POPULATION STRUCTURE OF *RHODODENDRON ARBOREUM* SMITH, AND ASSOCIATED TREE SPECIES ALONG THE ALTITUDINAL GRADIENT IN A MIXED FOREST OF RAINASKOT, LAMJUNG, NEPAL

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MARCH, 2022

DECLARATION

I, *"Prerana Khadka"*, hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement, and has not been published or submitted elsewhere, in whole or in part, for the requirement for any other degree or professional qualification. Any literature, data or works done by others and cited within this thesis has been given due acknowledgement and listed in the reference section.

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RECOMMENDATION

This is to recommend that the master's thesis entitled "**Population Structure of *Rhododendron arboreum* Smith and Associated Tree Species along the Altitudinal Gradient in a Mixed Forest of Rainaskot, Lamjung, Nepal"** is carried out by "Prerana Khadka" under my **supervision**. The entire work is based on original scientific investigations and has not been submitted for any other degree in any institutions. We, therefore, recommend this thesis work to be accepted for the partial fulfilment of M.Sc. Degree in Botany from Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

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APPROVAL

The thesis work submitted by "*Prerana Khadka*" entitled "**Population Structure of *Rhododendron arboreum* Smith and Associated Tree Species along the Altitudinal Gradient in a Mixed Forest of Rainaskot, Lamjung, Nepal"** submitted to Department of Botany, Amrit Campus, Tribhuvan University by *"Prerana Khadka"*, "5-2-37-824-2013*"* has been accepted for the partial fulfilment of the requirement for master's degree in Botany from Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

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ACRONYMS AND ABBREVIATIONS

DHM	Department of Hydrology and Meteorology
Masl	Meter above sea level
ANOVA	Analysis of variance
^{o}C	Degree Celsius
DBH	Diameter at breast height
E, W, N, S	East, west, north, south
GPS	Global positioning system
m	Meter
cm	Centimetre
ha	Hectare
SPSS	Statistical Package on Social Science
sq. km	Kilometer square
%	Percentage
<	Less than
>	Greater than
spp	Species
IP	Important value index percent
IVI	Important value index
RF	Relative Frequency
RD	Relative Density
BA	Basal Area
SD	Standard Deviation
pH	Potential of hydrogen

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ABSTRACT

Population structure is the number of individuals present in each of the definite girth classes of tree species. The main objectives of this study was to determine the population structure and regeneration of *Rhododendron arboreum* and its associated tree species along the three altitudinal range in a mixed forest of Rainaskot Lamjung. The study area was divided into three altitudinal range: lower (1200-1400masl), middle (1400-1600masl) and upper (1600 -1653masl). Altogether 75 circular quadrants, 25 from each altitudinal range were laid by using random systematic sampling method. Circular plot of 10m radius were laid for the study. Height and Diameter at breast height of the trees (>10cm dbh), associated trees (>10cm dbh), were recorded within main plot. Number of saplings and seedlings were recorded within main plot. Finally five soil samples were prepared from 25 soil samples collected from the center of the main plot within each altitudinal range. Total fifteen soil samples were taken for analysis such as Soil pH, organic matter, soil texture and 3 macro nutrients (NPK). A total of 13 tree species belonging to 11 different families were reported. The species richness in the forest increases with increasing altitude. The most frequent and dense tree species in the forest was *R. arboreum* with IVI value 77.7 and was present in 93.33% of the total sampling plots. The density of *R arboreum* was 257.52 individualha^{-1} with basal area 16.40 m^{2}ha^{-1}. In altitude wise comparison of density of *R. arboreum* with total tree density, upper altitudinal range had (393.28 individualha^{-1}), middle altitudinal range (248.19 individualha^{-1}), and the lower altitudinal range had (127.28 individualha^{-1}). IVI of *R. arboreum* was quite lower (68.19%) in the lower altitudinal range with compared to middle (70.02%) and upper altitudinal range (105.52%). The *R. arboreum* shows reverse J-shaped population structure and fair regeneration status in overall forest having higher number of seedlings compared to saplings. However, the numbers of saplings were less than the adults except in lower altitudinal range. The height class distribution of *R. arboreum* shows a reverse J-shaped distribution with little deviation in the upper altitudinal range. The soil pH of forest was found to be acidic. The seedlings, saplings and adults density were positively correlated with the nutrients such as nitrogen, phosphorus and organic matter except pH, potassium, canopy cover and litter depth. The anthropogenic disturbance, ecological diversity, and soil characteristics are responsible for the variation in population and regeneration attribute of the forest.

Keywords: Species diversity, Regeneration, Canopy, Soil parameters

CHAPTER 1

1. INTRODUCTION

1.1 Background

The Population structure (age or size) of tree species provides valuable information on population dynamics (Dang *et al.*, 2010). Information about population structure is important to understand the mechanism of species coexistence and long-term ecological processes of natural forest (Miura *et al.*, 2001). Population structures declare the dominance status of species and development within the community (Gairola *et al*., 2014). Although the population structure of plants is described either by age, size or by their life stage (Rabotnov, 1969), the population structure of woody perennial species is often estimated by size class distribution (Saxena and Singh, 1984; Venter and Witkowski, 2010). The population structure and recruitment patterns of forest are influenced by many factors like disturbance, competitive interactions between trees (North *et al*., 2004).

The study of population structure along the altitude could be instrumental in giving insight about the influence of environmental factors on the regeneration of natural forest (Wang *et al*., 2004). There are many environmental factors such as temperature, precipitation, atmospheric pressure, solar radiation, and wind velocity which changes systematically with altitude (Sharma *et al*., 2018). With the change in altitude, geographical and climatic conditions also change sharply (Bandopadhyay, 2016). To compare the differences in population performance between the adult trees and regenerating individuals along altitudinal gradients could be helpful to predict whether distribution range of a specific species is declining, stable, or expanding (Urbieta *et al*., 2011; Bell *et al*., 2014).

Natural regeneration is an important process for the existence of species in a community under variable environmental conditions (Khumbongmayum *et al*., 2005), it helps to predict the future health of the forest ecosystem (Good and Good, 1972; Saxena and Singh, 1984; Shankar, 2001; Pala *et al*., 2012). However, the natural regeneration of a tree species is manly depending on seed production and germination, establishment of seedlings and saplings (Rao, 1988). The presence of a sufficient number of seedlings, saplings, and trees in a forest indicates successful regeneration (Khan *et al.*, 1987; Dutta and Devi, 2013). The successful regeneration may depend on various factors like soil characteristics, slope, exposure, elevation, climatic conditions, disease, and population density of herbivorous animals (Malik and Bhat, 2016). The regeneration potential of plant species is higher in disturbed forest due to the open canopy (Koirala, 2004). The stability of forest ecosystem in long run can be indicated by the estimation of regeneration potential of tree species (Connell, 1978).

The genus *Rhododendron* belongs to family Ericaceae was first described by Carl Linnaeus in 1737 in *Genera plantarum* (Singh *et al.*, 2009). The word *Rhododendron* was derived from two Greek words Rhodon (rose) and Dendron (tree) which referred to rose tree (Sekar and Srivastava, 2010). It is an evergreen shrub or small tree with magnificent display of bright red flowers and considered to be one of the most impressive species of the genus with highly variable stature, hardiness, flower color and leaf (Udai and Sonam, 1990). *Rhododendron* is a very widely distributed genus, occurring throughout most of the Northern Hemisphere and extending to areas in southeastern Asia and northern Australasia (Shrestha *et al*., 2017). It does not occur naturally in South America or Africa. However, the highest species diversity is found in the Himalaya (Scott, 2010). The plant is initially present in mountainous areas characterized by acidic well-drained soils, regular rainfall, and cool summer temperatures (Horn, 2005). *Rhododendron* consists of more than 1000 species worldwide, among them 70% are classified to be vulnerable, threatened, endangered or critically endangered (Gibbs *et al*., 2011).

In Nepal, 32 species of *Rhododendron* are reported, among them most famous is *Rhododendron arboreum*, known as Laligurans in Nepali (Scott, 2010). It is evergreen much branched tree up to 25 m in height (Ranjitkar *et al*., 2014) distributed along subtropical and temperate region from 1200-3300 m (Shrestha and Budhathoki, 2012). The government of Nepal has declared *R. arboreum* as a national flower in 1992 (Shrestha and Budhathoki, 2012). *R. arboreum* is a multipurpose tree that provides wood for fuel, its flowers are used to make juice, squash, pickles and bark and the flowers are used for medicinal purpose (Mamgain*et al*., 2017). Looking at the benefits dispensed by *R. arboreum* to the environment and to the local communities, it can be regarded as an ecological keystone species (Paine, 1969) as well as a cultural keystone species (Cristancho and Vining, 2004; Garibaldi and Turner, 2004). The wood of *R. arboreum* is used as fuelwood for domestic cooking purposes (Bhatt and Sachan, 2004; Kumar and Sharma, 2009; Singh *et al*., 2010). As the altitude increases the fuel wood and fodder consumption values of the areas also increase (Mamgain, 2017). There is rapid deforestation going on and together with climate change it will become a serious problem in future (Singh *et al*., 2010; Dhanai *et al*., 2014).

