Age Structure and Regeneration of *Rhododendron arboreum* Sm. along an Altitudinal Gradient of Manaslu Conservation Area, Nepal Himalaya

A dissertation prepared for the partial fulfillment of the requirement for the completion of Master's Degree in Environmental Science

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Central Department of Environmental Science
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Submitted by
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CENTRAL DEPARTMENT OF ENVIRONMENTAL SCIENCE

Kirtipur, Kathmandu

LETTER OF RECOMMENDATION

We hereby certify that this dissertation entitled **Age Structure and Regeneration of *Rhododendron arboreum* Sm. along an Altitudinal Gradient of Manaslu Conservation Area, Nepal Himalaya** submitted to the Central Department of Environmental Science for partial fulfillment of Master's degree in Environmental Science by **Ms Luna Khadka** is based on scientific investigations carried out by the student under our supervision.

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LETTER OF APPROVAL

We hereby certify that this dissertation entitled **Age Structure and Regeneration of *Rhododendron arboreum* Sm. along an Altitudinal Gradient of Manaslu Conservation Area, Nepal Himalaya** submitted by Ms Luna Khadka to the Central Department of Environmental Science has been accepted as requirement for partial fulfillment of Master's degree in Environmental Science.

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DECLARATION

I hereby declare that this dissertation entitled **Age Structure and Regeneration of *Rhododendron arboreum* Sm. along an Altitudinal Gradient of Manaslu Conservation Area, Nepal Himalaya** is my own work and all other sources of information used, have been duly acknowledged. This work has not been published or submitted for any award.

………………

Luna Khadka

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Abstract

The age structure and regeneration of *Rhododendron arboreum* Smith. was studied along an altitudinal gradient of Manaslu Conservation Area, Nepal Himalaya ranging from 2180m to 3180m. Vegetation sampling was done by using quadrate method. Five plots of 10mX10m were located in each transect with vertical distance of 200m and horizontal distance of 100m. Altogether six tree species were recorded in the study area. *R. arboreum* was dominant followed by *Pinus wallichiana*. Altogether 46 cores from 27 trees and 10 stumps of *R. arboreum* were collected. In the population of *R. arboreum*, seedling accounted for 38.51%, sapling 33.33% and tree 28.14%, showing successful life cycle of the species. The regeneration status of *R. arboreum* was good at 2380m, fair at 2180m, 2580m and 2780m and poor regeneration at upper limit i.e. 3180m. The oldest and youngest cored trees recorded were 127 and 19 years respectively. A reverse J-shaped distribution was found in DBH class, age class and height class. The height of tallest and shortest *Rhododendron arboreum* recorded in the study area were 7m and 0.1m respectively. The correlation between age and DBH of *R. arboreum* was statistically significant($r=0.763$, $p<0.00001$). The mean annual radial growth of *R. arboreum* was 1.65mm.

Key words: DBH, Dendro-ecology, Growth pattern, Tree Ring

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Acronyms and Abbreviations

^{o}C	Degree Celsius
%	Percentage
cm	Centimetre
DBH	Diameter at breast height
et al.	and others (from Latin *et alii*)
etc	and so forth (from the Latin *et cetera*)
ha	Hectare
KMTNC	King Mahendra Trust for Nature Conservation
m	Metre
mm	Millimetre
m^2	Metre Square
NAST	Nepal Academy of Science and Technology
NCCKMC	Nepal Climate Change Knowledge Management Centre
NTNC	National Trust for Nature Conservation
SPSS	Statistical Package on Social Science
VDC	Village Development Committee
yr	Year

Chapter 1: Introduction

1.1 Background

1.1.1 Age Structure

The term, dendroecology, refers to the application of dendrochronological techniques to problem in ecology (Fritts & Swetnam 1989). Dendroecology is the science that uses tree rings, dated to their exact year of formation, to analyze temporal and spatial relationships between living organisms and their environment (Anonymous 2007). One of the general application of dendroecology deals with past forest disturbance that may leave no scar but affect the ring character influencing the tree's productivity and growth (Fritts 1976; Lorimer 1985). Tree age can be predicted by developing age-diameter models with small size sampling of trees. These models avoid the need for expensive and time-consuming age measurements in forest inventories.

Age structure investigations could give insights into the processes determining population structure overtime (Stewart 1986; Johnson & Fryer 1989; Svenson & Jeglum 2001). Studies of the age structure of a tree population might provide an insight into past and present regeneration patterns (Agren & Zackarisson 1990). The age structure of high altitude transect is more sensitive to the shifts of temperature than that of mid altitude transect. Age structure studies along an altitudinal gradient of a mountain would be helpful in understanding the influences of environmental factors on the regeneration of natural forest (Wang *et al.* 2004). The age structure of a stand can provide a fairly accurate picture of temporal variations in the establishment rate (Kullman 1991) i.e. a static age structure of living trees is the expression of change in the rate of tree recruitment and mortality over time (Harcombe 1987).

Quantitative reconstructions of age structure conditions (the distribution and range of tree ages), could also serve as a basic point of reference central to restoration and management of forest ecosystems (Covington *et al.* 1997; Fule *et al.* 1997; Mast *et al.* 1999). Assessing and analyzing age structures are therefore prerequisites for understanding ecological processes and restoration of natural forests (Duan *et al.* 2009). According to the principle of aggregate tree growth, radial growth during a particular year represents aggregate response to biotic and abiotic factors such as age related growth trends, climate and disturbance (Cook 1987). Previously no studies specific to the age structure and regeneration of rhododendron has been carried out along the altitudinal gradient in Nepal Himalaya.

1.1.2 Regeneration

Natural regeneration implies the process of re-growing or reproducing new individual plants in the community. It is the most important process to maintain the stable age structure of the plant species in a community, affected directly or indirectly by various climatic as well as edaphic factors (Singh & Singh 1992). The regeneration phase is a critical life stage for species in which changes in climatic controls hinder or enhance a species response to change (Bradshaw *et al.* 2000). The inclusion of seedlings and saplings in plant population structures would provide better information about the status of the species at early stage of regeneration. Plants maintain and expand their populations in time and space by the process of regeneration (Bharali *et al.* 2012).

The pattern of population dynamics of seedlings, saplings and adults of a plant species can exhibit the regeneration profile, which is used to determine their regeneration status (Bekele 1994; Teketay 1996). The issue of regeneration is mainly important for those forests which are under various anthropogenic pressures such as felling tree, grazing, trampling, etc (West *et al.* 1981). The three major components for successful regeneration of a species are: i) ability to initiate new seedlings, ii) ability of seedlings and saplings to survive and iii) ability of seedlings and saplings to grow (Good & Good 1972).

Many forest species are likely to fail to regenerate if the synchrony between their seed ripening and commencement of monsoon rain is broken due to climate change (http://www.climate-leaders.org). Trees are generally considered to be most vulnerable to climatic stresses during the regeneration phase. Climate change will affect flowering, pollination, seed formation, germination, and seedling survival. Regeneration success will, therefore, depend on the future capacity of trees to produce viable seed and on the capacity of those seeds to germinate (Johnston *et al.* 2009). Moreover, plants could generally grow and survive in a limited range of environmental gradients, e.g. temperature and light availability (Block & Treter 2001) and variation in these factors play important roles in shaping the age structure and forest regeneration at different altitudes (Duan *et al.* 2009).

1.1.3 Rhododendron

Rhododendron is the largest genus in Ericaceae family with over 1,000 species including many bushy species and a number of trees that grow to heights of up to 30meters (Scott 2010). The genus rhododendron is derived from the Greek words rhodos (meaning rose) and dendron (meaning tree) and was for the first time described by Carl Linnaeus in 1837 in *Genera Plantarum* (Tiwari & Chauhan 2006). They are widely distributed occurring throughout most of the Northern Hemisphere and extending to areas in southeastern Asia and northern Australasia. It does not occur naturally in South America or Africa. The oldest evidence of rhododendron has been found in southern China. The first known rhododendrons in Europe were those that grew in the Alps at an altitude between 1200m and 2400m (Scott 2010).

Rhododendrons are the denizens of mountains mainly inhabiting a vast section of Southeastern Asia stretching from Northwestern Himalaya through Nepal, Northeastern India, Eastern Tibet, Northern Burma and Western and Central China. Rhododendrons have a characteristic slow growth rate. Ranging in size from tiny mat-like growths in alpine region (*R. pumilum*, *R. setosum*) having a few cm fall individuals to giants having 25m (*R. arboreum*) is another characteristic feature of the genus (Tiwari & Chauhan 2006). Rhododendrons are found associated with other tree species or as pure stand in forest of the Himalaya where the highest species diversity is found (Scott 2010).

Of the over 30 species of rhododendron found in Nepal the most renowned is *Rhododendron arboreum*, known as *laligurans* in Nepali (Scott 2010). Since 1962, *R. arboreum* was adopted as a national flower of Nepal, suggestions have been put forward for a *Rhododendron* reserve in Nepal (Pokhrel 1999). There are extensive and magnificent *R. arboreum* forests throughout the country ranging in elevation from around 1,400 to 3,600 meters. Many of the tree species will take years to reach flowering, at least 20 or more, while at least 50 years is needed for a tree rhododendron to reach its optimum form (Scott 2010). Rhododendrons have been depleting in Nepal’s mountain as fast as sal (*Shorea robusta)* in the Terai. Rhododendrons experience natural and anthropogenic pressures and the later factors are realized as the main cause of their population decline (Badola 1992; Pokhrel 1999).

1.2 Statement of problems

Impact of climate change in plants is becoming visible nowadays and many species have been reported to be shifting upwards. Furthermore, climate change has an adverse impact on the regeneration and age structure of tree species. Lack of baseline data have been a major hindrance in assessing the impacts of climate change. Age structure and regeneration studies along the altitudinal gradient of mountain would be helpful in understanding the influences of environmental factors on the regeneration of natural forest. Furthermore, the age structure conditions could also serve as a basic point of reference central to the management of forest ecosystems. People utilizes forests for their well being, this may bring about changes in the density and composition due to uncontrolled lopping and felling of trees for fuel wood, fodder, timber, and grazing affecting the regeneration. Generally, conifers trees have been selected for the dendrochronological studies in Nepal and the broad leaved tree species are less studied. *R. arboreum* as a representative of broad leaved tree species has been selected for the study of age structure and regeneration. There has been growing concern about the sustainable management of *R. arboreum* as an important forest species. It is necessary to study and examine the growing concern about *R. arboreum* and try to determine the way to preserve and manage the forest. Rhododendrons often grow precariously on cliffs and ledges and sometimes grow at very high altitudes enabling us to extend tree-ring-based climatic proxy records beyond the tree line. In spite of such an exciting perspective, its potential as an ecological indicator for global climate change and dendrochronological studies is still unknown (Liang & Dieter 2009). Moreover, Manaslu Conservation Area is a comparatively less explored site in terms of research and till date no detailed studies on age structure and regeneration status of *R. arboreum* have been carried out in Nepal.

1.3 Research Questions

1. What is the age structure of the *R. arboreum*?
2. What is the regeneration pattern of the *R. arboreum*?
3. What is the growth pattern of *R. arboreum*?
4. Is *R. arboreum* suitable tree species for Dendro-climatic analysis?

1.4 Objectives of the study

The main objective of the research was to study the age structure and regeneration pattern of *R. arboreum* along an altitudinal gradient of Manaslu Conservation Area in Nepal Himalaya.

Specific objectives

- To estimate the Age-DBH relationship.
- To study the age structure of *R. arboreum* with special reference to tree ring.
- To study the regeneration pattern of *R. arboreum*
- To analyze the growth pattern of *R. arboreum*.

Chapter 2: Literature Review

2.1 Age Structure

Brubaker 1986. Age structure and regeneration dynamics can be used to infer population response to known environmental events and reconstruct forest development history.

Regmi 1998. *Pinus roxburghii* samples of Kulekhani area did not show clear ring. In spite of showing clear ring, *P. wallichiana* did not cross dated well because of human disturbances.

Renzo and Paola 2001. Age structure analysis revealed that the current sub-alpine forest stands were established 200-220 yr ago, probably following a clear-cut. The results showed that the growth rates of mature *Pinus cembra* and *Larix decidua* had increased. The growth rate of young trees (< 100 yr) of both species has decreased over recent decades. This could be due to competition caused by increased tree densities that have resulted from a decrease in grazing.

Svensson and Jeglum 2001. Investigations of age structure and regeneration dynamics could give insights into the processes that determine population structure and pattern over time.

Wang *et al.* 2004. 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.

