0.84$, $p < 0.05$), height and dbh ($r = 0.85$, $p < 0.05$) were also highly correlated. It was clear that in the ecotone, height and dbh of individuals increased with age and taller ones also had larger age and dbh (Fig. 8a, 8b, 8c).

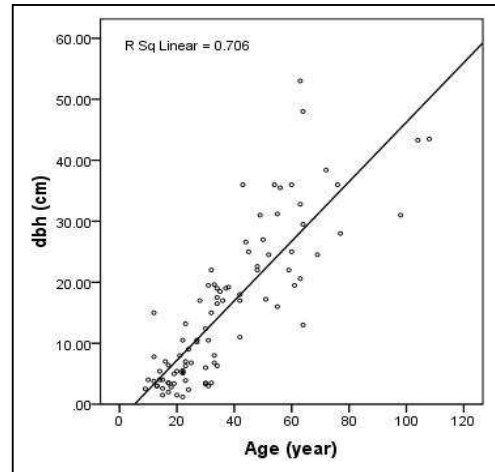
Furthermore, age, height and dbh all decreased with increasing elevations ($r^2 = 0.018$, 0.052 and 0.012 respectively). However, the influence of altitude on tree age was not significant ($F = 2.9$, $df = 1$, 154 , $p < 0.10$) and the relationship was found to be negative. The influence of altitude on tree height ($F = 0.010$, $df = 1$, 152 , $p > 0.20$) and dbh ($F = 1.051$, $df = 1$, 89 , $p > 0.20$) were also insignificant. Whereas, the relationships between age and height ($F = 19.224$, $df = 1$, 153 , $p < 0.0001$), age and dbh ($F = 216.158$, $df = 1$, 90 , $p < 0.0001$) and height and dbh ($F = 229.960$, $df = 1$, 90 , $p < 0.0001$) were significant (Fig. 8d, 8e, 8f).

5.5 Regeneration Dynamics and Recruitment History

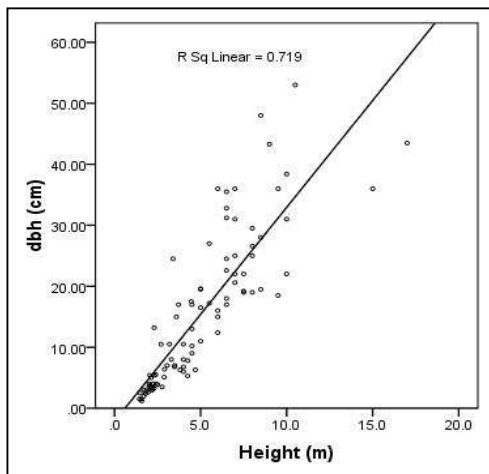
Almost reverse J-shaped and the right skewed frequency-dbh curve (Fig. 4a) and age structure (Fig. 6) of the *P. wallichiana* stand at the treeline ecotone, expected of uneven-aged forest stands in general, show the regeneration enhancement towards the recent decades. Pattern of the dbh depicts the prevalence of the younger individuals. Almost 69.1% individuals were less than 20 cm dbh. Similarly, the age structure also depicts the same. The age-class histogram showed that trees could be dated back to only the start of the 20th century. However, most of them were established and recruited in recent decades. Almost 52.6% of total studied individuals ($N = 156$) were found not to exceed age of 20 years. More than 50% of plants were established during and after 1990s. Among all size classes, 11-15 years aged trees represented larger in number, which indicates the increased rate of establishment in the late 1990s. Individuals of age ≤ 35 years accounted for 76.3%. More than one third of individuals in the ecotone were established during and after the late 1970s. Only 14.7% individuals were older than 50 years.