Rhododendron arboreum generally grow on slope areas. The population status of *R. arboreum* found to be different according to different altitude, lower altitude might have poor population and the upper altitude have excellent population. However, some discrepancies were also found because other factors, such as area topography, soil erosion, human settlements and agriculture etc. played a profound role in affecting the population (Mamgain *et al*., 2017). The major associates of *Rhododendron arboreum* was broad-leaved character of *Quercus leucotrichophora*, *Lyonia ovalifolia*, *Myrica esculenta* and *Pyrus pashia* (Singh, 2015). However, *R. arboreum* also found in association with *Schima wallichi*, *Castanopsis indica*, *Alnus nepalensis*, *Castanopsis tribuloides* (Chaulagain and Shrestha, 2018; Pandey *et al.*, 2014).

Soil properties determine the composition of plant community structure and regeneration of plants (Sigdel *et al*., 2015). Soil properties depend on different environmental factors such as slope, aspect, climate, landscape, microclimate, topography, and vegetation (Tsui, 2004). *R. arboreum* prefers light (sandy) to medium (loamy) soil and requires fairly moist and acidic soil (Srivastava, 2012), the acidic environment is created by the degradation of acidic litter of *R. arboreum* (Maithani *et al*., 1998). Slightly acidic forest soil (pH range from 5.5 to 7.2) has excellent ability to provide balanced nutrients (Gairola *et al*., 2012).

1.2 Rationale

The genus *Rhododendron* has many superior characteristics for its wide acceptance as fuel, timber, fodder, and flower for preparation of pleasant drink (highly medicinal) juice and squash throughout the Himalaya (Chauhan *et al*., 2017). The major threats to *Rhododendrons* are large-scale deforestation of their suitable habitats and unsustainable extraction for firewood by local people (Paul *et al*., 2005). The existence of plant community largely depends on its regeneration potential under varied environmental conditions like climate, soil characteristics and disturbance regimes (Sharma *et al*., 2018). 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 (Bharali *et al*., 2012). Understanding the factors affecting on regeneration patterns of forest forming species is very important to ecologist and forest manager (Slik *et al*., 2003). It helps them to undertake proper forest management planning, which in turn helps to utilize a forest ecosystem wisely and sustainably.

Rainaskot is located at historically important area of Lamjung district. *R. arboreum* is an important tree species providing wood for fuel, Flowers are used in making of juice, squash, pickles and bark and flowers are used for medicinal purpose. In addition, many lichens, moss, pteridophyte, and orchid plants inhabit, providing shelter for birds and animals that make up the micro-ecosystem. *R. arboreum can* be considered as an ecological keystone species given the benefits it brings to the environment and to the community (Paine, 1969).

Rhododendron arboreum is one of the most exploited species as area under *R. arboreum* forest is surrounded by local inhabitants of hilly areas in Rainaskot Lamjung. Moreover, till date no detailed studied have been carried out on population structure and regeneration of *R. arboreum* with reference to altitude particularly in Rainaskot Lamjung. Keeping this in view, an attempt had been made to assess the impact of altitude on population structure and regeneration status of *R. arboreum* as well as its associated species in Lamjung district of Rainaskot.

1.3 Research Question

The major research questions are as follows:

- How does the population structure of *R. arboreum* and associated tree species change along the altitudinal gradient in the forest?
- What is the regeneration pattern of *R. arboreum* along the altitudinal gradient?
- How do soil properties affect the regeneration of *R. arboreum* in three different altitudes of forest?
- How do litter depth and the litter weight varies in three different altitudinal ranges?

1.4 Objectives

The general objective of this research is to determine the population structure and regeneration pattern of *Rhododendron arboreum* and associated tree species along altitudinal gradient in Rainaskot, Lamjung. Following are specific objectives:

- To analyze the Important value index (IVI) and species diversity along the three different altitudinal range.
- To determine the regeneration pattern of *R. arboreum* along the altitudinal range.
- To analyze the effect of soil properties in the regeneration of *R. arboreum* in different altitudinal range.
- To analyze the litter depth and litter weight in three different altitudinal ranges.

1.5 Limitation of the Study

This research has many significances in the present context of ecological and biodiversity study in Nepal. This research helps in the ecological planning, forest management, eco-tourism promotion within the Rainaskot area. However, this research has following limitations:

- This research is primarily focused on dominance and regeneration of *R. arboreum* and associated tree species of the forest only.
- Shrubs and Herbs have not included.
- Sampling was not performed on very steep slopes.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Population Structures

Population structure has a direct impact on the community structure as population is a basic component of a community, which in turn demonstrates the developmental trend of the community (Xia *et al*., 2004). Zhang *et al*. (2007) studied on community structure of forest in Beijing and reported that the population structure is the combined exhibition of the status, function, development process and trends of tree species. Da *et al*. (2004) studied on population structure of dominant species in an evergreen broadleaved forest of eastern China and concluded that the population structure of a tree species shows its biological and ecological characteristics. Plant populations can be described in terms of age, size and shape of its individuals and genetic structure (Harper and White, 1974).

There are various factors such as age, genetic variability, resources heterogeneity, competition, effect of herbivore, parasites or pathogens and disturbance cases differences in size of plant population (Weiner and Solbrig, 1984; Coomes *et al*., 2003; Muller-Landau *et al*., 2006). Franklin (2003) studied on rain forest in Tonga and Poorter *et al*. (2006) studied on 54 moist forests, they reported that light quantity and quality are strong factors determining plant growth and population structure in plant communities. The most commonly used size variable for the analysis of population structure is diameter/girth at breast height (DBH/GBH) (Breckle, 1997). However, Teketay (1997) studied on seedling populations of woody species in forests of Ethiopia, the height class distribution for seedlings and saplings have also been used for the study of population structure of tree species.

Population structure studies along 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). As change in altitude, geographical and climatic condition also change sharply (Bandopadhyay, 2016). This creates diverse vegetation structure and high species diversity. (Chawla *et al*., 2008; Sharma *et al*., 2009; Majila and Kala, 2010) have reported that vegetation types differ with change in altitude. Therefore, altitudinal gradient was powerful natural attributes for testing ecological and evolutionary changes (Cui *et al*., 2005; Korner, 2007).

Various studies have been done on population structure of *Rhododendron arboreum*, Paul *et al*. (2019) studied on Population structure and regeneration status of *Rhododendrons* in temperate mixed broad-leaved forests of western Arunachal Pradesh, India and reported that the selected *Rhododendron* species including *R. arboreum* showed reverse J-shaped distribution with the density of tree species found to be higher in lower girth class and decreased with the increasing of girth classes.

Chauhan *et al*. (2017) studied on composition, population structure and regeneration of *Rhododendron arboreum* in Garhwal Himalaya, Uttarakhand, India. This study reported that in all-natural forest stands the associated species can also have played important role for the establishment and sustainability of particular species. The broad-leaved character of *Quercus leucotrichophora* major associates *R. arboreum* have been reported to capable conserve the water moisture at large amount in hill area and also beneficial in erosion control.

Bharali *et al*. (2012) studied on population structure and regeneration status of *Rhododendron* species in temperate broad-leaved forest of India and reported that the selected *Rhododendron* species shows reverse J-shaped population structure and fair regeneration status in all study stands having higher number of seedlings compared to saplings.

Tesfaye *et al*. (2002) studied on regeneration of tree species in Harenna forest of southeastern Ethiopia and reported that the reverse “J” distribution is considered as an indication of stable population structure with fairly good regeneration status.

Rao *et al*. (1990) studied on population structure of tree in subtropical broad-leaved forest along a disturbance gradient. They reported that *R. arboreum* showed a reverse J-shaped curve in the undisturbed and highly disturbed stands and a bimodal mound shaped curve in the mildly disturbed stand. Similar distribution curve was observed by Giri and Katzensteiner (2013) in mixed broadleaved forest of Himalayan region Nepal.

2.2 Regeneration

Tree regeneration can be predicted by their population structures (Khan *et al*., 1987). It helps to determine the serial stage of the community and predict the potential climax vegetation of a particular area (Gairola *et al*., 2014). The pattern of population dynamics of seedlings, saplings and adults of a plant’s species can reveal the regeneration profile, which is used to determine their regeneration status (Bekele, 1994). Good and Good (1972) considered three major components for successful regeneration of a species which are: i) ability to germinate the seeds, ii) ability of seedlings recruitment and saplings to survive and iii) ability of seedlings and saplings to grow. A population with sufficient number of seedlings and saplings and trees in a forest indicates successful regeneration (Khan *et al*., 1987; Dutta and Devi, 2013), while inadequate number of the species in a forest indicates poor regeneration (Tripathi and Khan, 2007). Successful regeneration provided long-term sustainability of a forest (Malik and Bhatt, 2016). Rehabilitation and ecosystem recovery also depend on regeneration capacity (Pandey and Shukla, 2001), which plays an important role in forest growth and management.

Regeneration status of tree species can be determined by using diameter at breast height (dbh) or girth at breast height (gbh) class distribution of trees (Everard, 1992). Bharali *et al*. (2012) studied on regeneration status of *Rhododendron* species in temperate forest of India and reported that fluctuation in population density of seedlings, saplings and adults along the altitudinal gradient can be linked with the prevailing environmental factors.