Bhuju *et al.* 2010. Established two permanent plots at tree line in Sagarmatha National Park, Nepal. The study measured all tree in the plots and collected cores of *Abies spectabilis*. The study aims at reconstructing environmental history and climatic condition of the area.

Batllori *et al.* 2010. The age structure of the tree lines, together with the lack of an age gap between seedlings and saplings, did not indicate recent episodes of high seedling mortality and suggest that recruitment has been frequent under current climate conditions.

Dang *et al.* 2010. Age and size studies along an altitudinal gradient are helpful for understanding the relationship between environmental factors and population dynamics.

2.2 Regeneration

Veblen 1986. A small sample of ages of seedling and saplings combined with their densities is sufficient for determining the regeneration status of each species.

Block and Treter 2001. It is also well documented that environmental factors influence the regeneration of plants, e.g. drought, water logging, high or low temperature, could also affect the age structure of plants.

Ghimire and Lekhak 2007. *Abies spectabilis* in the northern aspect of the Manang valley at an elevation between 3500m to 4000m showed that the size class distribution of *Abies spectabilis* as reverse J-shaped curve but regeneration potential was low under its own canopy.

Duan *et al.* 2009.Variation in a limited range of environmental gradients, e.g. temperature and light availability play important roles in shaping the age structure and forest regeneration at different altitudes.

Majila and Kala 2010. In general, the regeneration potential in most of the tree species declines with the altitude. The density of saplings and seedlings also represented the dominant species at each altitudinal range, which indicates the cyclic regeneration of forests in the Sanctuary area.

Bharali *et al.* 2012. The overall regeneration status of the tree species in the study stands exhibit fair regeneration with density of sapling population less than seedlings and adults.

2.3 Radial Growth

Swetnam *et al.* 1985. Occasionally the ring widths of an individual tree may show variation unlike that of all other trees at the site. The cause may have been factors that affect only that tree, such as lightening strikes, fire scars, or broken tops.

Cook 1987. According to the principal of aggregate tree growth, radial growth during a particular year represents an aggregate response of biotic and abiotic factors such as age related growth trends, climate and disturbances.

Earle 1993. The width of tree rings could indicate environmental factors affecting the growth of trees, e.g. the temperature and precipitation in the growth season.

Chhin and Wang 2005. Examined the radial growth response of white spruce [*Picea glauca* (Moench) Voss] to climate from two measurement heights [breast height (1.3m aboveground) versus stump height (0.3m above ground) in order to examine the role of sampling height in dendroclimatic analysis.

Du *et al.* 2007. The radial growth pattern around the year suggests that most of the diameter increments occur in May–July, though the cambial activity and leaf photosynthesis are considered to continue until late September.

Gaire 2008. Tree ring analysis of *Abies spectabilis* shows variation in between the radial growth in the recent years and in overall growth period.

Xing *et al.* 2012. Radial growth patterns of individual trees examined in our study varied within and among species. The differences in radial growth of trees suggest that the habitat of the subtropical forest under study is highly heterogeneous in space and such heterogeneity may contribute to the multi-species coexistence of the forest.

2.4 Rhododendron

Andre and Bernard 1995. Age structure and dynamics of *R. ferrugineum* populations in the Northwestern French Alps were studied and it was found that biotic and abiotic factors might be responsible for the speciation and survival of species.

Suzuki and Noshiro 2001. Nepalese *Rhododendron* species have diffuse-porous wood with distinct growth rings and evenly distributed small vessels and heterocellular rays.

Gratzer and Rai 2004. Maximum age of *Abies densa* and *Rhododendron hodgsonii* saplings was 39 and 21 years, respectively.

Rong and Li-xin 2006. In general, the seedling pool of *R.simiarum* population in most plots were abundant and the age structure was stable, so that *R.simiarum* population can stably expand in the community.

Liang and Eckstein 2009. The dendrochronological potential of rhododendron is inspiring the exploration of the variation in radial growth of more rhododendron species occurring in various forms from sub-tree to shrub and dwarf shrub along altitudinal gradients of their distribution and their climatic responses in south-east Tibet. The mean annual growth rate of snowy *Rhododendron nivale* is 0.36 mm.

Elliott and Vose 2012. In this study maximum age of *Rhododendron maximum* stems (ramets) was 120 years; as older ramets died they were replaced by younger ramets through vegetative reproduction, thus an individual genet survives for much longer than the maximum ramet age.

Chapter 3: Materials and Methods

3.1 Study Area

Manaslu Conservation Area (MCA) lies between 28° 20' - 28° 45' latitude to 84° 29' - 85° 11' longitude. in Gorkha District in the western development region of Nepal. MCA comprises of seven VDCs namely Samagaon, Lho. Bihi, Prok, Chumchet, Chhekampar and Sirdibas in the northern part of the district. All the VDCs except Sirdibas are bordered with China (Tibet) on the northern side. The elevation of the Manaslu Conservation Area ranges from 1,400m to 8,163m. The major peak in the project area is Manaslu Himal (8,163m) which lies in Samagaon VDC. The area is rich in biodiversity. *R. arboreum* is found in Sirdibas-Prok and Lho VDC's (KMTNC 1998).

The present study was carried out in April-May 2012. The study site is located on a north facing slope in a forest stand named Thangin (N28°30.779' E084°51.000') of Prok VDC starting from the altitude 2180m to 3180m (Figure 1). The major vegetation seen at the altitude of 2180m was *Pinus wallichiana* where as *R. arboreum* was dominant at an altitude of 2380m.

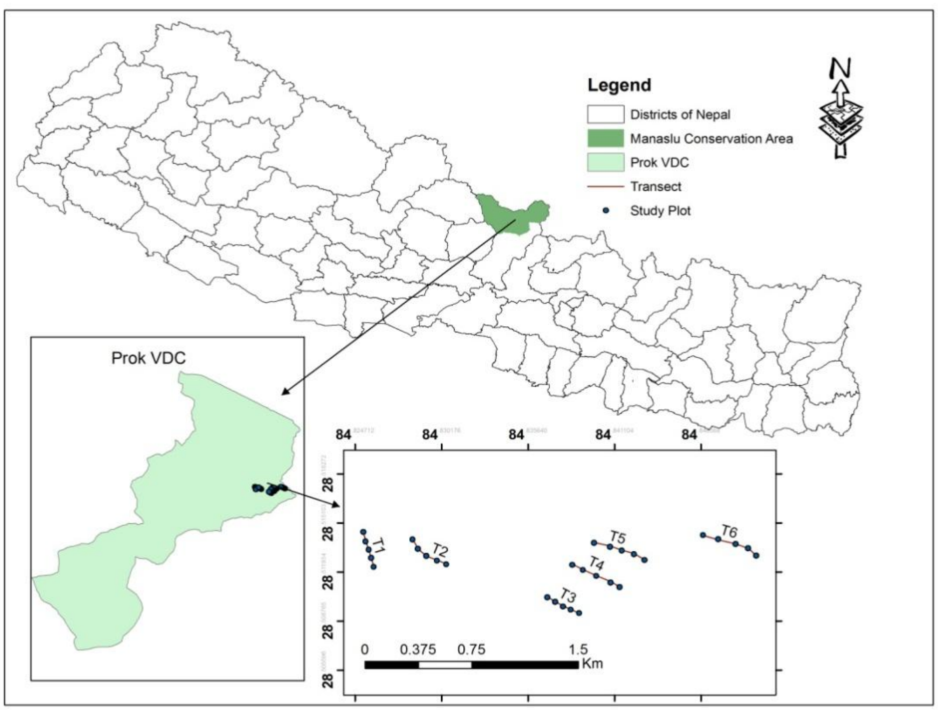

Figure 1. Map of study area showing transects (T)

3.2 Research Design

The research design for this study was analytic, descriptive and scientific.

3.3 Review of Literature

Related literatures were reviewed from global to local level. Literatures were reviewed for the better understanding of the research.

3.4 Methods of Data Collection

Primary and secondary data were collected as described below.

3.4.1 Primary Data Collection

Primary data were collected from field sampling, lab analysis and field observations.

3.4.1.1 Field Sampling

Vegetation sampling was done by quadrate method, and the sample quadrates were located by systematic random sampling method. Sampling was done in northern aspect. The quadrate size was 10mX10m. Sampling was carried out from upper elevation (3180m) to lower elevation (2180m). The quadrate was laid at an altitudinal difference of 200m and horizontal difference of 100m. A total of 30 quadrates were sampled. Number of individuals of each species in tree stage was counted and diameter at breast height (DBH, measured at 137cm above the ground) of *R. arboreum* measured. Individuals of tree species were divided into three growth stages: trees (DBH>10 cm), saplings (DBH<10cm, height>137cm) and seedling (height<137cm). Population density and frequency of the target species along with the seedling and sapling were determined.

Each quadrate were divided into four sub quadrates of 5m × 5m, and two small quadrates lying diagonally were selected randomly for sampling seedlings and saplings. In each small quadrate, height of each seedling, DBH and height of saplings, and their number were recorded. Graph was plotted by viewing the canopy of a tree in a graph paper (10 big square units as a quadrate size of $10x10m^2$), firstly standing in the centre of quadrate and moving some steps forward and backward to estimate the canopy cover. The covered area was shaded by a pencil. Canopy cover percentage was calculated by counting the number of shaded units in the graph paper.

The tree cores were extracted from base (0.5cm) and breast height (1.3m) using an increment borer (Haglof, Sweden, diameter: 5.12mm, length: 12inch). Altogether 46 cores from 27 trees and 10 stumps of *R. arboreum* were collected. Two cores per tree were collected but in some trees, only one core was collected when another side was not suitable. The collected cores were properly inserted in a plastic straw and labeled by giving a tree code and core number. The samples were taken to NAST Dendro-laboratory for analysis.

3.4.1.2 Laboratory Analysis of Tree-ring

Laboratory methods mainly included mounting, sanding and polishing of cores. It further included counting of rings and measuring the distance between the rings. The tree cores were dried and mounted in a wooden frame and sanded using progressively finer sandpaper until growth ring boundaries were clearly visible. The ring boundaries were clearly visible after sanding by 1000 grits sand paper. Four tree cores were discarded as the boundary was not clearly visible. The ages of cores were determined by counting the number of rings using the stereo zoom Lintab microscope setup and an attempt was made to cross date the tree rings by the program COFECHA. Efficient and precise measurement of annual tree-ring widths is best accomplished with a sliding stage micrometer interfaced with a microcomputer (Robinson & Evans 1980). Individual rings were measured by moving the core samples on the sliding stage under a Lin-tab microscope set up. The measurements were subsequently recorded in the computer. The growth pattern of the target species were determined by measuring the distance between two annual rings using TSAP (Time Series Analysis and Presentation Program) win professional 0.62©2002-2008, a computer program.

3.4.2 Secondary Data Collection

Secondary data were collected from the published relevant journals, magazine articles, books, web site, thesis reports, official records, etc.

3.5 Numerical Analysis

Density and frequency of the tree species were determined to study the population structure and the regeneration status of *R. arboreum*. The formulas for calculation of the attributes are given below:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrates in which an individual species occurred} \times 100}{\text{Total number of quadrates sampled}}$$

$$\text{Density (stem/ha)} = \frac{\text{Total number of individuals of a species in all plots} \times 10000}{\text{Total number of plot studied} \times \text{Size of the plot } (m^2)}$$

3.6 Data analysis

The obtained data and collected information was analyzed using Excel (2007) and SPSS (16) computer programmers for the interpretation of result. Data and information were quantified and presented in table chart and graph.

Chapter 4: Results

4.1 Plot Characteristics

There were altogether 30 sampling plots distributed in six transects ranging from 2180m to 3180m in the present study. The plots were spread between latitudes of 28.51454° to 28.509503° N and longitudes of 84.829884° to 84.825213°E. They all were in steep slope, mostly above 50° and some were even above 60°.

4.2 Population Structure

All together six tree species were recorded (*R. arboreum*, *R. barbatum*, *R. campanulatum*, *Castonopsis indica*, *Pinus wallichiana and Mahonia nepalensis*) at the study area (Table 1). The highest density of *R. arboreum* was observed at 2380m (340 stem/ ha) followed by 2780m (160 stem/ha), 2580m (120 stem/ha), 2180m (120 stem/ha), 3180m (100 stem/ha) and 2980m (0 stem/ha). The total density of trees were highest at 2580m (700 stem/ ha) followed by 2380m (660 stem/ha), 2780m (460 stem/ha), 3180m (300 stem/ha) and 2980m (260 stem/ha). At 2380m and 2180m *R.arboreum* had higher density compared to other species. While at 3180m, 2980m, 2580m and 2780m highest density were observed for *R. barbatum* (160 stem/ ha), *R. barbatum (*180 stem/ha), *P. wallichiana* (260 stem/ ha) and *P. wallichiana* (220 stem/ ha) respectively.