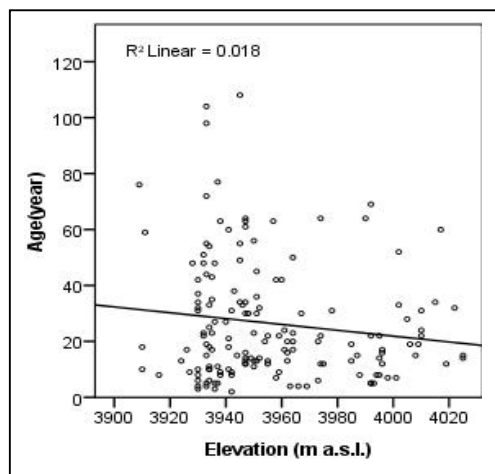
a. Age vs. Height



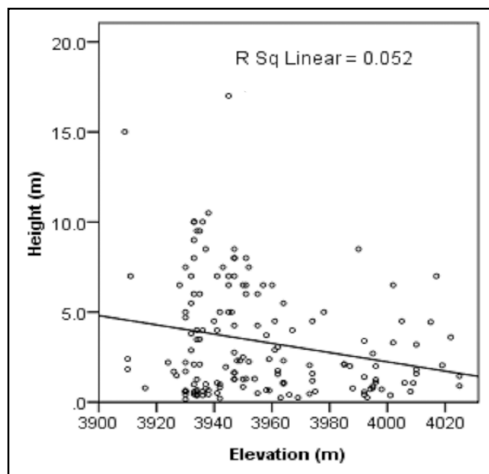
b. Age vs. dbh



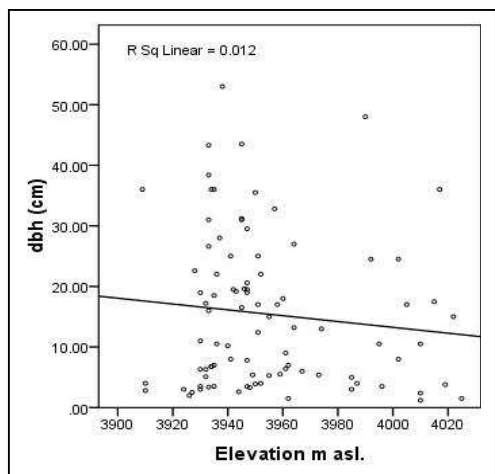
c. Height vs. dbh



d. Elevation vs. Age



e. Elevation vs. Height



f. Elevation vs. dbh

Fig. 8: Relationships between different parameters based on linear regression analysis

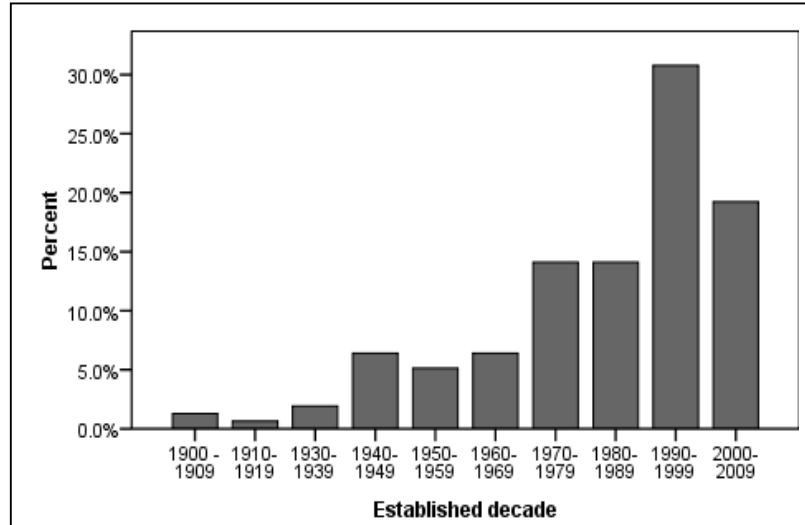


Fig. 9: Decadal establishment history

Fig. 9 shows the establishment in different decades. The situation of the ecotonal tree age distribution along altitude shows that the colonization of the species began from by the beginning of the 20th century with establishment of few sporadic individuals. The pine recruitment and establishment occurred in this population at low levels (weak period) before 1940s (3.8% of total established trees), at moderate levels after then to about late 1960s (17.9% of total establishment). But the consistent regeneration has taken place gradually towards upslope in recent past decades especially after the 1960s (78.2% establishment occurred after 1960s) with abrupt surge in 1990s and 2000s. Among all individuals ca. 30.8% establishment happened in 1990s and the 2000s decade is the next large establishment decade with 19.2% establishment. (50% of total population established during these two decades and the peak 10-year period of pine origination in the ecotone is the 1990s).