Malik and Bhat (2016) studied on regeneration status of tree species in Western Himalaya of India and reported that the successful regeneration depends on various factors such as soil characteristics, slope, and wide variation in altitude, climatic conditions, disease, and population density of herbivorous animals. Pokhriyal *et al.* (2010) also studied on regeneration status of tree species in Garhwal Himalaya reported that the regeneration of a species is affected by fire, grazing, light, canopy density, soil moisture, soil nutrients and anthropogenic pressure. Khadka (2013) studied on Regeneration *of R. arboreum* along an altitudinal gradient of Manaslu Conservation Area, Nepal Himalaya. The regeneration status of *R. arboreum* in most of the altitudinal range show fair with density of sapling population less than seedlings and adults were observed. The fair regeneration of the tree species along the altitudinal gradient suggests their tolerance to partial biotic pressure and wider ecological amplitude, this observation was made by Sharma and Kala (2018) for the medicinal plants along the altitudinal gradient in Dhauladhar mountain range of Indian Himalayas. Noshiro *et al*. (2010) studied on distinct altitudinal trends in wood structure of *R. arboreum* in Nepal and reported that in Rolwaling area this species grew throughout the altitudinal range, from 1200 to 3500 m, but in Bajhang-Khaptad area it grew only above 2000 m due to the lack of enough precipitation below this altitude.

Canopy is the main factor affecting for the successful regeneration. It was observed by Sharma (2016), studied on Demography and growth trade of *Rhododendron campanulatum* at tree line ecotone of Annapurna Conservation Area, Mustang, Nepal.

2.3 *Rhododendron* and Associates Species

More than 90% of the world's *Rhododendrons* population is mainly concentrated in northwestern Himalaya to southeastern Asia with an extension to Nepal, northeastern India, eastern Tibet, northern Burma, and western and central China (Tiwari and Chauhan, 2006). There are 32 species of *Rhododendron* found in Nepal (Rajbhandari and Watson, 2005). The *R. arboreum* species is distributed in North America, Europe, Australia, India, Bhutan, Nepal, China, Myanmar, Thailand, Sri Lanka, Pakistan, and Tibet (Purohit, 2014). The size of genus *Rhododendron* ranges from small alpine mats (*R. pumilum*, *R. setosum*) with a few individuals a few centimeters long to giant 25 m (*R. arboreum*) (Tiwari and Chauhan, 2006).

Rhododendrons are found associated with other tree species or as pure stands in the Himalayan forests, where the greatest species diversity was observed (Scott, 2010). *R. arboreum* are found in association with *Schima wallichi*, *Castanopsis indica*, *Alnus nepalensis*, *Castanopsis tribuloides*, this was supported by the study of Chaulagain and Shrestha (2018) in Chameli community forest, Bhaktapur, Nepal. Pandey *et al*. (2014) also reported the similar associated tree species from the Mid Hill of central Nepal.

Singh (2015) studied on *Quercus leucotrichophora* forest stands of Garhwal Himalaya, Uttarakhand, India reported that *R. arboreum* found in assocciation with broad-leaved character of *Q. leucotrichophora*, *Lyonia ovalifolia*, *Myrica esculenta* and *Pyrus pashia.*

2.4 Uses of *Rhododendron arboreum* and Anthropogenic Factor

Rhododendron arboreum is very important plants that have diverse used in medicine, household use, esthetic use, and decorative purposes. This statement is supported by the research carried out by many researchers on *R. arboreum.* (Bhatt and Sachan, 2004; Kumar and Sharma, 2009; Singh *et al*., 2010) suggested that the wood of *R. arboreum* is used as firewood for domestic cooking. Srivastava (2012) studied on an overview of *R. arboreum* and it revealed that *R. arboreum* is important plant of hilly region with extensive medicinal and commercial uses. Mamgain (2017) reported that *R. arboreum* is a multipurpose tree species which provides wood for fuel, its flowers are used for juices, squash, pickles, medicinal purposes and its bark is also used for medicine. *Rhododendrons* are subjected to natural and anthropogenic pressure, and the latter factors are considered to be the main cause of their population decline (Pokhrel, 1999). Mamgain (2017) studied on Population assessment, mapping, and flowering response of *Rhododendron arboreum* a keystone species in central Indian Himalayan region of Uttarakhand, India and reported that the anthropogenic factors impact on the survival and spread of the *R. arboreum* species at low altitudes the populations of this species will be gradually reduced at the lower region and then the pressure would be mounted on the middle altitude region plants.

2.5 Soil Characteristics in *R. arboreum* Forest

R. arboreum prefers light (sandy) to medium (loamy) soil and requires fairly moist and acidic soil (Srivastava, 2012). Pathak *et al*. (2021) studied on propagation and cultivation of *R. arboreum* in Nepal. They found that *R. arboreum* is acid loving plant. Therefore, it prefers acidic soil. Dahal *et al*. (2018) studied on Physico-chemical properties of soil in Lamjung district and observed that soil pH level decreases with increasing altitude and slope gradient. Similar observation done by Sigdel *et al*. (2015) on physico-chemical characteristics of soil along an altitudinal gradient in central Nepal, they found that soil pH had negative relationship with increasing altitude but soil nitrogen, organic matter, soil moisture and water holding capacity was found to be increasing with increasing altitude. *R. arboreum* favors acidic soil for its growth this result was reported by Stehn *et al*. (2011) studied on high elevation ground-layer plant community composition across environmental gradients in spruce-fir forests.

The literature reviews provided further insight into the current study. A general understanding of the research questions and objectives related to the population structure, and regeneration of *Rhododendron* species was carried out. The *Rhododendron* is the national flower of Nepal, and it has multiple uses in medicine, aesthetics, and decoration. Thus, the population structures and regeneration of *Rhododendron* were studied in the Rainaskot forest of Lamjung district. The Rainaskot area has its own historical, cultural, and tourist importance. *Rhododendron* is an abundant plant species from an altitude of 1200 m to 1653 m. This new research would help in the exploration of species diversity and association with *R. arboreum* in the Rainaskot mixed forest. This research reveals its importance in scientific research.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Accessibility

Present research was carried out in the community forest of Rainaskot, Lamjung District located in Rainas Municipality Ward Number-9 (Figure 3.1). The geographical location of the study area ranges from 28°16′58.44″ north Latitude to 84°26′27.24″ east Longitude. The approximate area of the study site is more than 140 ha and the study covered altitude range from 1200 m upto1600 m. The forest is located at the Northeast and Northwest facing slope of a ridge extending East-West at Rainaskot Area. The study area is well accessible by motorable black topped road up to Paudi which is the small bazar of Lamjung District. From Paudi bazar, the area is accessible with a mix of gravel and black topped road up to the Rainaskot historical homestay. The study area is located at the eastern and around the homestay. The Rainaskot area has great historical, cultural, religious importance with a special and ecological biodiversity. The forest area is a popular hiking trail for many local tourists to reach Rainaskot hill.

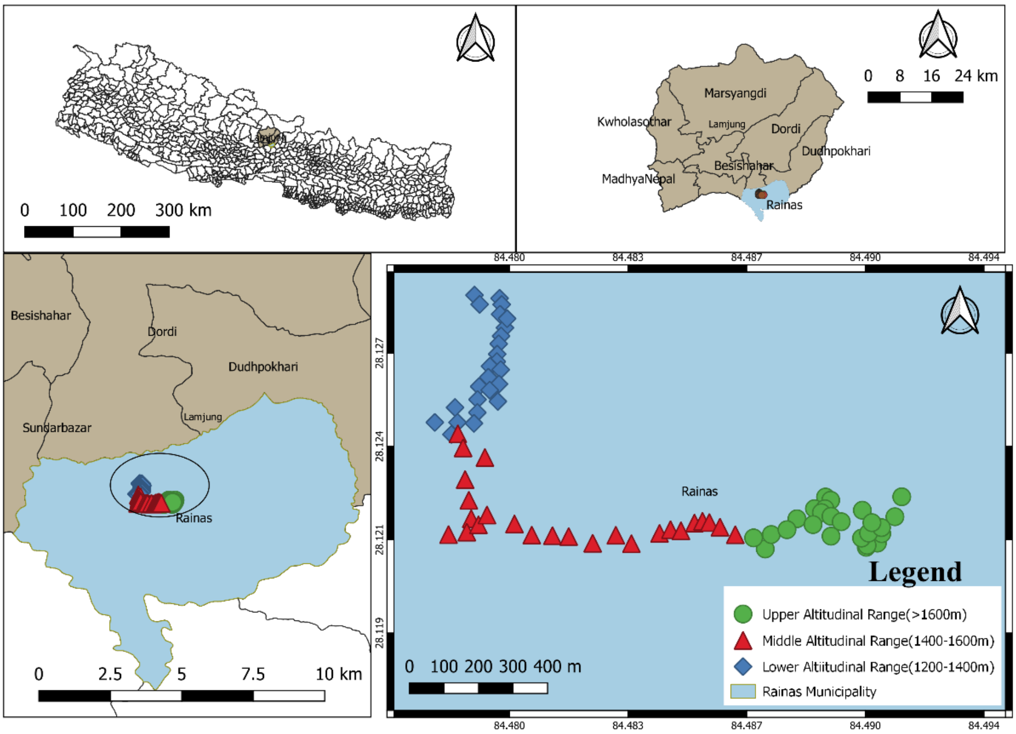


Figure 3.1. Location Map of the study area (Source: Government of Nepal, Department of Survey, 2020)

3.1.2 Climate

The climate of Rainaskot lies within the cool, sub-tropical climatic zone of Nepal. The lower part is quite warm and the area near the ridge is cool type. A thirty-year climatic data (1990-2020A.D) both temperature and precipitation were analyzed, which was taken from Department of Hydrology and Meteorology (DHM) Meteorological station of Khudi bazar Lamjung district west of Rainaskot area. The monthly and yearly temperature was converted into average minimum and maximum monthly temperature. The mean annual temperature was 21.23°C. The average monthly maximum temperature was 27.78°C and average monthly minimum temperature was 14.67°C (Figure 3.2). The maximum monthly temperature (31.85°C), was found in August and minimum average monthly temperature (5.98°C) was found in December. The analysis of monthly average precipitation for 30 years shows the highest rainfall value of 860 mm in July, where December and January show the lowest rainfall (Annex I).