Table 1. Density of different species at tree stage at different elevation.

S.N	**Altitude (m)**	**Density(stem/ha) of different species at tree stage**						**Total Density (stem/ha)**
		R. arboreum	*R. barbatum*	*R. campanulatum*	*Castanopsis indica*	*Pinus wallichiana*	*Mahonia nepalensis*	
1	3180	20	160	120	0	0	0	300
2	2980	0	180	0	0	80	0	260
3	2780	160	80	0	0	220	0	460
4	2580	120	120	0	160	260	40	700
5	2380	340	0	0	20	60	240	660
6	2180	120	0	0	0	100	0	240

Canopy cover was calculated in % (Table 2). The highest canopy cover was observed at 2380m (63%) followed by 2180m (56%), 2580m (40%), 2780m (22%), 3180m (20%) and 2980m (13%).

Table 2. Canopy cover of the study plots

SN	Altitude (m)	Canopy Cover % 1	2	3	4	5	Average Canopy cover (%)	Remarks
1	2180	44	69	61	73	31	56	Heavy coverage of shrubby vegetation
2	2380	83	17	74	75	68	63	
3	2580	75	22	18	25	59	40	
4	2780	18	22	20	17	33	22	
5	2980	17	18	14	8	10	13	Thick ground coverage
6	3180	55	8	11	10	18	20	Thick ground coverage

4.3 Regeneration

The frequency and density of *R. arboreum* at different developmental stages along an elevation gradient are listed in Table 3 and Figure 2 respectively. The study showed the regeneration status of *R. arboreum* was good at 2380m, fair at 2180m, 2580m and 2780m and poor regeneration at 3180m (upper limit). Seedling accounts for the highest density at 2380m (580 stem/ha) and lowest density at 2980m and 3180m (0 stem/ha). Sapling accounts for the highest density at 2380m (420 stem/ha) and lowest density at 2980m and 3180m (0 stem/ha). Tree stage accounts for the highest density at 2380m (340 stem/ha) and lowest density at 2980m (0 stem/ha). *R. arboreum* has the high regeneration at 2380m where the canopy cover is high and vice-versa. Of the total population of *R. arboreum* seedling accounted 38.51%, sapling 33.33% and tree accounted 28.14%. Seedling has the highest population share and tree has the lowest.

Table 3. The frequency of different developmental stages of *R. arboreum* at the elevation gradient

S.N	**Altitude (m)**	**Frequency (%)**		
		Tree	Sapling	Seedling
1	3180	20	0	0
2	2980	0	0	0
3	2780	100	80	40
4	2580	100	100	100
5	2380	100	100	100
6	2180	100	60	100

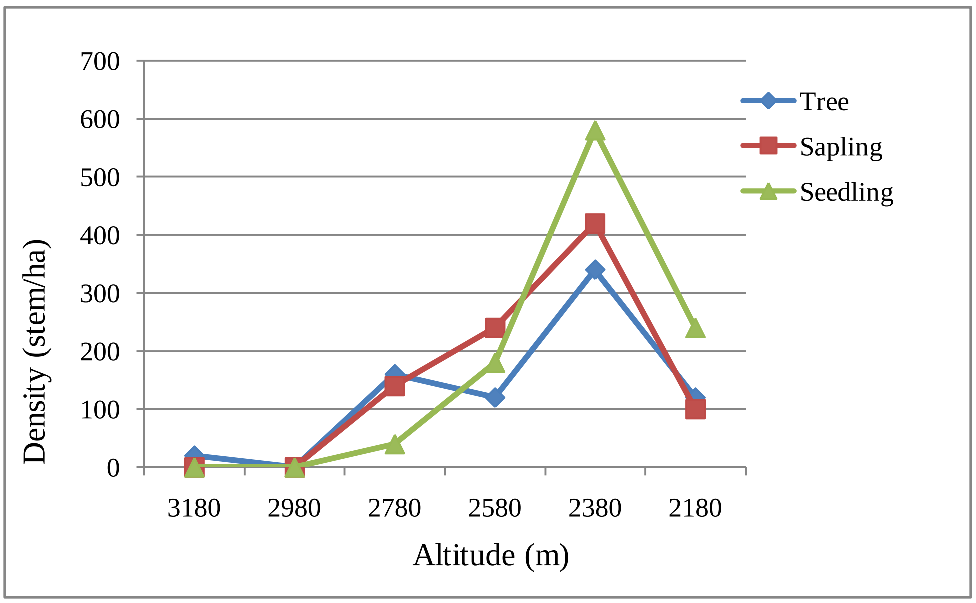

Figure 2. Density of *R. arboreum* at different development stage and different elevation

A regression analysis model between number of seedling/sapling and canopy cover was established (Figure 3). The negative regression equation shows that the regeneration increases with decrease in canopy cover and vice-versa.

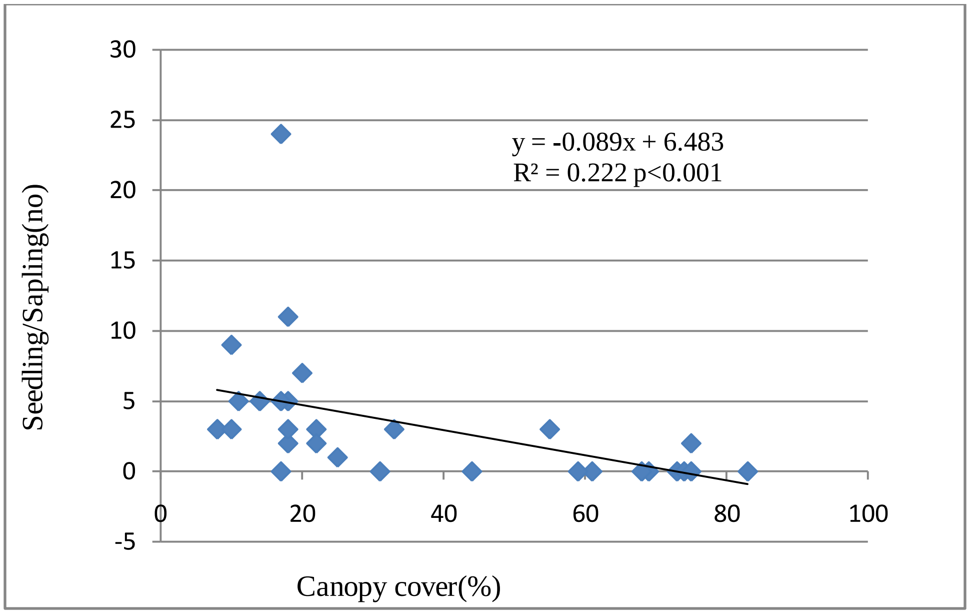

Figure 3. Relation between regeneration and canopy cover

4.4 Height Class Distribution and Age-Height Relationship

The height class was grouped in 1m interval (Figure 4). Since the number of seedling accounted the highest rank, the class interval (0-1) accounts the highest % followed by class interval (1-2). The height of the tallest and the shortest *R. arboreum* recorded in the study area were 7m and 0.1m respectively.

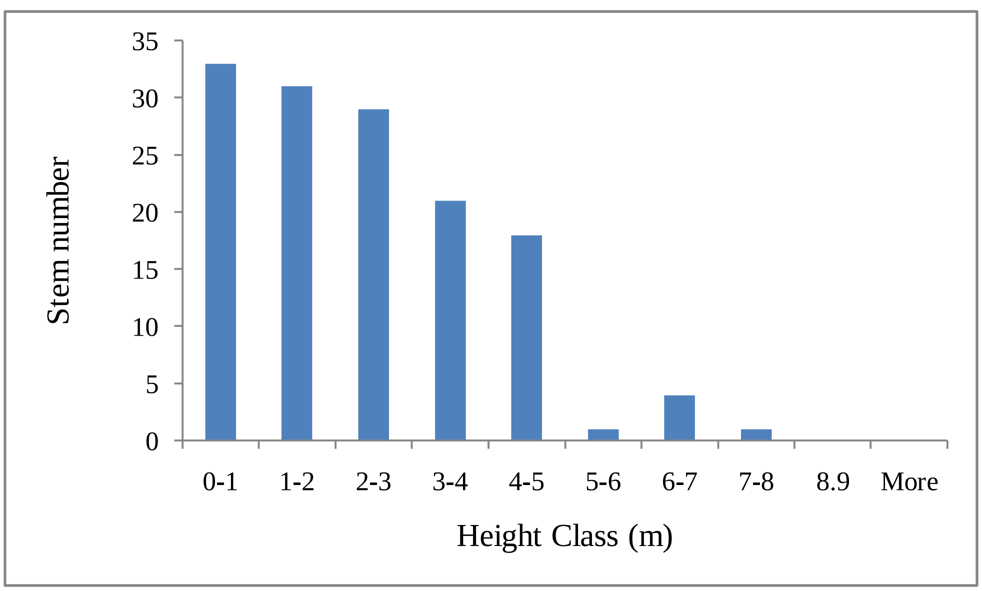

Figure 4. Height class distribution of *R. arboreum*

A regression analysis model between age and height of *R. arboreum* was established (Figure 5). The linear age-height equation was used to calculate the age of seedlings. *R. arboreum* takes about 26 years to reach the breast height i.e. 1.3m.

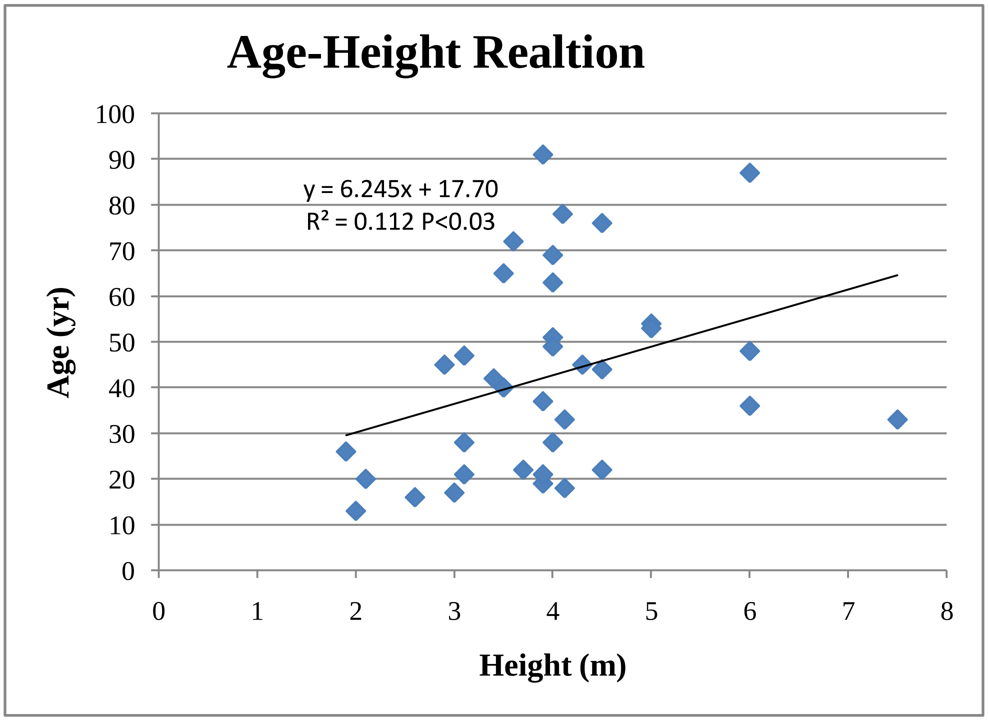

Figure 5. Age-Height relation of *R. arboreum*

4.5 Distribution of DBH

The DBH class was grouped in 5cm class interval. The class interval (5-10) of DBH distribution of *R. arboreum* accounted the highest distribution i.e. 28% and the class interval (35-40) and (40-45) lacks the distribution of that size. The largest DBH of *R. arboreum* was recorded at 2380m (47cm) followed by 2580m (23cm), 2180m (24cm), 2780m (18cm) and 3180m (17cm). The smallest DBH of *R. arboreum* was recorded at 2380m (3cm) followed by 2580m (5.2cm), 2780m (6cm), 2180m (11cm) and 3180m (17cm). A reverse J-shaped distribution was found in DBH class (Figure 6). This type of DBH distribution indicates the sustainable regeneration (Figure 6).