The establishment near the forest line (in the lower elevation range, 3910-3940 m) was consistent with most establishments in early 20th century (Fig.7). The 3941-3970 m elevation band also had the similar trend but establishment apparently started from later half of 1940s and more establishments in 1990s. Towards the upper elevational ranges, the establishment was more concentrated after 1970s (Fig. 7). Between mid-1940s and mid-1970s, there was some recruitment gap in the 3971-4000 m range where remarkable regeneration occurred in late 1990s while in the uppermost range, establishment initiated in early 1950s with regeneration gap between early 1960s to mid-1970s.

5.6 Present Location of Treeline and Timberline

As per the operational definition of treeline and timberline (forest line) in this study, in Ngawal, the current treeline position was estimated to be at about 4020 m a.s.l. (at 4019, 4015 and 4022 m a.s.l. respectively in the Transect A, B and C); whereas, timberline was found to lie at about 3930 m a.s.l. and the timberline position ascended from west to east (at 3909, 3928 and 3930 m a.s.l. in the Transect A, B and C, respectively). The treeline ecotone stretched within about 100 m altitudinal gradient and along about 150m at ground. Fig. 8d suggests there was not a clear correlation between tree age/sizes and the altitudinal gradient. In Ngawal, seedlings and saplings seemed to establish above the current treeline, too (personal observation). But it can be estimated that the treeline has not shifted in last at least two decades. Treeline forming

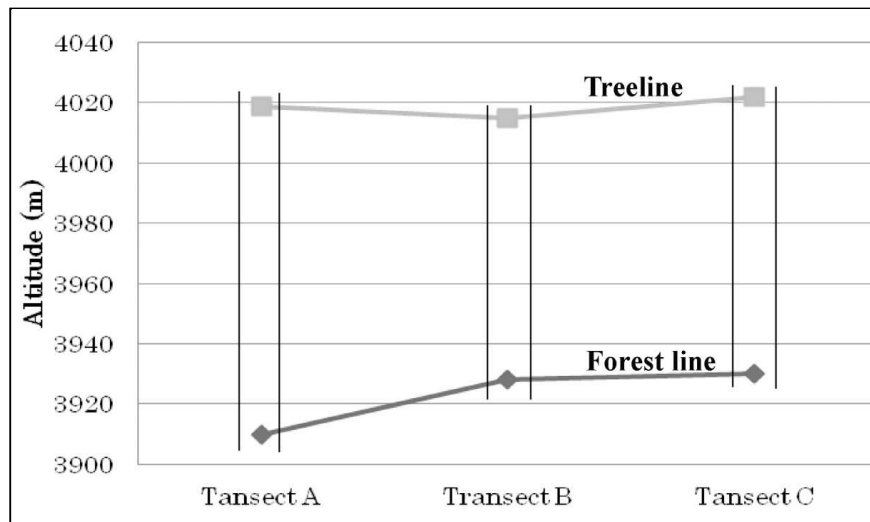


Fig. 10: Schematic picture of treeline ecotone

trees were found of age greater than 30 years i.e. those trees were established before 1980s. The Age-Height regression ($y = -0.063 + 0.13x$) (Fig. 8a) showed that the age of trees to attain 2 m height is ca. 15 years. Hence, the current treeline tree may have gained the minimum tree stature in early 1990s i.e. current treeline position might have been reached in early 1990s and since then the treeline seems to be static.

Chapter: VI

DISCUSSION

6.1 Distribution and Ecotone Structure

Pinus wallichiana forms the almost monodominant stand in the treeline ecotone. It can form stand in dry valleys and outer arid areas (Negi, 1994) and is a common upper ecotonal species in western Himalaya growing pure or in association with birch and Juniper (Dubey *et al.*, 2003). It may form pure stand on south and south west facing slopes (Chaudhary, 1998) and in northerly slope generally in association with Junipers and other species (Shrestha, 1982) in Nepal Himalaya. In Ngawal, the common associated species is *Juniperus indica* and *J. squamata*. The treeline position is ca. 4020 m a.s.l. but in upper Manang, even the species limit does not expand beyond 4000 m (Shrestha *et al.*, 2007).