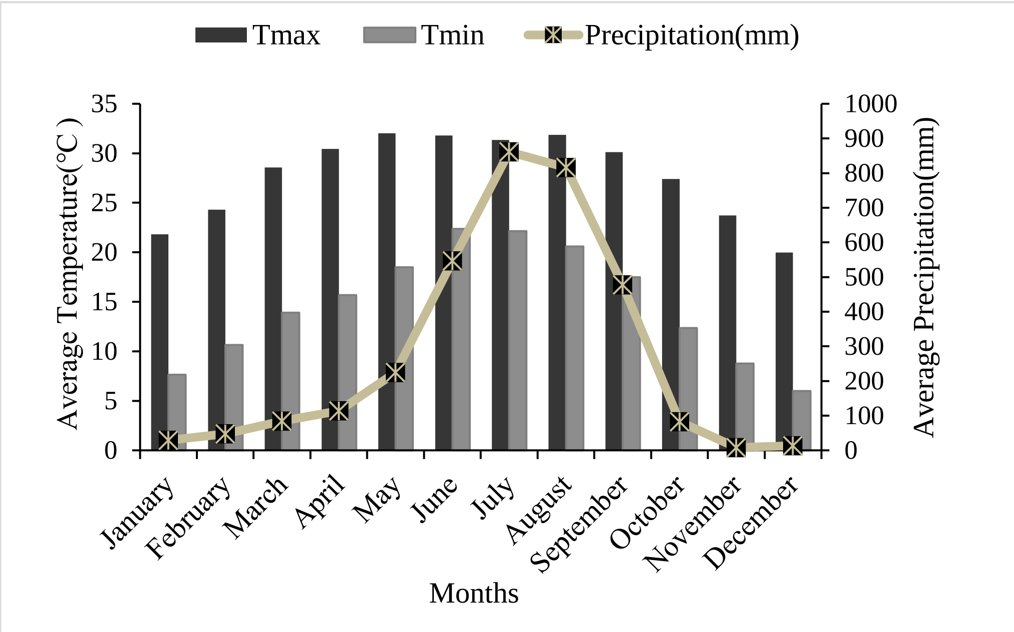


Figure 3.2. Average monthly maximum (T_{max}) and minimum (T_{min}) temperature with precipitation recorded at Khudi Bazar Station for 30 years. (Source: DHM)

3.1.3 Vegetation

The forest was mixed type, the tree species such as *Rhododendron arboreum*, *Schima wallichi*, *Castanopsis indica*, *Myrica esculenta* and *Lyonia ovalifolia* were most frequent and dominant vegetation of the study area. Other tree species such as

Mallotus tetracoccus, Falconeria insignis, Phyllanthus emblica, Albizia lebbek, Litsea doshia, Alnus nepalensis, Luculia gratissima and Madhuca longifolia were found to be associated within the study area. Dominant vegetation was different at different altitudinal ranges. In the lower altitude, *S. wallichi* was a dominant tree. While in middle and upper altitudes *R. arboreum* and *C. indica* was most dominant species respectively.

3.2 Study Species

Rhododendron arboreum Sm. (Ericaceae) is an evergreen much branched tree up to 25 m in height (Ranjitkar *et al*., 2014). *R. arboreum* is an important tree species distributed in hilly areas of Nepal. Unlike the 1000 m altitude range for most *Rhododendron* species of Nepal, *R. arboreum* grows throughout Nepal from 1000 m in the subtropical region to 4000 m at the upper limit of the subalpine region (Noshiro, 1997). Flowers bears deep red or crimson to pale pink in color and flowering season is from March April/ June-September (Srivastava, 2012). It is a multipurpose tree that provides wood for fuel, its flowers are used to make juice, squash, pickles and bark and the flowers are used for medicinal purpose (Mamgain, 2017).

3.3 Methods

For collecting and analyzing data the descriptive and quantitative methods were used in this study. All collected and analyzed data were mainly primary in nature and secondary data sources for climate interpretation were used.

3.3.1 Field Work

The reconnaissance survey was carried out from September 20th to 25th in 2019 A. D to ensure accessibility and working strategy in the field. Field traverse along the forest gives preliminary ideas about vegetation, climate, topography, and fieldwork plan. The main field work was carried out from January 4th to February 10th in 2020 A.D.

3.3.1.1 Vegetation Sampling

The population structure and regeneration of *R. arboreum* was studied within 16% (23 ha) out of total area by using circular stratified random systematic sampling method. The altitude wise collected data was divided into three altitudinal ranges i.e., lower altitudinal range (1200-1400 m), middle altitudinal range (1400-1600 m) and upper altitudinal range (1600-1653 m). Altogether 75 quadrats were studied from three altitudinal range, 25 quadrats in each altitudinal range. In each altitudinal range 25 quadrats were laid down with spacing of 20-50 m depending upon slope and topography.

During vegetation sampling very steep slopes and rocky places were avoided which resulted to unequal length of plots. In each quadrat, the structural attribute of woody plant species was categorized as individuals of each species were grouped into seedling (height < 20 cm), sapling (diameter at breast height; DBH <10 cm and height >20 cm) and mature tree (DBH >10 cm) as per Deb and Sundriyal (2008). Seedling and saplings were enumerated within the 10m circular area. In each quadrat all individuals of *R. arboreum* and associated tree species were recorded and their height and diameter at breast height (DBH) were measured. Diameter at breast height was measured by DBH tape and height of tree species were measured with the help of clinometer. The geographical location of each quadrat (longitude, latitude, and altitude) was recorded by using Global Positioning System (GPS).

The other characteristics such as litter weight, litter depth and canopy cover were estimated from the field study. The litter cover was collected from the 1m diameter circular plot and weighted using the digital weighing machine. The depth of litter over was measured by using measuring scale. Canopy cover was estimated from visual observation on photograph taking at the center and four corners of the quadrate. Final canopy cover percentage was estimated taking and average of all canopy cover percentage from each photograph.

The identification of the plants was done by knowing local name from local people with wide knowledge of the species in vernacular names and by referring to the flora guide's books (Polunin and Stainton, 1987; Stainton, 1988; Waston *et al*., 2011).

3.3.1.2 Soil Sampling

From each altitudinal range, 25 soil samples (15 cm depth) were collected from center of the 25 quadrats. The collected samples of nearby 5 quadrats were mixed thoroughly to prepare final sample. In this way 5 soil samples from each altitudinal range were prepared for laboratory work. Altogether 15 soil samples were used for the study of soil pH, organic matter (OM), soil texture, Nitrogen, Phosphorus and Potassium.

3.3.2 Laboratory Work

Soil pH, organic matter (OM) content, soil texture and 3 macro nutrients (Nitrogen, Phosphorus and Potassium) were determined in the air-dried soil samples at the Laboratory of Central Department of Environment Science, Tribhuvan University, Kirtipur, Kathmandu Nepal. Soil pH was measured by pH meter in a 1:1 mixture of soil and distilled water; OM content by the Walkley and Black method; total N by the micro-Kjeldahl method; available P by Olsen's modified carbonate method; and available potassium (as K_2O) by flame photometer method. Procedures and methods that have been described in Gupta (2000) was used in this laboratory analysis.

3.3.3 Data Presentation and Analysis

3.3.3.1 Numerical Analysis

The frequency, density and IVI of tree species were calculated by using the method described by Zobel *et al*. (1987). The formula used to calculate value of frequency density dominance and IVI is given below:

Frequency (F)

Frequency is the proportion of sampling units containing the species.

$$\text{Frequency(F, \%)} = \frac{\text{No. of quadrat in which species occurred}}{\text{Total no. of quadrat studied}} \times 100$$

Relative frequency (RF)

$$\text{Relative Frequency (RF, \%)} = \frac{\text{Frequency of individual Species}}{\text{Total frequency of all species}} \times 100$$

Density (D)

Density of species is a count of the numbers of individuals of each species within the quadrat (Kent and Coker, 1992).

$$\text{Density (individualha}^{-1}\text{)} = \frac{\text{Total number of individuals of a species in all plots}}{\text{Total number of plots studied} \times \text{Size of the plot (m}^2\text{)}} \times 10000$$

Relative density (RD)

$$\text{Relative Density(RD, \%)} = \frac{\text{Density of individual species}}{\text{Total density of all species}} \times 100$$

Basal Area (BA)

Basal area is the cross-sectional area of a tree, it was calculated from DBH and represented as $m^2\ ha^{-1}$ for different size classes.

$$\text{Basal area(BA)} \ = \frac{\bar{\wedge}\ d^2}{4}$$

Where,

D = diameter at the breast height

π = 3.1416

$$\text{Basal area of a species (m}^2\text{ha}^{-1}) \ = \frac{\text{Total basal area of a species}}{\text{Size of the plots (m}^2)} \times 1000$$

Relative Basal Area (RBA):

Relative basal area can be obtained by comparing the basal area of occurrences of all the species present.

$$\text{Relative Basal Area (RBA, \%)} \ = \frac{\text{Basal area of individual species}}{\text{Total basal ara of all species}} \times 100$$

Importance Value Index (IVI)

The *important value index* (IVI) indicates the relative ecological importance of a woody species in each of the project sites (Kent and Coker, 1992).