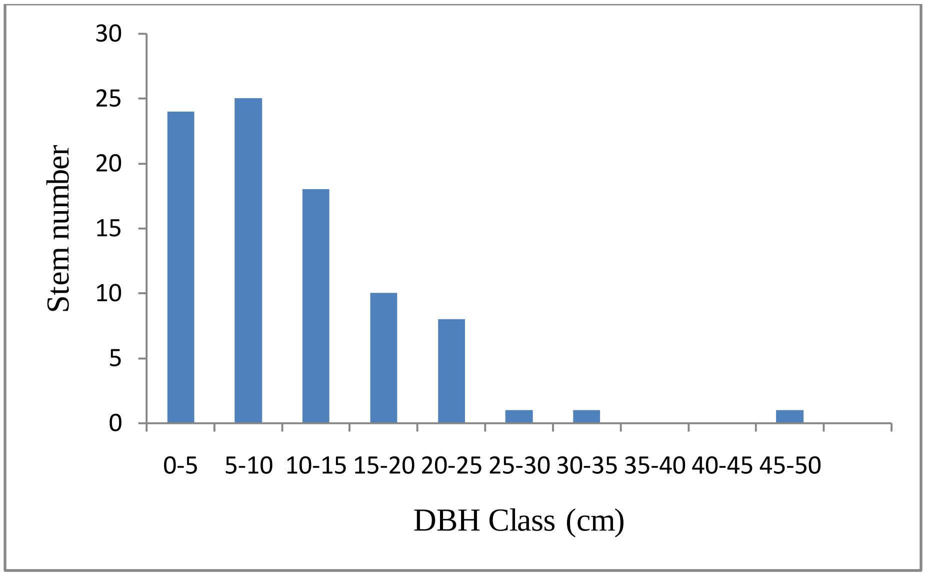

Figure 6. DBH Class distribution of *R. arboreum*

4.6 Age-DBH Relationship

A regression analysis model between age and DBH of *R. arboreum* was established (Figure 7). A linear age–diameter equation from the cored trees was calculated, which was then used as a predictive model to estimate the age of trees (which were not cored) from their diameters. The correlation between age and DBH of *R. arboreum* was statistically significant (r=0.7639). The oldest tree (127years) recorded accounts the highest DBH measured i.e. 47cm.

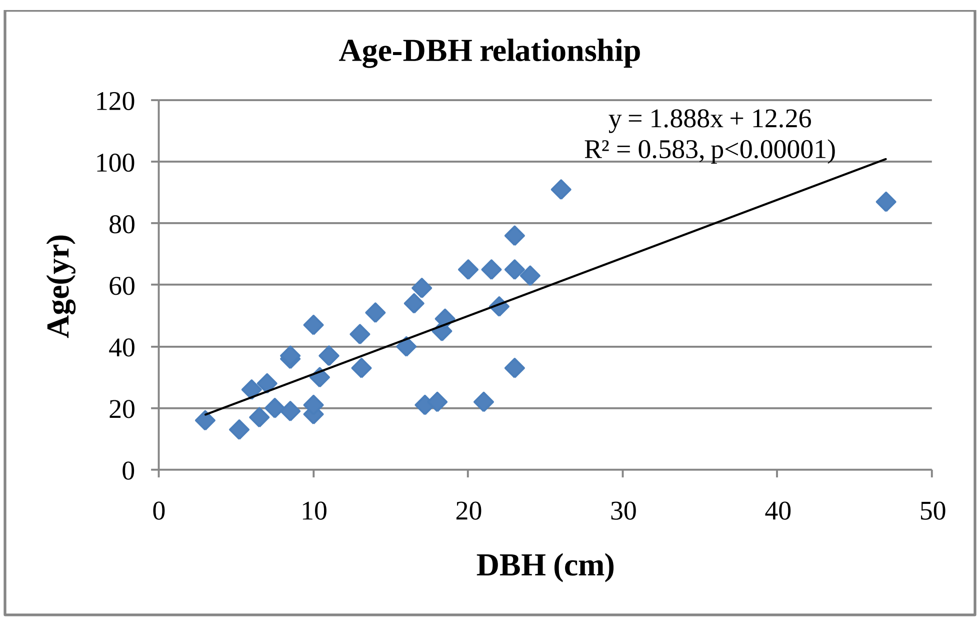

Figure 7. Age-DBH relationship of *R. arboreum*

4.7 Age Structure

Age-DBH and age-height relation was used to estimate the age of *R. arboreum*. Age of individual *R. arboreum* tree and sapling were estimated by adding the number of 26 rings to each cores, the estimated number of years for *R. arboreum* to reach coring height. The age class was grouped in 10 year class interval (Figure 8). The class interval (20-30) accounts the highest % i.e. 32.62% and there were no trees of that age in some class intervals. The oldest tree recorded was 127 years old.

Figure 8. Overall age class distribution of *R. arboreum*

Age class was also classified with reference to elevation. Since, single tree (59yr) was recorded in 3180m and 2980m lacks *R. arboreum* age histogram was not constructed for these elevations. The class interval (40-50) and (60-70) accounts the highest distribution at an elevation 2780m (Figure 9) whereas class interval (20-30) accounts the highest distribution in rest of the elevation. Age group (0-10) and (10-20) lacks the distribution in all elevations except at 2380m. The oldest tree recorded in 2780m, 2580m, 2380m, and 2180m were 73, 71, 127 and 98 years respectively.

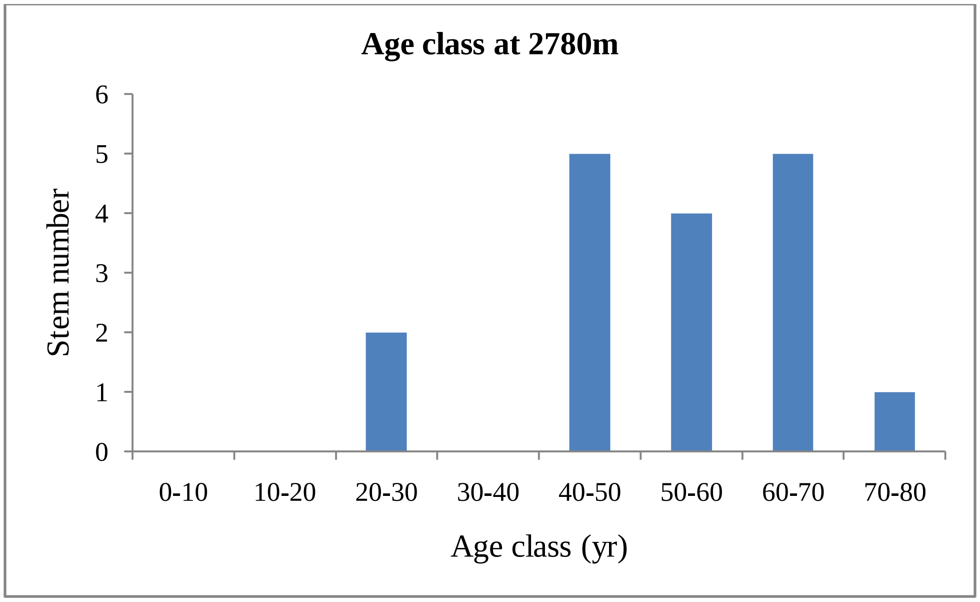

Figure 9. Age class distribution of *R. arboreum* at 2780m

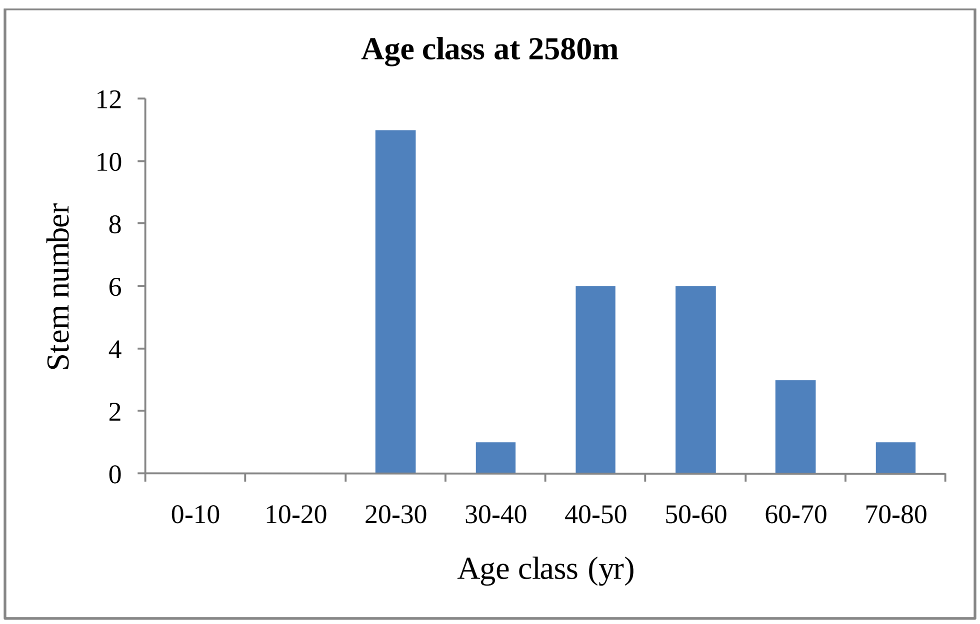

Figure 10. Age class distribution of *R. arboreum* at 2580m

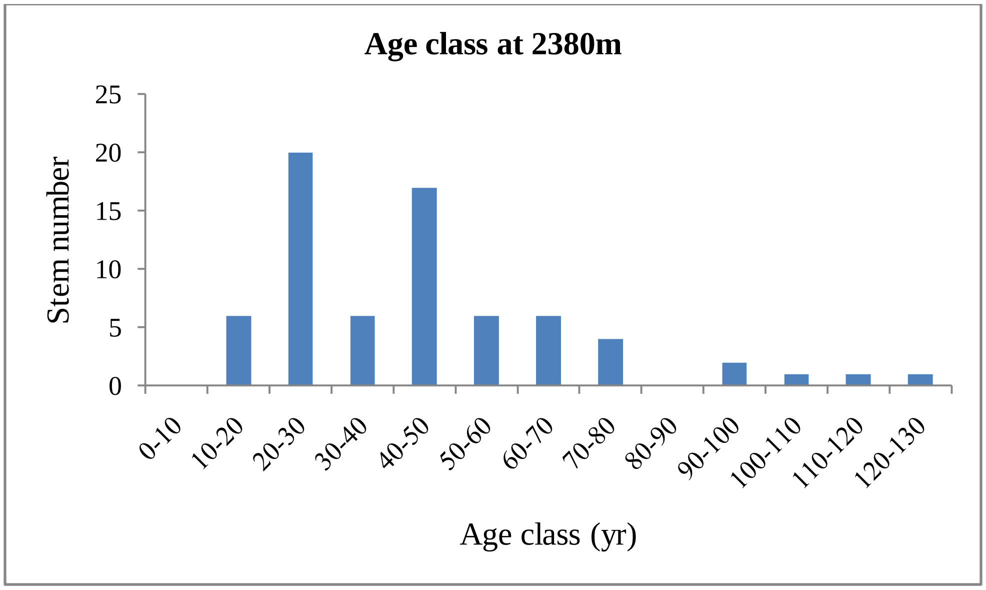

Figure 11. Age class distribution of *R. arboreum* at 2380m

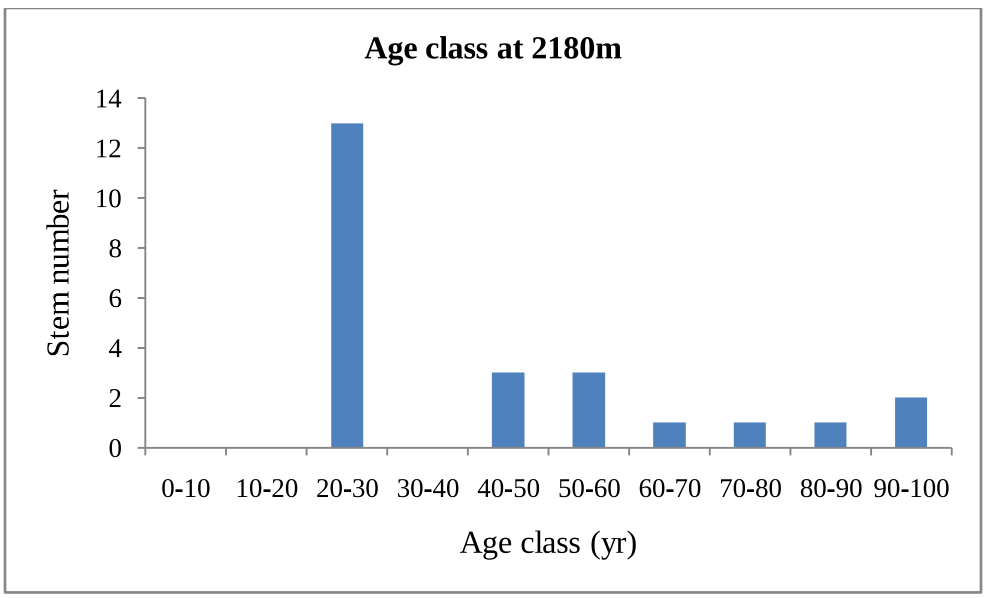

Figure 12. Age class distribution of *R. arboreum* at 2180m

The average age of *R. arboreum* was calculated with reference to elevation (Figure 13). The highest average age of the species calculated was 59 year at an elevation 3180m, followed by 2780m (52years), 2380m (44 years), 2180m (42years) and 2580 (42 years) .