The tree individuals tend to be of short stature towards the upper elevational limit (Negi, 1994) and similar are their age and dbh which is the common features in a treeline ecotone. Similar decreasing trend was also reported from *Abies spectabilis* treeline ecotone in Langtang (Gaire, 2008). The pine individuals in the ecotone are shorter towards upper ranges relative to the individuals of the same ages in lower elevation band. Rather, upper individuals, occurring in relatively harsher conditions, have more branching. The wind blowing at the treeline seems to keep the trees constantly under pressure. The east facing slopes, devoid of forest and the individuals in the treeline ecotone having flag shaped structure (crown diameter ratio, 1: 1.22) with more branches (longer branches in west side than east ones) may be the indicator of wind effect.

The ecotone is composed of numerous seedlings, saplings and some trees but the tree height doesn't seem to decrease significantly in upper ranges (Fig 5, 8e). Remarkably stunted and krummholz form was absent there so that the treeline can be said of 'abrupt' type that might be the characteristic of the anthropozoogenic type. An 'abrupt' treeline of birch in upper Manang appears to be due to land use specially, livestock (Shrestha *et al.*, 2007). Frequent pine seedling in juniper bush may be interpreted as an indicator of anthropozoogenic influences because the bush might

have protected the newly established seedling from mechanical damages from human and animals as the seedlings were scanty in bare surface. Grazing *chauris*, horses, foot trails etc reflect the intensity of human disturbances and remains of abandoned *Goths* reflects past disturbances. These kinds of disturbances possibly have controlled in large extent to gain natural renaissance of ecotone structure and dynamics.

6.2 Age Structure and Population Dynamics

The static age structure i.e. the range and distribution of tree ages of tree populations provides a fairly accurate picture of temporal and spatial variations in establishment rate (Kullman, 1991 cited in Wang *et al.*, 2006), recruitment and mortality history (Harcombe, 1987) and thus the population dynamics. Because trees of the same size (height or dbh) can have big differences in age due to different growing conditions, age structure can be used to better understand the recruitment and regeneration history. Various factors like seed production and dispersal, competition, climatic fluctuation, grazing, pathogens, and anthropogenic disturbances etc., could influence the age structure of a plant population (Brubaker, 1986). As to a population under optimal conditions, i.e. no severe disturbances of human, pathogens and animals, the age structure will be determined by climatic variability, biological traits and the adaptability of the plant species. And in the disturbed site the responses to the disturbances can override responses to the climate changes.

The recruitment patterns in the treeline ecotone in Ngawal showed increasing trend with time and space. There was lower to moderate establishment in the first half of 20th century, whereas significant events started by 1970s with the prominent periods of high recruitment in 1990s onward. Age structure fits the somewhat reverse J-shape trends with some fluctuations, this may be because establishment in the ecotone was influenced more importantly by human activities and other disturbances (Shrestha and Vetaas, 2009) besides climatic warming. It is obvious that new recruitments have occurred but fig. 7 shows that regeneration was not so pronounced towards the treeline. Climatic harshness might have limited the seedling establishment with increasing mortality. However, fig. 5 shows that mean age decreased with altitude (insignificant, fig. 8d). That means pine population has advancing in the ecotone. Higher percentage of younger age-class shown in age structure implies that pine has

been recruiting and stem density is increasing. It was hypothesized that age structure has primarily been influenced due to recent warming. But anthropogenic pressure also play crucial role. Many researchers relate variation in tree line populations' age structure to climatic variation (Gamache and Payette 2005; Kullman, 2005). In contrast, several studies conclude that recent establishment of trees in other treeline ecotone results from reduced and released anthropogenic pressure i.e. declined human land use (more pronouncedly from around middle of 20th century) that occurred in parallel to climatic warming (Hofgaard, 1997; Holtmeier, 2003; Cairns and Moen, 2004; Gehrig-Fasel *et al.*, 2007). Considering the temperature trend in Chame (no remarkable increase in temperature), the temperature warming in Ngawal might not have more influence whereas there is remarkable change in land use (Shrestha and Vetaas, 2009). On this basis, it can be concluded that the irregularities in recruitment pattern in time and scale may be resulted mainly from human disturbances.