Relative frequency, Relative density, and Relative basal area each indicate a different aspect of the importance of a species in a community. Therefore, the sum of these three values should give a good overall estimate of the importance of a species. This sum is called the importance value.

IVIi =RFi +RDi + RBAi

Where,

IVIi = Importance Value Index of species i

RFi = Relative Frequency of species i

RDi = Relative Density of species i

RBAi = Relative Basal Area of species i

Diversity of species:

Density of species: it is a count of the numbers of individuals of each species within the quadrat. The Shannon-Wiener diversity index (H') takes into account the species richness and proportion of each species in all sampled quadrats of each transect of study area. The following formula was used to analyses the tree species diversity (Magaurran, 1988):

$$\text{Shannon} - \text{Wiener index } (H') = -\sum Pi(\text{Ln } Pi)$$

Where,

H’ = Species Diversity Index

P_i = Proportion of individual species

Pi = ni/N

ni = number of individuals of species i,

N = total number of individuals

Simpson’s Dominance Index

Simpson’s diversity index was calculated according to Simpson (1949) the formula is given as follows:

$$\text{Simpson's Index (D)} = \frac{\Sigma\, n(n-1)}{N(N-1)}$$

Where,

N = Total number of species collected

n = Number of individuals of a species

$$\text{Simpson's index of Diversity (DI)} = 1 - D$$

Evenness (E):

Species evenness refers to the closeness of each species in their numbers (Tiwari *et al.*, 2018). Evenness is calculated as proportion of observed and maximal diversity (Pielou, 1969).

$$E = H'/H_{max}$$

Where, E = evenness (value range from 0 to 1)

H’ = Shannon index

H_{max} = (ln s) = maximum possible diversity

S = the number of species

Similarity index (SI)

The similarity index helps to determine the interspecific association between the species of plant communities (Sorensen, 1948). Sorensen's species similarity index between the altitudinal ranges was calculated according to Nath *et al*.(2005).

$$\text{Similarity index(SI)} = \frac{2C}{A + B} \times 100$$

Where, A = Total number of species in transect A

B = Total number of species in transect B

C = Total number of common species both altitudinal ranges

Population structure of tree:

Population structure of *Rhododendron arboreum* and its associated tree species was determined by arranging the diameter of tree species in diameter class interval by referring the study of Atsbha *et al*. (2019). The histogram was constructed by using the density of individuals of tree species (Y-axis), categorized into eight diameter classes (X-axis) i.e., 10-25 cm, 25-40 cm, 40-55 cm, 55-70 cm, 70-85 cm, 85-105 cm, and 105-120 cm.

The height of trees species was presented by making height class intervals Burju *et al*. (2013). The height of *R. arboreum* was classified into five classes with 4 m intervals' 1-4 m, 4-8 m, 8-12 m, 12-16 m and 16-20 m. The densities of individuals were summed up falling in the diameter at breast height (DBH) or height classes.

Regeneration of species:

The regeneration of tree species was determined by comparing the density of seedling, sapling and of mature tree. According to Khan *et al*. (1987); Shankar (2001) and Khumbongmayum *et al*. (2006), different regeneration categories (fair, good, not, new, and poor) were created to determine the regeneration status of each species. The categorized regeneration status was as follows:

- Good regeneration if seedlings > saplings > adults.
- Fair regeneration tree > sapling > seedling.
- Poor regeneration, if a species exists only in sapling stage, but no seedlings, saplings may be less than, more than or equal to adult.

- No regeneration, if a species has only adults but absent of both seedling and sapling.
- New regeneration if a species has only sapling or seedlings but no adult.

Litters Measurement:

- The litter cover was collected from the 1m diameter circular plot and weighted using the digital weighing machine.
- The depth of litter cover was measured by using measuring scale.

3.3.3.2 Statistical Analysis

One-way ANOVA were performed to test the altitudinal ranges wise differences in distribution of different life forms (density of seedlings, saplings and adults) of *R. arboreum* and species richness in different altitudinal ranges. This different statistical analysis was performed by using SPSS version 16. R-studio was used to check correlation between life form of *R. arboreum* and other environmental factors (soil parameters, altitudes, canopy, and litter).

CHAPTER 4

4. RESULTS

4.1 Vegetation Structure

Altogether, 13 tree species belonging to 11 families were recorded from study sites. The overall study area was divided into 3 altitudinal ranges according to the altitude difference, with a total of 25 quadrats in each altitudinal range. The number of tree species encountered at the study area varied from one altitudinal range to another. Eleven tree species were recorded from the upper altitudinal range (1600-1653m), followed by 9 species in middle altitudinal range (1400-1600m) and 7 species in lower altitudinal range (1200-1400m). The forest was a mixed forest of *Rhododendron arboreum*, *Schima wallichi*, *Castanopsis indica*, *Myrica esculenta,* and *Lyonia ovalifolia*, with some other tree species. In lower altitudinal range, the dominating tree species were *S. wallichi, R. arboreum, C. indica*, *M. esculenta,* and *Albizia lebbek.* In middle altitudinal range, the dominant tree species were *R. arboreum*, *S. wallichi, C. indica, M. esculenta,* and *L. ovalifolia,* and in the upper altitudinal range, the dominant tree species were *R. arboreum*, *S. wallichi*, *C. indica, Mallotus tetracoccus, M. esculenta*, and *Alnus nepalensis* (Annex II).

4.1.1 Density and Frequency Distribution of the Plant Species.

The total population density of Rainaskot forest was found to be 612.60 individualha^{-1}. *R. arboreum* was the most abundant plant species within the forest, with a total density of 257.52 individualha^{-1}. The densities of other tree species, *S. wallichi, C. indica, M. esculenta,* and *L. ovalifolia* were 216.85 individualha^{-1},101.39 individualha^{-1}, 65.33 individualha^{-1} and 18.24 individualha^{-1} respectively.

An altitude wise comparison of density of *R. arboreum* with whole tree density of forest is shown in Figure 4.1. The total maximum tree density (745.83 individualha^{-1}) was recorded in middle altitudinal range and the minimum (459.46 individualha^{-1}) was in lower altitudinal range. The highest density (393.28 individualha^{-1}) of *R. arboreum* was found in upper altitudinal range and the lowest density (127.28 individualha^{-1}) was found in lower altitudinal range.

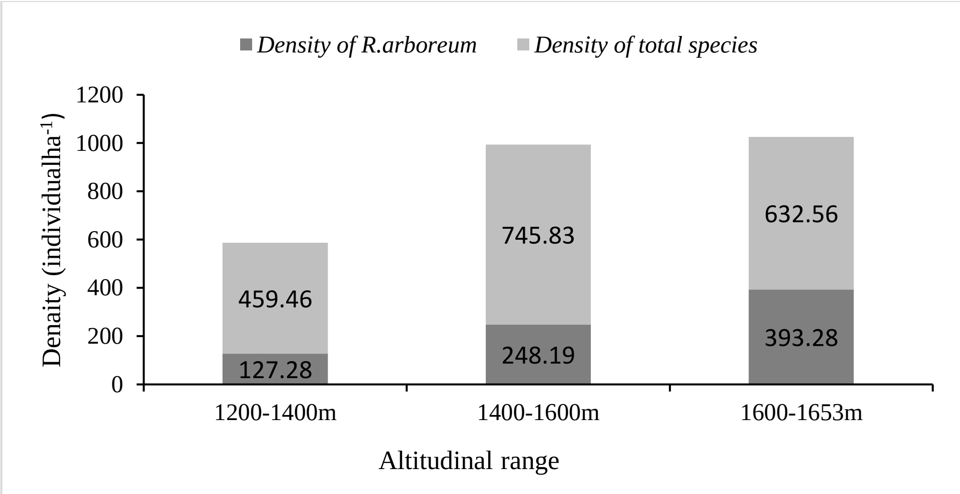


Figure 4.1. Comparison of density of *R. arboreum* with whole trees density including associated species of forest

The most frequent and dense tree species was *R. arboreum*, which was present in 93.33% (Figure 4.2). Seedlings and saplings were present in 58.66% and 70.66% in the forest, respectively.