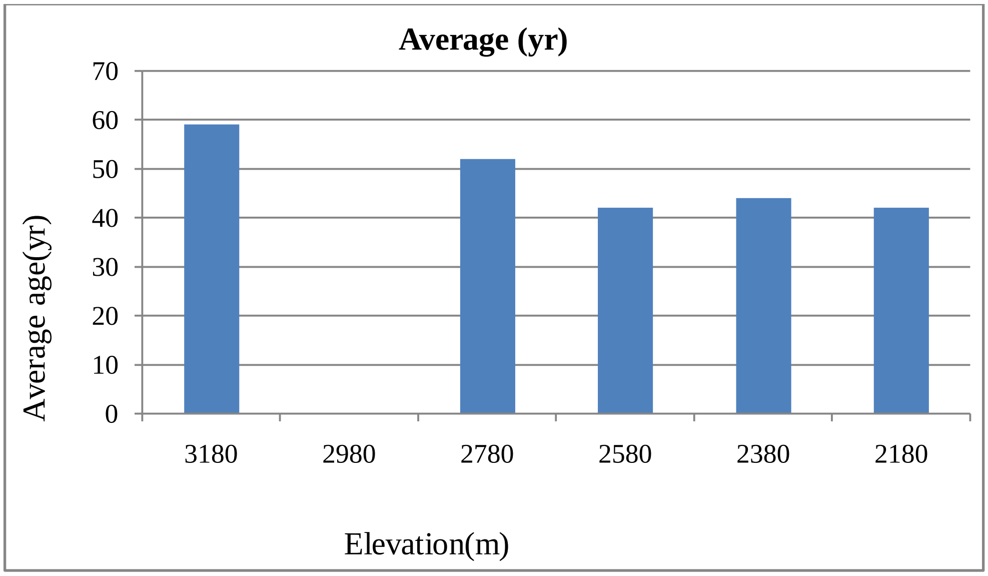

Figure 13. Average age of *R. arboreum* with reference to elevation

4.8 Growth Pattern

The radial growth pattern of *R. arboreum* along an altitudinal gradient is shown in Figure 14. It showed that the trend of annual radial growth of *R. arboreum* increased from the lower altitude (2180m) to middle altitude (2580m) and consecutively decreased upward to higher altitude (3180m). The maximum annual radial growth rate recorded is 3.98mm/yr at 2580m followed by 2380m (3.19mm/yr), 2780m (2.45mm/yr), 2180m (2.05mm/yr) and 3180m (1.56 mm/yr) the minimum growth recorded at 3180m, 2780m, 2580m, 2380m, and 2180m were 1.29mm/yr, 1.04mm/yr, 1.08mm/yr, 0.88 and 0.69 respectively. The annual radial growth (Figure 15) shows some common signal in cores of certain year.

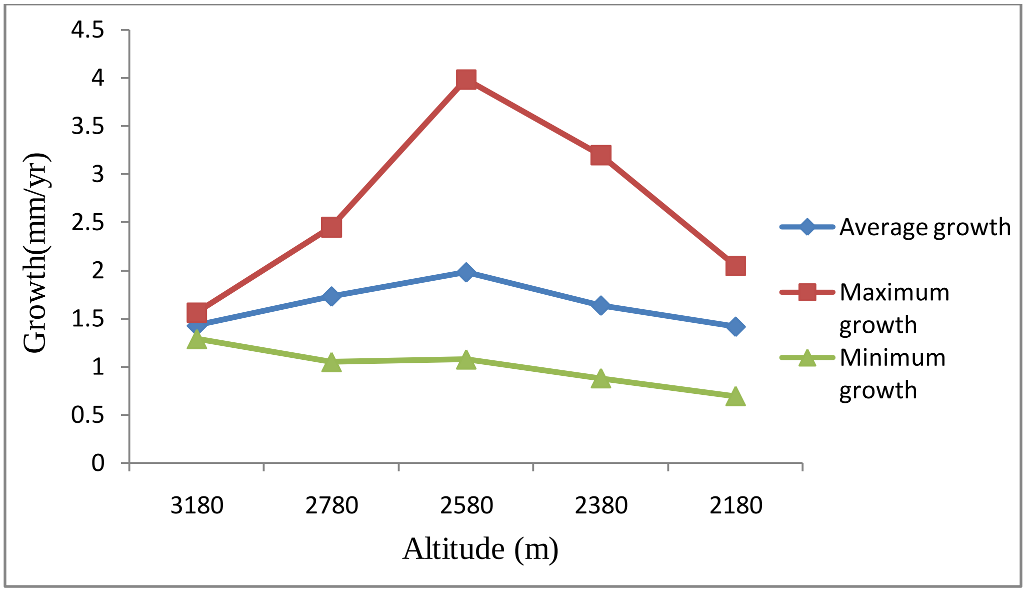

Figure 14. Radial growth pattern of *R. arboreum* with reference to elevation gradient

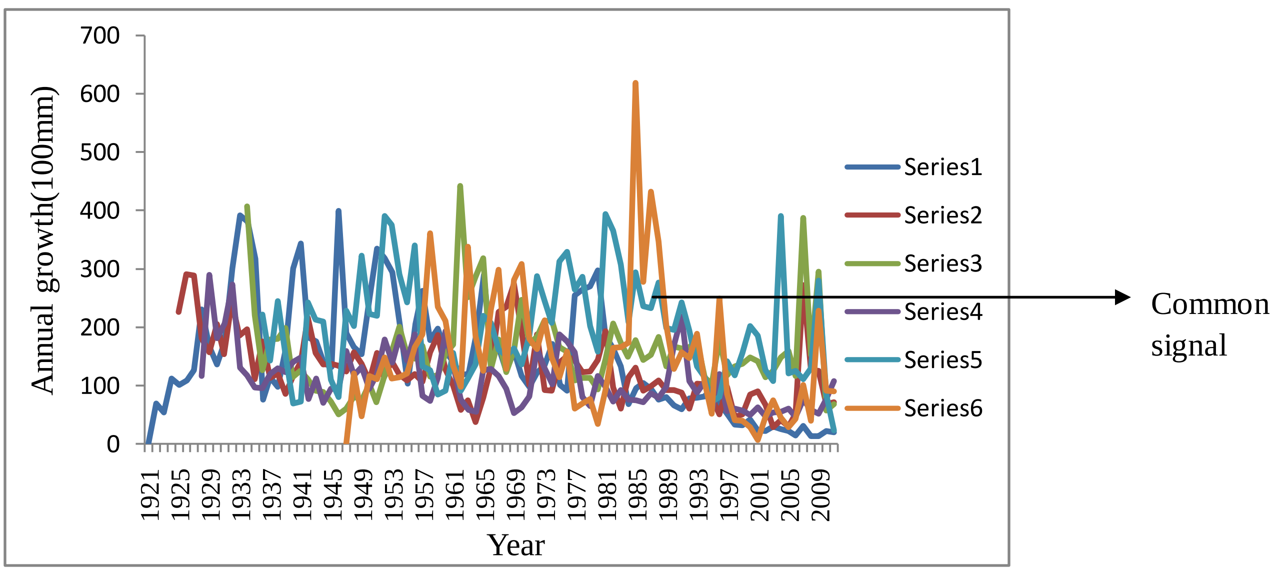

Figure 15. Annual radial growth of *R. arboreum* with reference to year

The mean annual radial growth rate of *R. arboreum* is 1.65mm. The descriptive statstics shows that the mean value deviates by 0.66 with maximum growth rate 3.982 mm/yr and minimum growth rate 0.693 mm/yr.

Chapter 5: Discussion

The study area was dominated by *R. arboreum* and *P. wallichiana*. Six tree species were recorded in the study area, *R. arboreum* having the highest density and *R. campanulatum* the lowest. This shows that the study area is less diverse in term of tree species. Highest canopy cover was observed at 2380m and lowest at 2980m. The study area at lower elevation was quite disturbed due to grazing and lopping of trees for fuel wood and timber. Signs of anthropogenic disturbances like stumps, woods and partially burnt trees of *R. arboreum* and *P. wallichiana* were present in the study area.

5.1 Height Class and Diameter at Breast Height Distribution

Height class of *R. arboreum* showed the reverse J-shaped structure. There was no significant difference in the average tree height between the elevations, where as the tallest and the shortest tree recorded in the study area were of 7m and 0.1m respectively. Bolli *et al*. (2007) also reported that they did not find a significant difference in average tree height between the strata.

The DBH class of *R. arboreum* showed the reverse J-shaped structure. Ghimire and Lekhak (2007) studied the regeneration of *Abies spectabilis* and found that the size class distribution of the species as reverse J-shaped curve. Similar observations were made for *A. spectabilis* of Langtang National Park studied by Gaire (2008). There was similarity between the shape of DBH distribution and age distribution. Similar observations were made for oak of Ozark Highlands of Missouri studied by Loewenstein *et al*. (2000). The study of *R. arboreum* at the interval of 5cm showed reverse J-shaped curve showing maximum number of trees in the group 0-5 cm. Qiaoying *et al*. (2008) also found similar results and reported that the diameter class structure of *Abies georgei* population showed a reverse J-shaped and 0-5 cm and 5-10 cm diameter classes accounted for 79% and 9.4% respectively.

The reverse J-shaped class distribution of trees in a community indicates the sustainable regeneration (Vetas 2000). The age DBH relationship is highly correlated with regression coefficient 0.583. Ross *et al*. (1982) reported that regression analysis of diameter and age for over story individuals yielded r^2 values 0.47-0.83 for *Quercus prinus* and 0.03-0.53 for *Quercus coccinea* in Appalachian oak forests in southwest Virginia. The age-DBH relationship used to estimate the age of non cored trees showed that the oldest *R. arboreum* is 127 years old and the youngest is 19 years old.

5.2 Age Structure

The age class of *R. arboreum* showed the reverse J-shaped structure. Duan *et al*. (2009) reported that *Larix chinensis* shows the reverse J-shaped age structure in the mid-altitude transect. Svensson and Jeglum (2001); Penuelas *et al.* (2007) reported that age structure and size distribution of long-lived tree populations growing under near optimum conditions often show a reverse-J-shape due to the initially high mortality of juvenile trees in the smallest size class. Age structure of *R. arboreum* in the study area was dominated by young trees. The data suggests that *R. arboreum* has been there over the past 127 years indicating that trees would be dated back to twentieth century. Gaire (2008) reported that the age structure of the *Abies spectabilis* forest growing at the tree line showed that trees could be dated back to the late 19th century. The age of *R. arboreum* ranged from 19-127 years, which seems to be successfully established between 1884 and 1992. The oldest tree recorded in 2780m, 2580m, 2380m, and 2180m were 73, 71, 127 and 98 years respectively. Elliot and Vose (2012) studied the age and distribution of *Rhododendron maximum* stems (ramets) and found the youngest specimen was 6 years and the oldest specimen was 120 years.

The age structure of *R. arboreum* at altitudes 2180m, 2380m and 2580m was characterized by the dominance of seedling and sapling, 2780m suggest the mixed proportion of the species whereas 2980m lacks the species and a single tree was spotted at 3180m. The age class histogram with reference to elevation shows that there may be favorable condition for *R. arboreum* (approximately 127 years ago in mid 1880s) at an elevation 2380m and then the species might have distributed to lower elevation (2180m) (approximately 98 years in early 1910s) back and then to higher elevation 2580m and 2780m (approximately 70 years ago in early 1940s) and 3180m (approximately 59 years ago in early 1950s). This indicates the past trend of distribution.