Population dynamics i.e. the rates of population growth and decline are controlled by life-history characteristics, interactions with other plants and animals, and responses to disturbances besides changes in climatic parameters. Some characteristics or interactions allow rapid changes, while others buffer populations against wide fluctuations. To speak about biological factors, long juvenile and adult life spans, plasticity of growth, reproduction and successional status, competitions for above and belowground resources, genetic variations etc. buffer or slow population changes; whereas, high seed production, dispersal and seedling survival with favorable conditions, disturbances (for example: fire, by far the most frequent and widespread form of disturbance in forest ecosystems) that release or reduce the crown or root competition may speed up population changes (Brubaker, 1986). Climate change obviously drives the dynamics but anthropogenic disturbances may change the direction of dynamism. An empirical evidence of population responses to climate comes from the sites that have escaped substantial human disturbances. In the human disturbed ecotone, however, the stand densification is obvious. Significant increase in density (increased establishment) after 1970s may have followed in close synchronicity with warming (temperature has increased significantly from then in Nepal Himalaya, Shrestha *et al.*, 1999) but to test this hypothesis, no sufficient climate data was available and reduced human pressure also may have the role.

6.3 Regeneration

The regeneration is obvious with nearly reverse J-shape age structure and also with frequency-diameter and frequency-height curve (fig. 4, 5 and 6). The regeneration of the present population began by 1900s. Regeneration had significantly increased after 1970 (78.2% of total established) while a great surge was noticed in last two decades (Fig. 9). Fifty percent (50%) of individuals were established in these two decades. This showed establishment trend was corresponding with the warming during these decades and the reduced grazing pressure towards the recent decades. Increased recruitment in late 20th century is also reported from several alpine treeline studies (eg. Rochefort *et al.*, 1994; Szeicz and MacDonald, 1995; Motta and Nola, 2001; Camarero and Gutierrez, 2004). Seed production, germination and establishment are especially sensitive to environmental variations. In the high altitude in treeline ecotone, seedling mortality is predisposed by mainly low temperature, harsh climate, and wind. Mortality rates during early stages are much higher than during the adult stages (Brubaker, 1986). The reverse J-shaped age and size structure shown by the *P. wallichiana* population growing under the near optimum conditions is due to high mortality of juveniles in the smallest age class (Dang *et al.*, 2010). So, favorable growing conditions are essential for successful establishment and stand continuity. The micro-environmental factors and episodic climatic events have crucial role for the establishment (Szeicz and MacDonald, 1995).

In the treeline ecotone, seedlings were noticeably observed well protected in bush of *Juniperus squamata*. Prostrate Juniper provides the protection for pine seedlings from browsing and other external injuries. Such protection is also known as nurse effect (Camarero and Gutiérrez, 2002). This favors recruitment success in the stressful environment around treeline ecotone. Furthermore, the cone bearing trees were also abundant and hence it would not limit regeneration due to lack of viable seeds. Shrubs, krummholz and adult trees keep higher soil moisture protecting against wind abrasion and snow distribution. All such conditions might have improved seedling survival establishment (Szeicz and MacDonald, 1995; Camarero and Gutiérrez, 1999; Holtmeier and Broll, 2005). Reduced human encroachment on land use in recent decades accompanied with increasing temperature (Shrestha *et al.*, 1999) could be considered to result in acceleration of pine establishment, regeneration and growth gradually towards upper altitudes with remarkable role of the low shrubs.

The age and size structure distributions showed that regeneration is real in the ecotone and the studied populations were dominated by small individuals (Fig. 4, 6, 9, Table 1) and the distribution was heterogeneous. The individuals less than 10 cm dbh accounted for 42.6% and those of age ≤ 20 years accounted for 52.6%. Tree to sapling plus seedling ratio varied with elevation (1:0.77 in the lowermost elevation range but 1:1 in the uppermost range). Similarly, the younger proportion increased from west to east. The tree to sapling plus seedling ratio were 1:0.4, 1:0.51 and 1:2 respectively in Transects A, B and C. These suggest that establishment was abundant in the stand in recent decades but seedling and sapling distribution was spatially heterogeneous which may be relatively common under natural conditions (Shrestha *et al.*, 2007). The reason to occur increasing regeneration from west to east is unknown. Micro-topographic feature and wind effect may have brought the difference in regeneration. The sensitivity of the vegetation to temperature is related to the stand structure and geographical conditions. At sites near the ridges, with low vegetation cover, or on steep slopes where the soil can easily become dry, the response of the tree growth to climatic factors may be much higher (Du *et al.*, 2007). Transect C was located toward the ridge-edge to the east. The regeneration surge after 1970s may be the synchronization with warming temperature but, the irregularity in recruitment may be due to anthropozoogenic factors as some dilapidated *Chauri-hut* were seen.. Grazing activity in this area without sufficient thorny shrubs may have suppressed the regeneration of *Pinus wallichiana* in the recent past and the rapid increase in population regeneration in the late twentieth century may have been due to the direct cause of reduced anthropogenic influence.