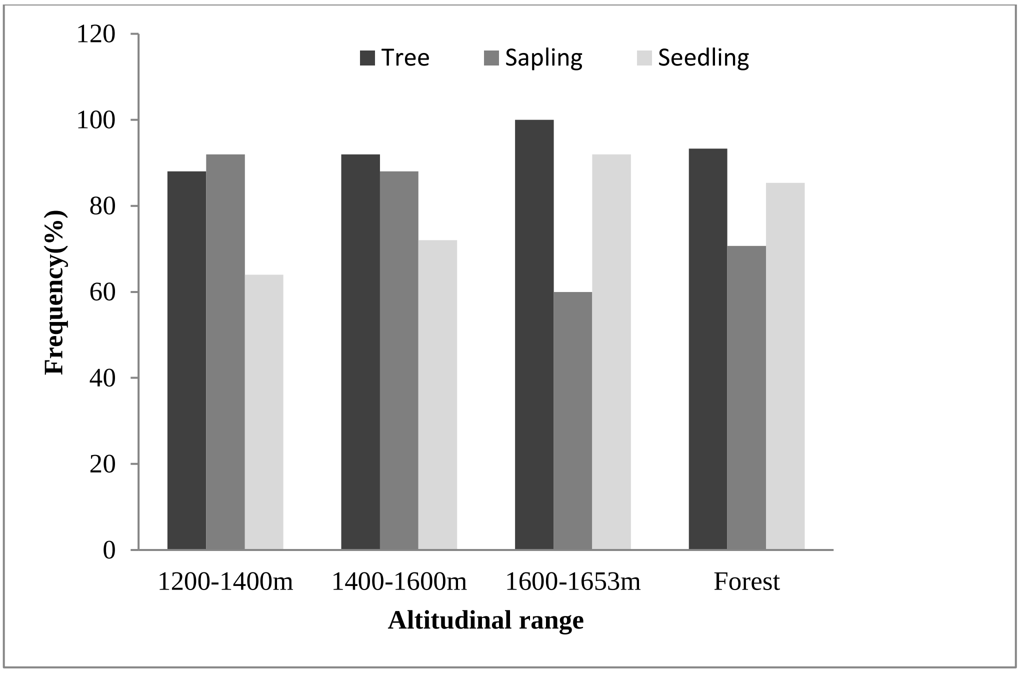
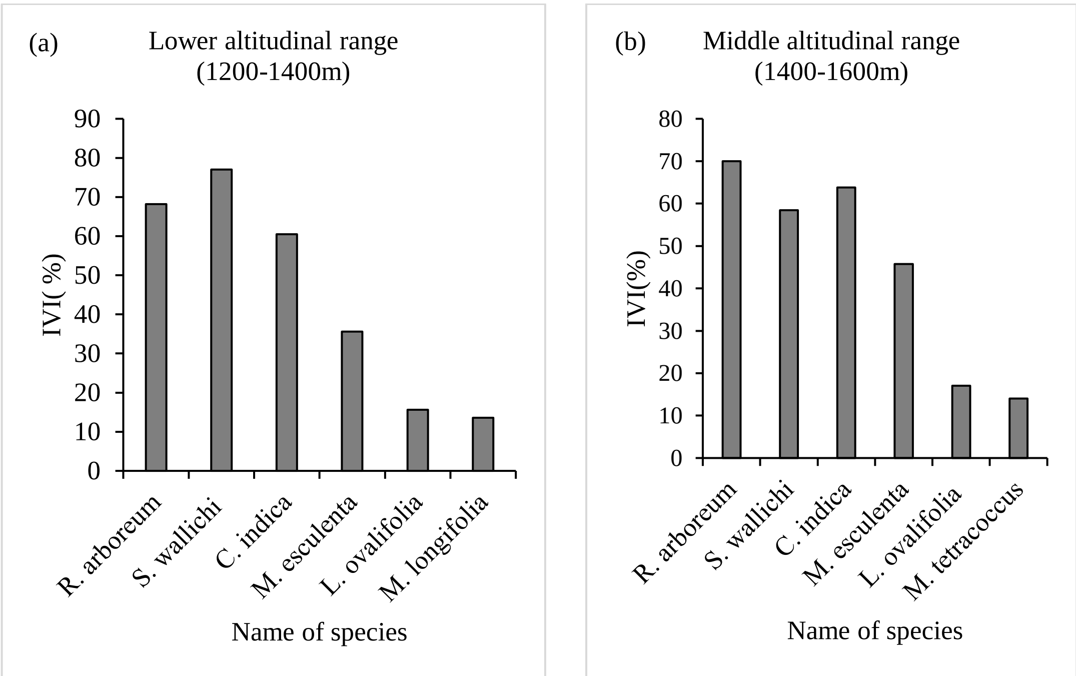


Figure 4.2. Altitude wise frequency of *R. arboreum* based on life stages

The frequency percentages of trees, saplings and seedlings were 88%, 92%, and 64% in lower altitudinal range (1200-1400m), respectively. Similarly, there were 92%, 88% and 72% in middle altitudinal range (1400-1600m) for trees, saplings, and seedlings, respectively. Likewise, 100%, 60% and 92% for trees, saplings, and seedlings in upper altitudinal range (1600-1653m) respectively (Figure 4.2).

4.1.2 Importance Value Index (IVI).

The IVI helps to understand the ecological significance of species in a community structure. Altitude wise, ecologically important plant species are as shown in Figure 4.3. Based on the Importanance value index (IVI), the tree species *Rhododendron arboreum*, *Schima wallichi*, *Castanopsis indica*, *Myrica esculenta* and *Lyonia ovalifolia*, were the most important species in the forest. Among them, *R. arboreum* showed the highest value (77.78%) followed by *S. wallichi* (50.57%) *C. indica* (47.97%) *M. esculenta* (33.14%) *Mallotus tetracoccus* (13.94%) and *L. ovalifolia*, (12.68%). The lowest important value index (IVI) was of *Madhuca longifolia* (6.44%) followed by *Luculia gratissima* (8.92%), *Alnus nepalensis* (9.01%), *Litsea doshia* (9.22%), *Albizia lebbek* (9.51%), *Phyllanthus emblica* (10.24%) and *Falconeria insignis* (11.08%) which indicates they are the least ecologically important species in the forest (Annex II). In all altitudinal range, *R. arboreum* was the most dominant tree species, except in lower altitudinal range in which the dominant tree species was *S. wallichi*, with a high IVI value (77.56 %). The important value index of *R. arboreum* was quite lower (68.19%) in lower altitudinal range compared to the middle (70.02%) and upper altitudinal ranges (105.52%).



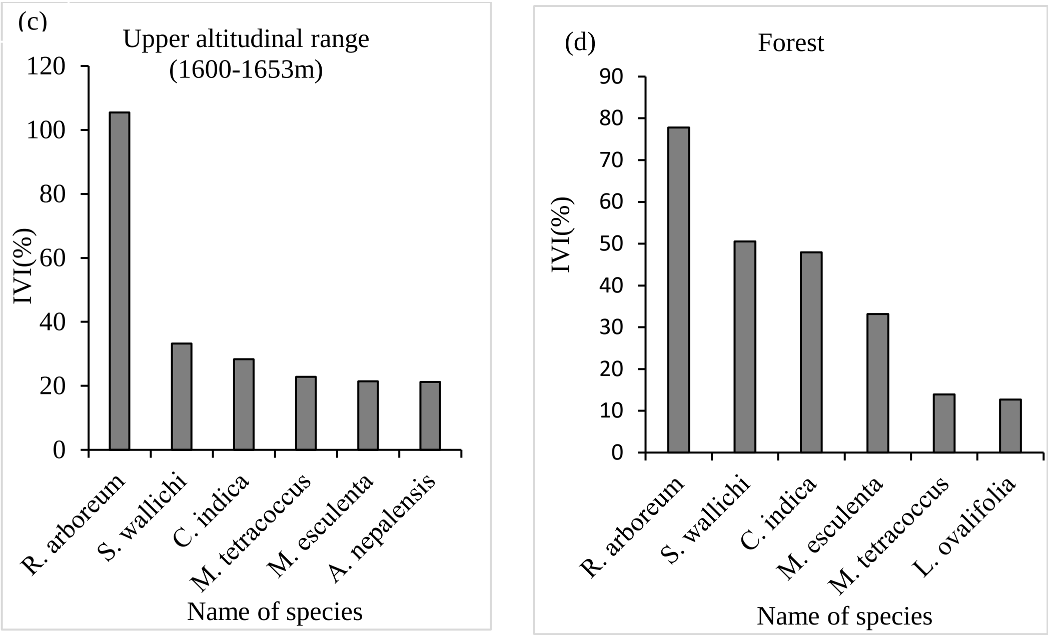


Figure 4.3. Important value index (IVI) for *R. arboreum* and associated species

4.2 Species Diversity

The number of tree species encountered at the study area varied from one altitudinal range to another. Eleven tree species were recorded from the upper altitudinal range (1600-1653m), followed by nine species in middle altitudinal range (1400-1600m) and seven species in lower altitudinal range (1200-1400m).

Statistically, one-way ANOVA was applied to tree species richness. The tree species richness across the altitude showed a significant difference (P = 0.029) and variance ratio was (F = 3.705). Thus, the tree species richness significantly varied along with altitude (Table 4.1). The significant variation in tree species richness among the three altitudinal ranges (Figure 4.4).