The average age of *R. arboreum* with reference to elevation doesn't follow any specific trend which may be due to single tree in 3180m and variation of stem number in other altitude (may affect the average age). The tree rings could not be cross dated well. It may be due to the unclear boundary and anthropogenic disturbances in the lower altitude. Bhattacharya *et al.* (1992) reported that dating of *P. wallichiana* and *Cupressus dumosa* was problematical the samples examined from this species did not crossdate well primarily due to strong serial persistence in the tree ring series. The similar observations have made for *P. wallichiana* and *P. roxburghii* of Kulekhani area in central Nepal studied by Regmi (1998). Some of the age class lacks the distribution of certain age group. Lopping of *R. arboreum* trees may have affected the age class distribution of *R. arboreum*,

5.3 Regeneration

Shankar (2001) reported the regeneration status of species based on population of adult (trees), seedlings and saplings. It was considered as good regeneration, if seedlings > saplings > adults; fair regeneration, if seedlings > or ≤ saplings ≤ adults; poor regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults). Since the population size of seedling is greater than sapling, sapling size greater then tree (seedling>sapling>tree), indicates that the overall regeneration status is good. The regeneration status of *R. arboreum* is good at 2380m, fair at 2180m, 2580m and 2780m and poor regeneration at upper limit i.e. 3180m. Bharali (2012) studied the selected *Rhododendron* species (viz., *R. kenderickii* and *R. grande*) and reported that they show fair regeneration in all the study stands having higher number of seedlings compared to saplings.

Although *R. arboreum* has the good number of seedling and sapling along the altitude (except upper limit), the highest concentration was observed at the middle altitude (2380m-2580m). Similar observations were made for *Quercus leucotrichophora* of Binsar Wildlife Sanctuary studied by Majila and Kala (2010). Such trend may indicate that the number of seedling and sapling also represent the dominant species along an each altitudinal range in the Himalaya. A single adult (absence of seedling and sapling) *R. arboreum* was reported in the upper limit. It may be due to the shift of the limiting factor. Generally, the density of seedling and sapling is found high in the area with high canopy gap. The present study also follows the general trend, density of seedling and sapling was found low in area with high canopy cover. Numbers of seedlings/saplings were comparatively low at higher elevation. The reason could be that the regeneration was much affected by harsh environmental condition of the high altitude such as low temperature and long gestation of snow coverage. Moreover, in the plots with low seedling, there was either heavy coverage of shrubby species or ground vegetation, which might have deterred the seedlings to grow.

5.4 Growth Pattern

The average annual radial growth pattern of *R. arboreum* seems consecutively increasing to certain level with reference to elevation from 2180m to 2580m and consecutively decreases with increase in elevation from 2580-3180m. This indicates that 2580m favors the growth of R. arboreum. 2580m has the highest annual growth rate where as 2180m has the lowest.

The average annual radial growth rate along an altitudinal gradient is 1.63mm where as mean annual growth rate is 1.654mm with standard deviation 0.66 and sample variance 0.43. The average radial growth of *A. spectabilis* was found to be 3.3mm per year Gaire (2008). Liang *et al*. (2009) reported that the mean annual growth rate of snowy *R. nivale* is 0.36mm. The common signal in certain years in many cores showed that it can be further used for dendroclimatic analysis. X-ray densitometry technique may give clear data on ring width and wood density Bhattacharya *et al.* (1992).

Chapter 6: Conclusion and Recommendations

6.1 Conclusion

This study showed that the study area, Thangin forest stand of Prok VDC, Manaslu Conservation area (Nepal) was less diverse in terms of trees as only six tree species were recorded. The study area was dominated by *R. arboreum* and *P. wallichiana*. The DBH class, age class and height class of *R. arboreum* shows the reverse J-shaped structure. The age DBH relationship is highly correlated with regression coefficient 0.583. The tree rings could not be cross dated well. The data showed that the *R. arboreum* would be dated back to late 19th century.

The regeneration status of *R. arboreum* is good at 2380m, fair at 2180m, 2580m and 2780m and poor regeneration at upper limit i.e. 3180m. The average annual radial growth pattern of *R. arboreum* seems consecutively increasing to certain level with reference to elevation from 2180m to 2580m and consecutively decreases with increase in elevation from 2580m-3180m. Reports suggest that *R. arboreum* is found even up to 3500m. The high steepness of the mountain and other environmental disturbance such as ground coverage might have deterred the advancement of the species in the present site. This needs further studies.

This study has attempted to answer the questions concerning *R. arboreum* study by using dendroecology. The data presented in this study would be base line data for future climate change study and will be helpful in future researches and monitoring. The study shows the past and present trend of distribution and age of *R. arboreum* which may give insight to the stakeholders in policy making.

6.2 Recommendations

- X-ray densitometry technique is recommended for the further cross dating of the *R. arboreum* samples.
- Manaslu Conservation Area Project should take effective steps to control the anthropogenic pressure in the lower elevation (2180m).

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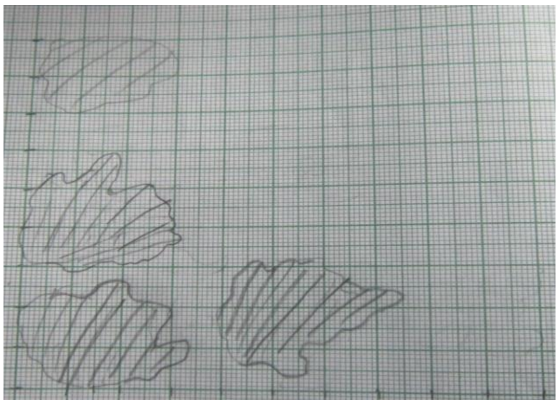
Annex I: GPS point and slope of study plots

S.N	Altitude (m)	Transect/Plot	Latitude N	Longitude E	Slope (^{o})
1	3180	T1P1	28.512265°	84.825882°	54
2		T1P2	28.512854°	84.825711°	52
3		T1P3	28.513391°	84.825572°	54
4		T1P4	28.513917°	84.825372°	55
5		T1P5	28.514524°	84.825213°	55
6	2980	T2P1	28.512434°	84.830459°	51
7		T2P2	28.512676°	84.829884°	49
8		T2P3	28.512983°	84.829195°	50
9		T2P4	28.513452°	84.828672°	47
10		T2P5	28.514052°	84.828337°	46
11	2780	T3P1	28.509284°	84.838855°	50
12		T3P2	28.509503°	84.838323°	47
13		T3P3	28.509704°	84.837829°	51
14		T3P4	28.510010°	84.837330°	50
15		T3P5	28.510301°	84.836845°	48
16	2580	T4P1	28.510976°	84.841409°	62
17		T4P2	28.511257°	84.840833°	56
18		T4P3	28.511689°	84.839933°	68
19		T4P4	28.512067°	84.839104°	60
20		T4P5	28.512402°	84.838424°	45
21	2380	T5P1	28.512716°	84.842986°	45
22		T5P2	28.513103°	84.842320°	55
23		T5P3	28.513336°	84.841555°	50
24		T5P4	28.513580°	84.840807°	46
25		T5P5	28.513825°	84.839790°	50
26	2180	T6P1	28.512999°	84.850048°	55
27		T6P2	28.513479°	84.849532°	55
28		T6P3	28.513763°	84.848749°	57
29		T6P4	28.514063°	84.847635°	56
30		T6P5	28.514321°	84.846696°	54

Annex II: Canopy cover

Plots at 2180m

1.



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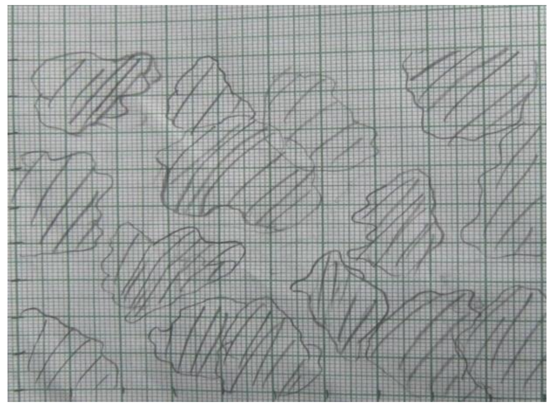

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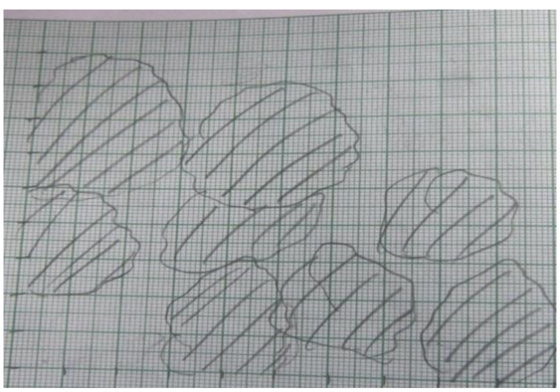

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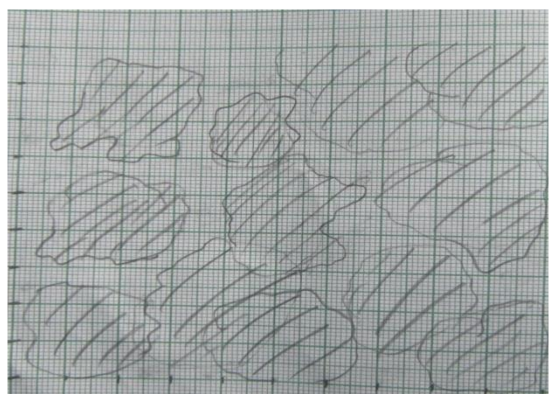

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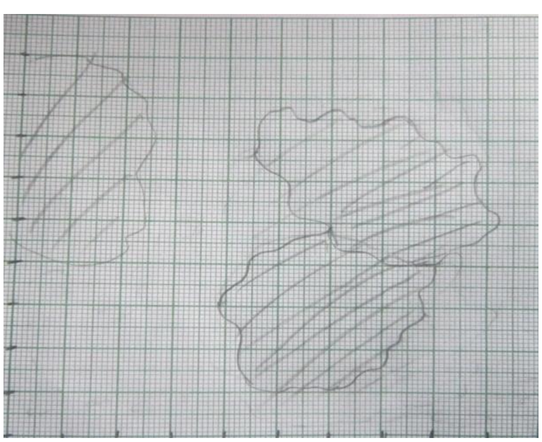
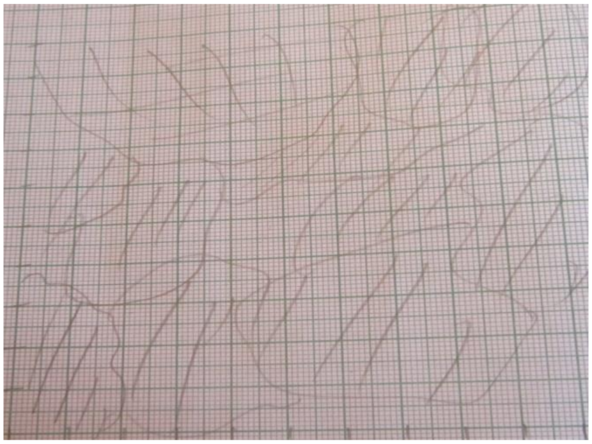


Canopy cover plots at 2380m

1.