6.4 Treeline Dynamics and Ecotonal Responses as Potential Climate Proxy

In treeline ecotones, plants are growing near their physiological tolerances and hence can be sensitive to small changes in temperature and other disturbances. With this sensitivity, the ecotones may provide detection of alterations of disturbances (climatic, anthropozoogenic, etc.). There exist complex interactions among climates, topography, orography, disturbances etc. to determine the position of treeline. Climate change and land-use modifications are amongst the vital factors influencing the distribution of tree populations.

The treeline ecotonal densification in Ngawal may be suggestive of climate warming and/or land use change (Shrestha and Vetaas, 2009) as the biological responses. As suggested by Holtmeier (2003) the coupling of the responses to climate warming is too weak with too many intervening processes for that to use as an indicator. It has been proved difficult to assign casual factors linking climate and treeline position in human encroached area and there seems to exist complex and entangled effects of climate and land use changes along with local conditions, microclimate, other anthropozoogenic pressures etc. on treeline responses. Spontaneous invasion of seedlings and young growth into almost treeless areas above the anthropogenic forest limit and the changing physiognomy of scattered and hitherto environmentally suppressed trees in the treeline ecotone are often readily ascribed to the effects of warming climates (Holtmeier and Broll, 2005). In absence of proper records of anthropogenic disturbances and climate, simultaneous reduction of anthropogenic pressure and increase in temperatures complicates the interpretation of the results.

In treeline ecotone of Ngawal, it was somewhat obvious that climatic influences on treeline structure may be significantly confounded by various anthropozoogenic pressures. It can't be declared the current treeline position is natural i.e. climatically determined or anthropogenic type. But it was obvious that the treeline position has remained static at least for two or three decades. Although the treeline position is mainly determined by temperature (eg. Innes, 1991; Daniels and Veblens, 2004), livestock and/or natural herbivory (Cairns and Moen, 2004) and other types of landuse of human interference also have significant influences on the position and structure. Lower moisture availability limited tree recruitment in the Andes (Daniels and Veblens, 2004). Anthropozoogenic activities might in the past have controlled seedling establishment as the frequent seedlings were seen in Juniper and Caragana thickets that may indicate the influence. Similar pressure has checked the upslope migration of Scandinavian mountain birch treeline (Cairns and Moen, 2004). While in the Ngawal treeline ecotone, most of the *P. wallichiana* seedling and sapling specimens were seemed to survive intermingled with dense thickets of juniper shrubs, which may also be interpreted as an indicator of wind and anthropozoogenic influences, because the dense shrub communities can protect seedlings and saplings

of *P. wallichiana* from wind damages, trampling, grazing and lopping activities (facilitative interaction). Grazing activity in this area without sufficient thorny shrubs might have suppressed the regeneration of *P. wallichiana* in the recent past. Shrestha and Vetaas (2009) also had attributed the low species turn over and low variation in species richness in the ecotone to the grazing and browsing pressure in the area in past.

The upward expansion of the treeline ecotone is reflected in the decreasing mean tree age with increasing elevation (Kirilyanov *et al.*, 2011). Besides, significantly younger trees towards treeline and successful regeneration at the upper growth limit in recent decades also are indicative of future changes in the upper treeline stability and a potential for the treeline advance (Hofgaard *et al.*, 2009; Kirilyanov *et al.*, 2011). The present pattern of the pine population dynamics, progressive pine densification and decline in pine age and size through the altitudinal gradient in the treeline ecotone may be influenced largely by reduced grazing pressure and climate warming also may have some influence which cannot be confidently predicted as heterogeneity in seedling distribution was found there. However, the pine population showed potential to upward treeline shift in recent future. Future colonization, densification and stand continuity depend on tree establishment. Trees are more tolerant (Brubaker, 1986). Seedlings and saplings have to cope with natural hazards up to several years to ensure a successful recruitment (Szeicz and MacDonald, 1995). Without supplementary experiments and observations on seedling survival under exceptional conditions, predictions on future recruitment in the ecotone are difficult.