Table 4.1. Comparing Species richness at different altitudes (One-way ANOVA Analysis)

Source	Degree of freedom	Sum of squares	Mean square	F value	Significance (P value)
Between altitude	11.84	2	5.92	3.705	0.029
Within altitude	115.04	72	1.598		
Total	126.88	74			

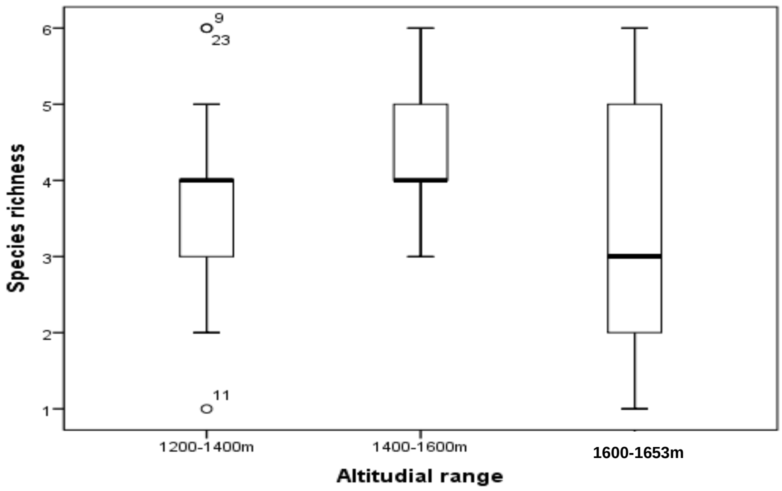


Figure 4.4. Box plot showing difference in species richness among three altitudinal ranges.

The highest Simpsons index value (0.77) was recorded in middle altitudinal range and the lowest value (0.57) in upper altitudinal range (Table 4.2). The Shannon–Wiener index value (1.60) was found to be the highest in middle altitudinal range and (1.34) to be the least value in upper altitudinal range. The lower altitudinal range showed a Shannon–Wiener index value of (1.44) but the relatively least evenness value (1.29). Therefore, the highest species diversity of tree species was recorded in middle of the altitudinal range. The highest relative value (1.70) of species evenness was found in upper altitudinal range.

Table 4.2. Diversity indices along the three different altitudinal range

Altitudinal range (m)	**Shannon-Wiener diversity index**	**Simpson's index**	**Simpson's index of Diversity**	**Evenness**
1200-1400	1.44	0.26	0.73	1.71
1400-1600	1.60	0.23	0.77	1.68
1600-1653	1.34	0.42	0.57	1.29

4.2.1 Sorenson Similarity Index

Sorenson Similarity Index helps to determine and compare the similarities of plant species in altitudinal range lower and middle, lower and upper, and middle and Upper. The lower and upper altitudinal ranges had the highest similarity index of 77.7%, followed by the middle and upper altitudinal ranges with a similarity index of 70%, and the lower and middle altitudinal ranges with the lowest similarity index of 62.6% (Figure 4.5). The common plant species between lower and upper altitudes was 7, with 7 plant species in lower altitudinal range and 11 plant species in upper altitudinal range. In middle and upper altitudes also had 7 common plant species, of which the middle altitudinal range had 9 plant species, whereas the upper altitudinal range had 11 plant species. In both lower and middle altitudes with the lowest percentage of Sorenson similarity index had 5 common plant species. In which lower altitudinal range had 7 total plant species, while in middle altitudinal range had 9 plant species.

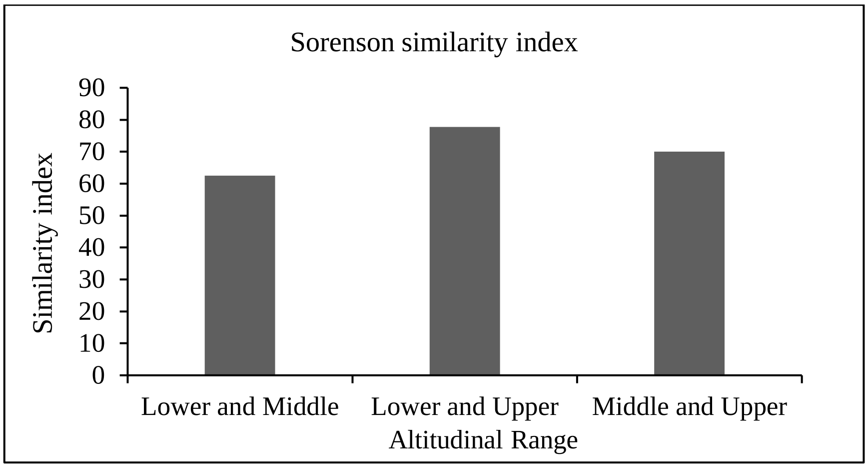


Figure 4.5. Sorenson similarity index between three altitudinal ranges

4.2.2 Basal Area (BA)

Basal area describes the average amount of an area occupied by tree stems, which is a better measure of the relative importance of the species than stem count. The total basal area of the *Rhododendron arboreum* in the forest calculated from DBH data was 16.40 m^2ha^{-1}, which is 24% coverage on the ground. The basal area of *R. arboreum* was 4.20 m^2ha^{-1} (6% area occupied) in lower altitudinal range, 9.85 m^2ha^{-1} (30% area occupied) in middle altitudinal range, and 6.74 m^2ha^{-1} (40% area occupied) in upper altitudinal range (Figure 4.6). The total basal area of *R. arboreum* stems increases with an increase in altitude.

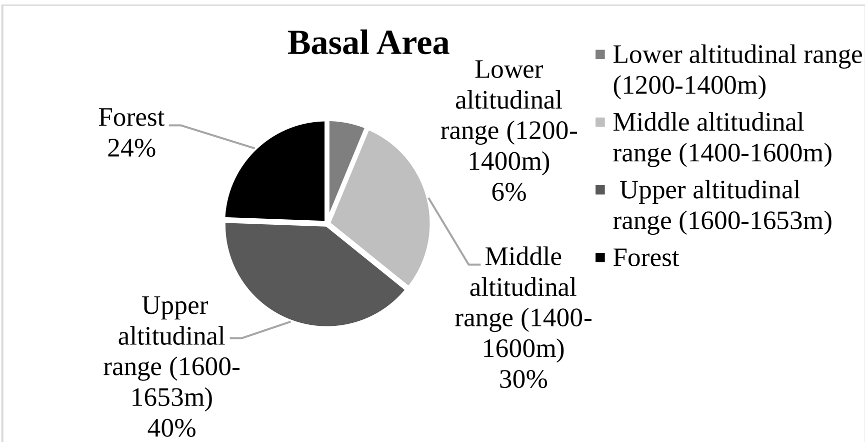


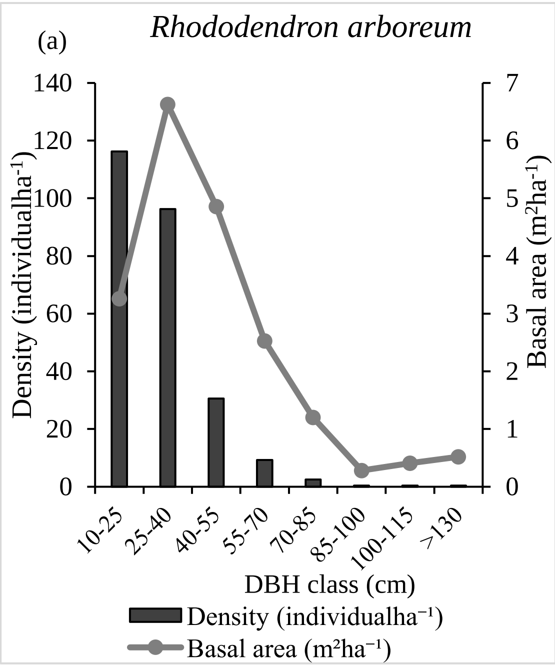
Figure 4.6. Basal area of *R. arboreum* in the forest and in three altitudinal ranges

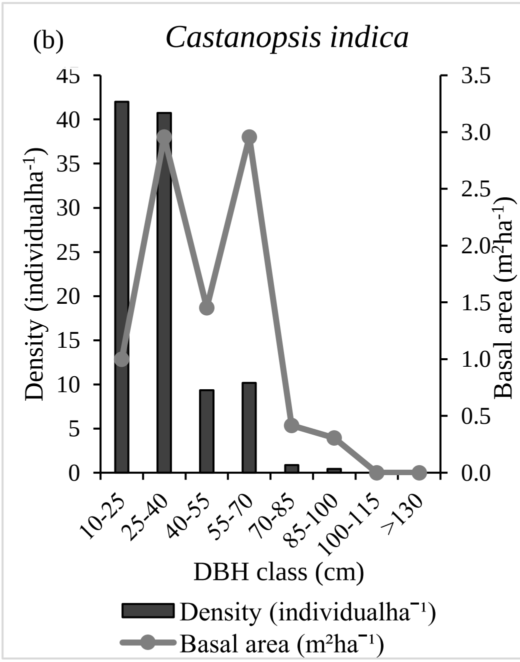
4.3 Population Structure

4.3.1. Population Structure of Tree Species

The overall population structure of tree species depending on size-class distribution yielded a reverse J-shaped diameter at breast height (DBH)-density distribution curve. Four species namely, *Rhododendron arboreum, Schima wallichi, Castanopsis indica,* and *Myrica esculenta,* were selected according to the highest IVI values based on the quantitative data of community structure. The density of tree species has decreased with increasing diameter, except for *C. indica*, which showed a density of individuals slightly higher in the DBH class 55-70cm than in the DBH class 40-55cm within the present study area, Rainaskot (Figure 4.7).