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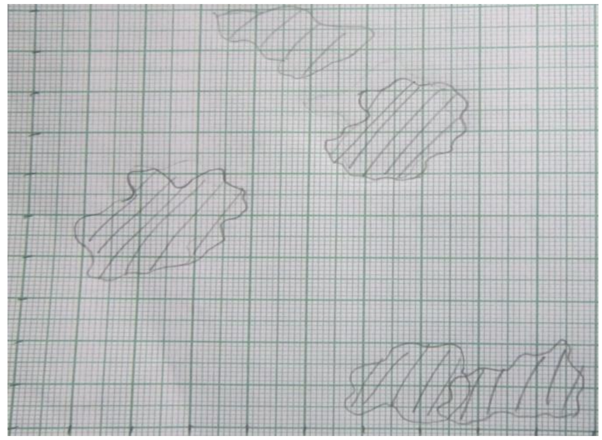

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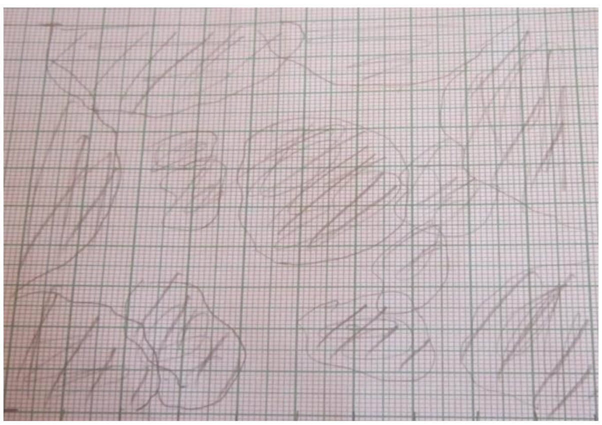

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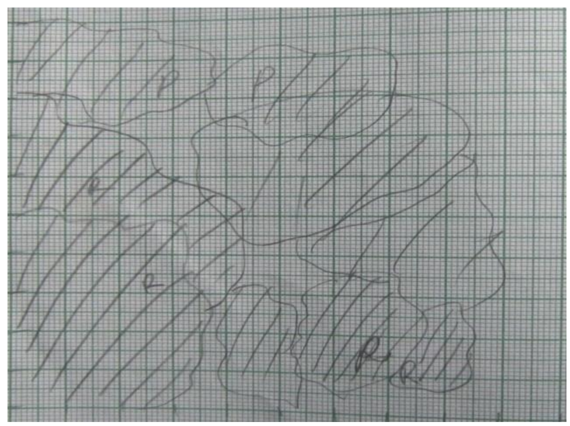

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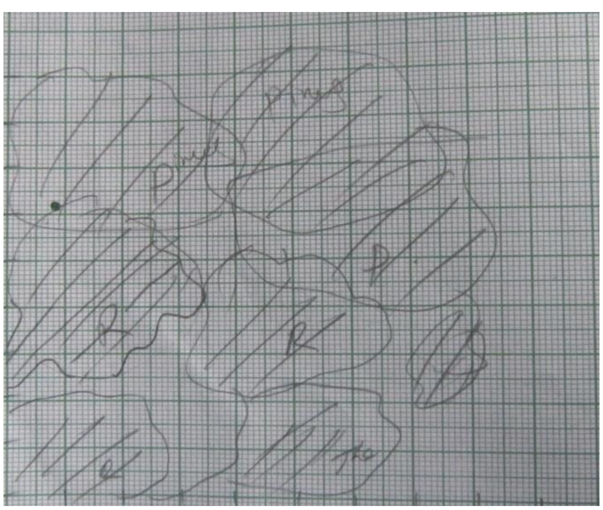
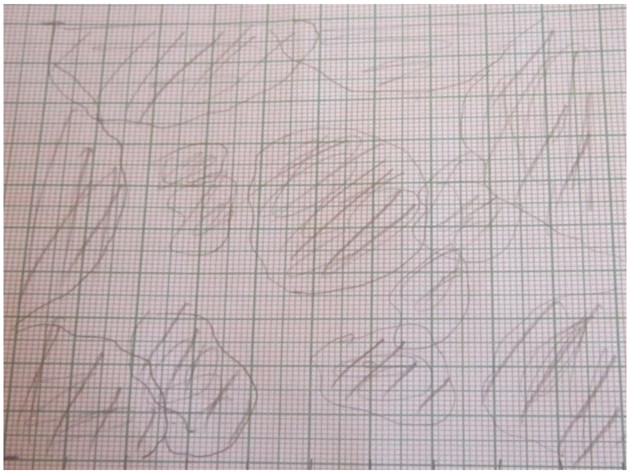


Canopy cover plots at 2580m

1.



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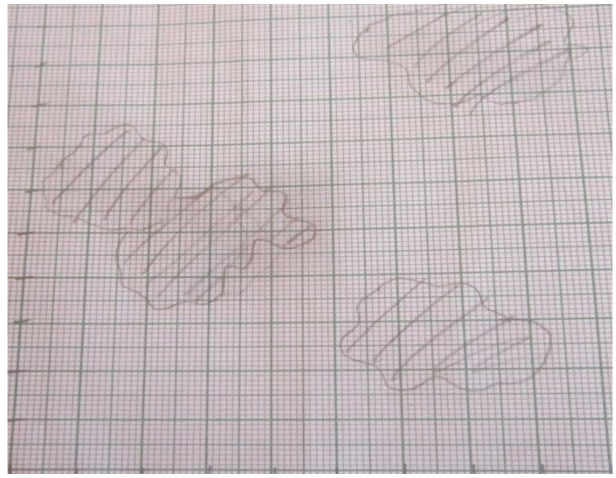

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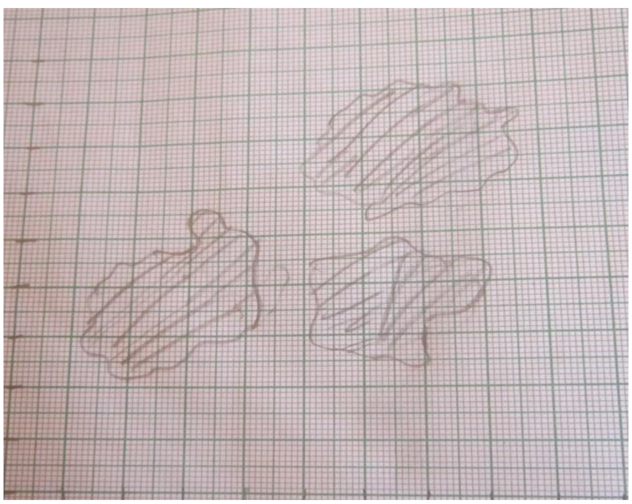

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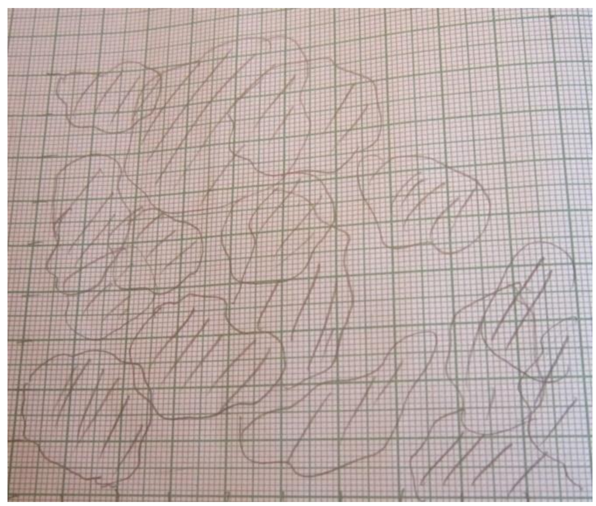

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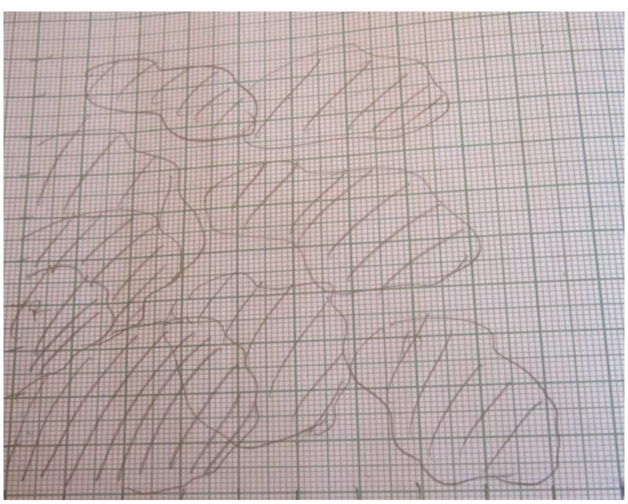
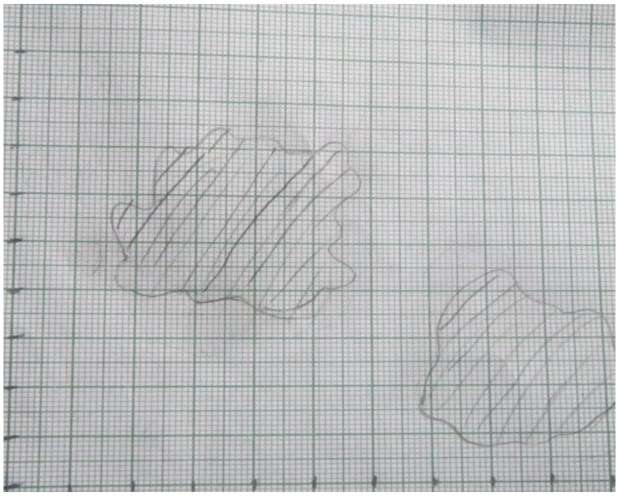


Canopy cover at 2780m

1.



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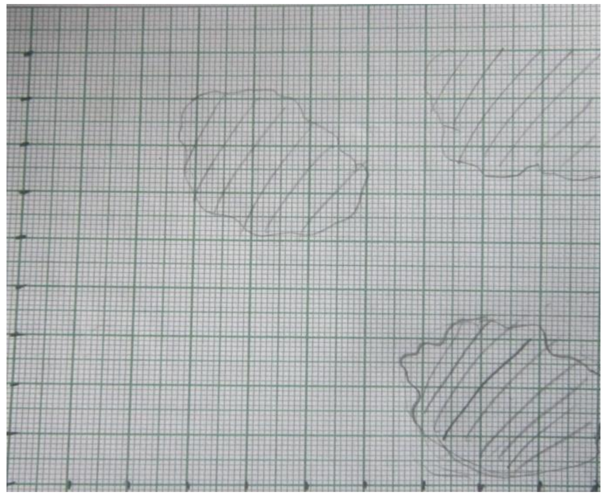

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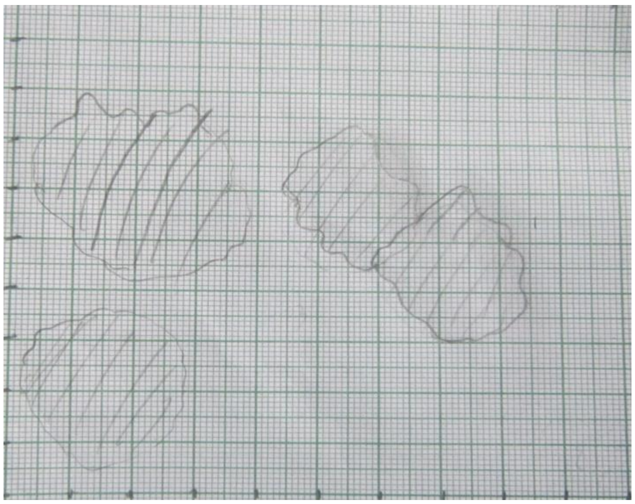

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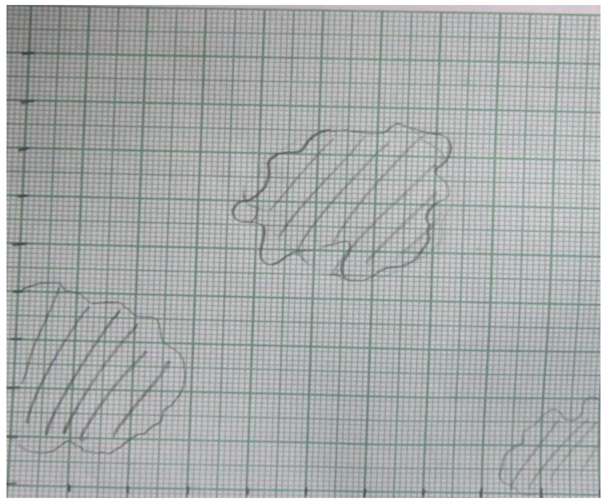

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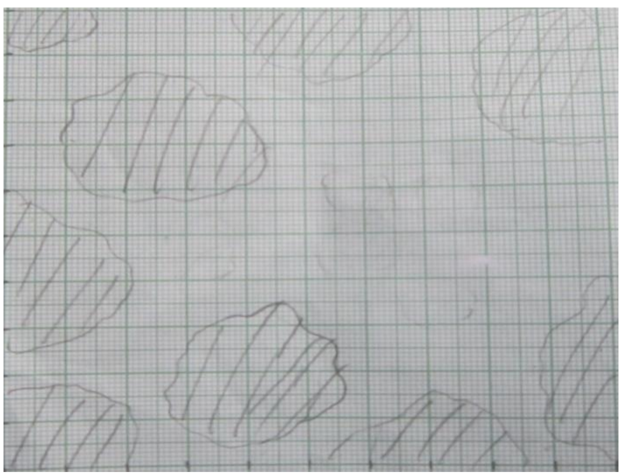
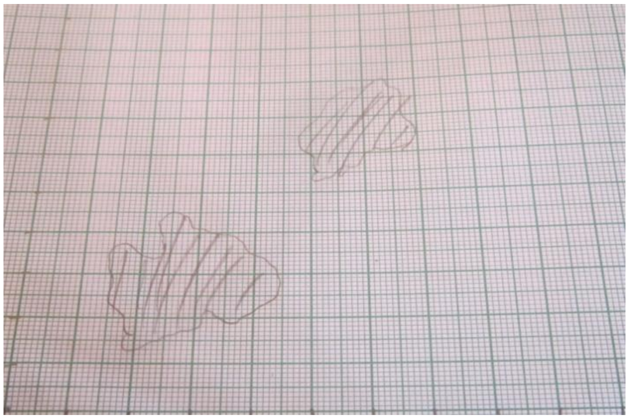


Canopy cover plots at 2980m

1.