Both recent warming and released human pressure seems to be propitious for discernible regeneration. However, both of the above proposed natural and anthropogenic driving mechanisms of tree-line dynamics require more evidence and need more case studies. The dominance of recently established pines (1970s–2009 period) in the ecotone reinforces the idea that recent land use changes synchronous with recent climate warming may have triggered the observed dynamics.

Chapter: VII
CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Age structure analysis in this study has tried to decipher the understandings about the pine population dynamics and regeneration history in the treeline ecotone of Ngawal. Almost reverse J-shaped age- and size structure showed that the majority of the pine population was recruited by 1970s and significant regeneration and densification since then coincided. The age vs. height regression model facilitated to make estimation that the current treeline position (4020 m a.s.l.) might have attained at least about two decades ago and has remained static for the decades. The age of the treeline trees does not denote the recent advance but the regeneration status and trends indicate the future potential for imminent treeline advance. Furthermore, the age structure and population dynamics have somewhat substantiated the ecotone densification in recent decades which might be triggered by climate warming synchronous with recent release of human pressures. Present pattern of pine population dynamics, progressive densification and decline in pine age and size through the altitudinal gradients in the ecotone might have been influenced by warming climate. However, heterogeneity in establishment and ecotone structure might be attuned to human stresses along with climatic variations. The unclear trend in size and age distribution also may denote anthropogenic disturbances in the past. Furthermore, the treeline response to climate may have overridden by recently reduced anthropogenic pressures. So the treeline dynamics could not be predicted by temperature rise alone even under the current global warming scenario but it seems to be influenced its naturalness by anthropogenic factors, too.

This study provides an evidence of ecotonal response and reiterates the sensitivity of the ecotone to future climate change. Also, the study ameliorates somewhat the research gap for treeline ecotone in Ngawal. The dynamics and regeneration heterogeneity necessitates the further studies incorporating anthropogenic factors on treeline responses to climate change. Long series of climate information (high resolution long-term data) are necessary to gain insight into the natural variability of climate, their causes and to develop a better understanding of the linkage between treeline shifts and climatic dynamics.

7.2 Recommendations

Age structure and population dynamics in treeline incorporated with other ecological, dendrochronological (ring width and radial growth analysis etc. and paleoclimatic reconstruction), and anthropogenic aspect would provide better and valuable insight into the understanding of the long-term dynamics vis-à-vis climatic variability.

The site lacks climate data. Dendrochronology, which is a powerful and productive technique of paleoclimatic investigation, should be encouraged here. Rigorous and concerted efforts are needed to develop tree-ring-chronologies, as surrogate climate records, providing valuable data for climate change studies in the region.

Focus of future research on long-term and area-wide monitoring of regeneration and tree development to capture the full dynamics in the treeline ecotone and better identify the underlying drivers.

Reconstruction of dynamics of leaning trees and branches through cross dating compression wood in tree rings may facilitate in determining the impacts of wind.

Ecosystem being disturbed by human activities, age structure and dynamics cannot be predicted by temperature alone even under a scenario of global warming. Hence, for the disentangling pursuit, further studies must encompass land use change and climatic change to find out whether the human pressure has overridden the warming trend i.e. is the treeline response from the event (reduced human pressure) rather than a trend (climatic warming).

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Annex I

Table: correlation

Correlation between		Correlation coefficient
Age	Height	0.883
Age	Basal diameter	0.907
Height	Basal diameter	0.887
Elevation	Age	-0.136
Elevation	Height	-0.228
Elevation	Basal diameter	-0.096

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

Annex III

Photo Plates



Study site, Ngawal



Treeline ecotone, Ngawal



Laying Vertical Transect in treeline ecotone



Observation of a seedling in juniper thicket



Taking increment core



Counting annual rings in Lab (NAST)