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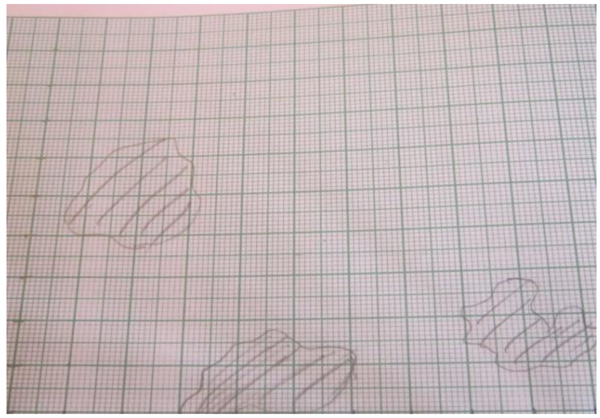

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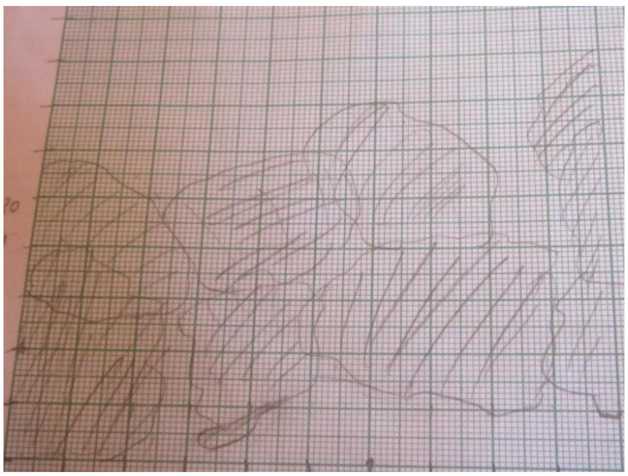

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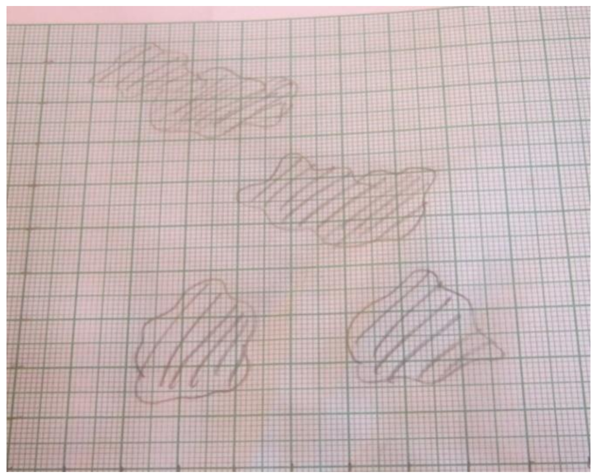

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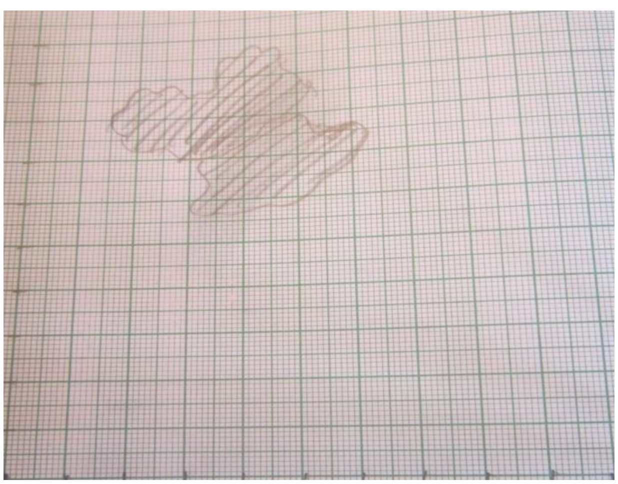
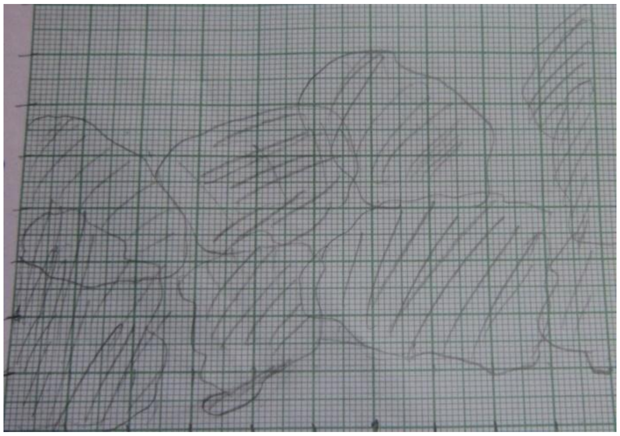


Canopy cover plots at 3180m

1.



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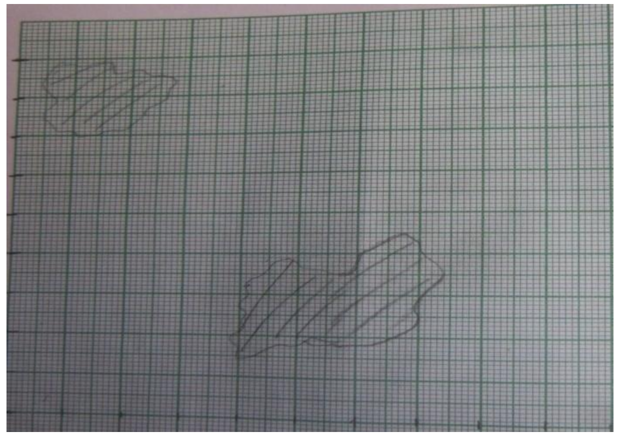

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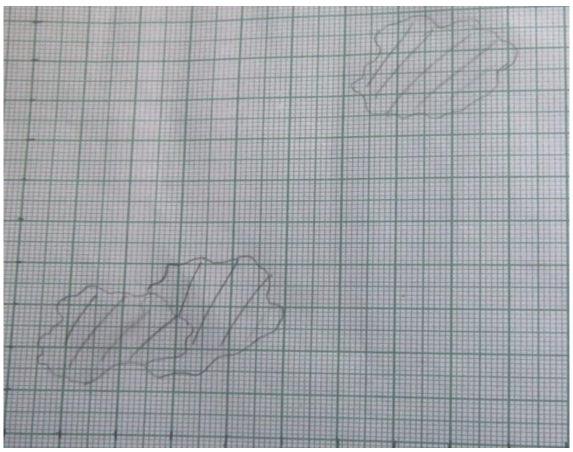

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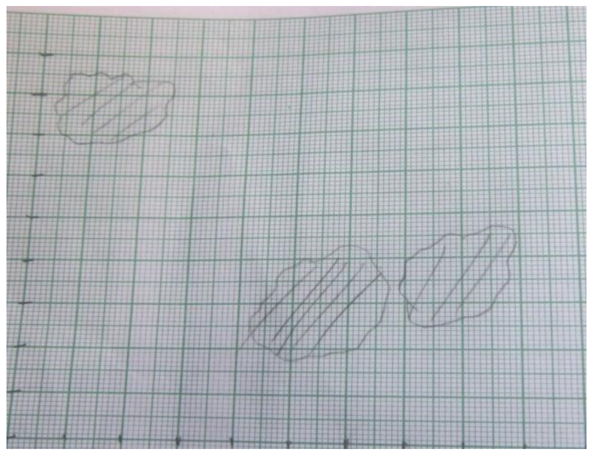

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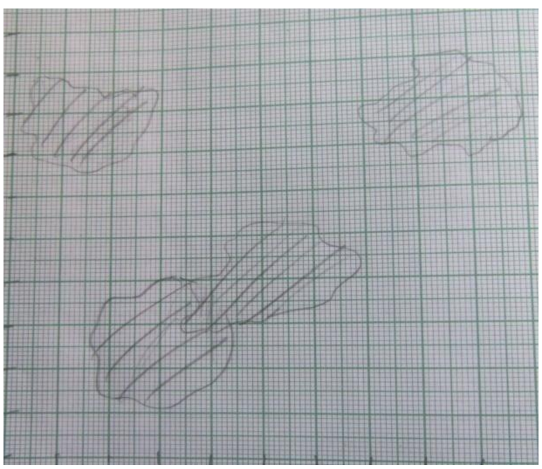
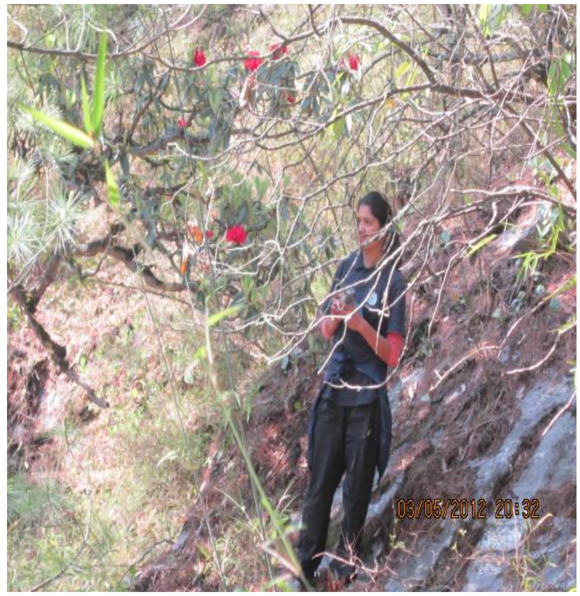


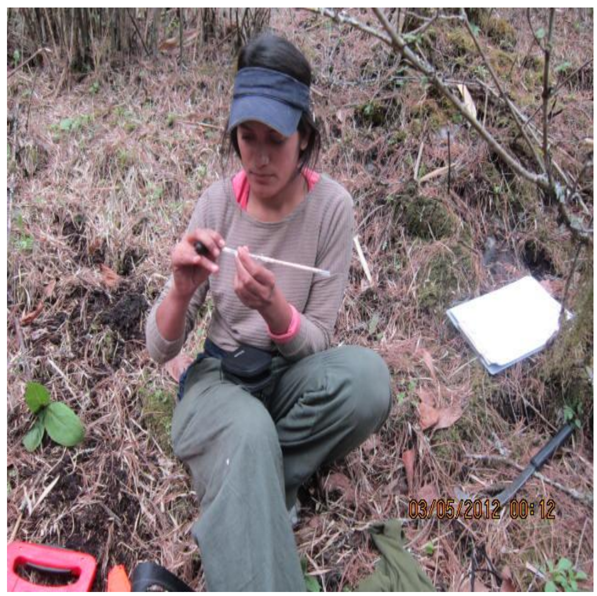
Annex III: Photo plates

(a) Measuring the DBH of *Rhododendron arboreum*



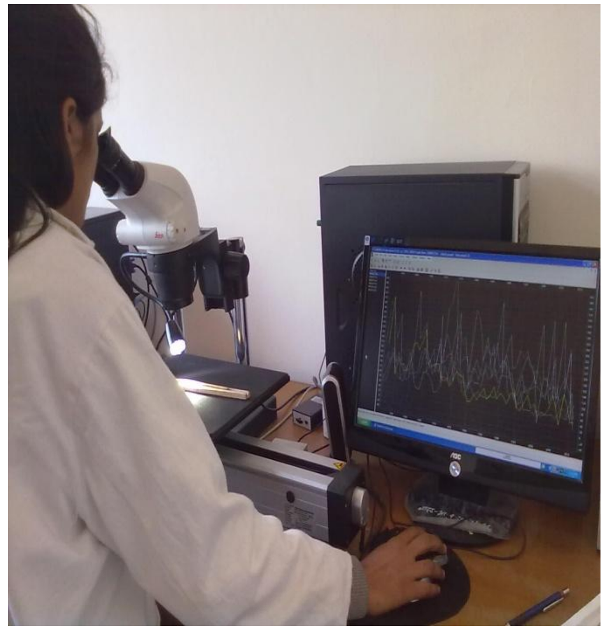
(b) Trying to measure tree height with clinometer

(c) Extracting a tree core



(d) Inserting the tree core in a plastic straw

(e) Counting the ring in a Lin-tab microscope.



(f) Measuring the radial growth in a Lin-tab microscope attached to a computer

(g) Tree cores after sanding

(h) Tree stump after sanding