The highest stand density of *R. arboreum* (116.24 individualha^{-1}) was recorded in the 10-25cm DBH class, followed by 25-40cm (96.30 individualha^{-1}) and 40-55cm (30.55 stemha^{-1}) DBH class, and it gradually decreased with increasing DBH class. The lowest density was found to be 0.42 individualha^{-1} in DBH class 85-100cm, 100-115 cm and >130cm. The highest value of basal area (6.63 m^{2}ha^{-1}) of *R. arboreum* was calculated in 25-40cm DBH class, followed by 40-55 cm (4.86 m^{2}ha^{-1}), 10-25cm (3.26 m^{2}ha^{-1}) and the lowest (0.28 m^{2}ha^{-1}) in 85-100 cm DBH class (Figure 4.7a).





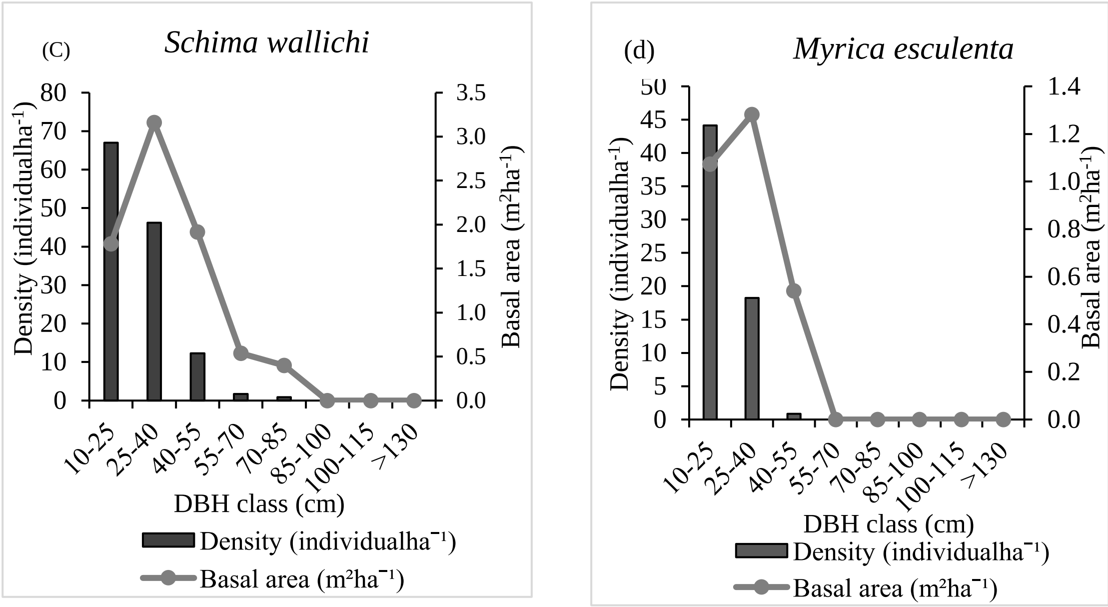


Figure 4.7. Density (Individualha-^{1}) and basal area (m^{2} ha^{-1}) recorded in different DBH classes of a few dominant tree species in the study area: (a) *R. arboreum* (b) *C. indica* (c) *S. wallichi* (d) *M. esculenta*

The highest stand density(42 individualha^{-1}) of *C. indica* was found in the DBH class 10-25 cm, followed by 25-40 cm (40.73 individualha^{-1}) and 55-70 cm (10.18 individualha^{-1}) DBH classes, and the lowest density (0.42 individualha^{-1}) was found in the DBH class 85-100 cm. The highest basal area values (2.96 m^{2}ha^{-1}) were found in the DBH classes of 25-40cm and 55-70cm. The lowest value (0.31 individualha^{-1}) was found in the DBH class 85-100cm (Figure 4.7b). *S. wallichi* showed a reverse J-shaped DBH-density distribution population curve. The highest density (67.03 individualha^{-1}) was found in DBH class 10-25cm, followed by 25-40cm (46.24 individualha^{-1}), 40-55cm (12.30 individualha^{-1}). The lowest density (0.85 stemha^{-1}) was in DBH class 70-85cm. The basal area was found to be higher (3.16 m^{2}ha^{-1}) in DBH class 25-40cm and lowest 0.40 m^{2}ha^{-1} in DBH class 70-85cm (Figure 4.7c). *M. esculenta* was completely absent in higher DBH classes (55-70cm to >13cm) with highest individuals (44.12 individualha^{-1}) in 10-25cm DBH class, followed by (18.24 individualha^{-1}) in the 25-40cm and (0.85 individualha^{-1}) in the 40-55cm (Figure 4.7d). The basal area was found to be highest (1.28 m^{2}ha^{-1}) in the 25-40cm DBH class and lowest (0.54 m^{2}ha^{-1}) in DBH class 40-55cm.

4.3.2 Population Structure of *R. arboreum*

The population structure of *R. arboreum* showed reverse J-shaped DBH-density distribution curves all over the forest (Figure 4.8a). The density of the tree was found to be maximum in the 10-25cm DBH class and followed by the 25-40cm DBH class in all altitudinal ranges. In lower altitudinal range, individuals at the highest diameter classes were missing (Figure 4.8b). In middle altitudinal range, density distribution curve showed a typical reverse J- shape with little deviation as stem density decreased with increasing DBH except for DBH class less than 10-25cm (Figure 4.8c). The upper altitudinal range showed reverse J-shaped DBH-density distribution curves (Figure 4.8d). Individuals with the largest DBH class size (>130cm) were few in the forest and upper altitudinal ranges, but completely absent in the middle and lower altitudinal ranges.

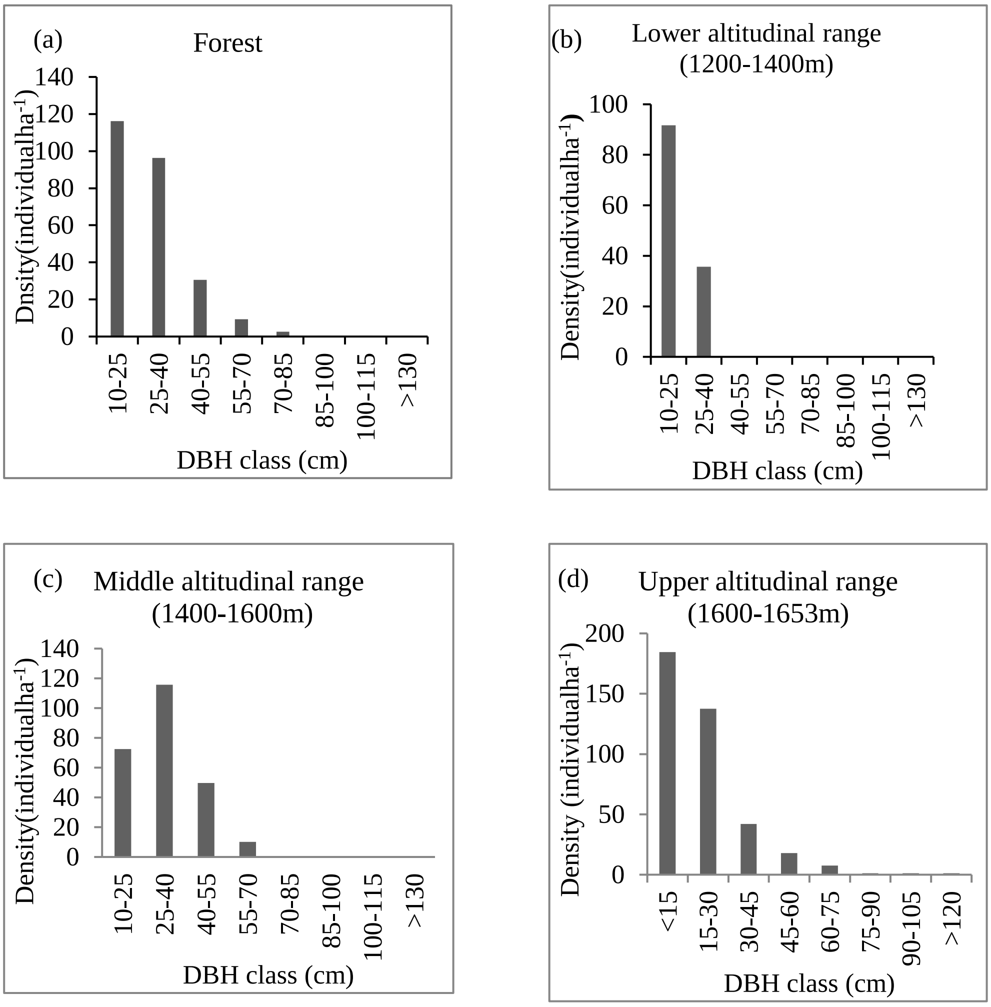


Figure 4.8. DBH size class distribution of *R. arboreum* in the study area; (a) In overall forest, (b) Lower altitude range, Middle altitude range, (c) Middle altitude range, (d) Upper altitude range

4.3.3 Height Class Distribution of *R. arboreum*

The height class distribution of *R. arboreum* shows an inverted J-shaped distribution (Figure 4.9) with little deviation in the upper altitudinal range (1600-1653m). The highest numbers of individuals were found in the low height class, with gradual decreases toward the high height classes. This represents healthier population dynamics of vegetation in the study area. The result showed that the height of *R. arboreum* trees with a smaller height were denser in upper altitudinal range (1600-1653m) in comparison to the lower and middle altitudinal ranges, the density of trees within the tree height range of 4 to 8m was highest (329.64 individualha^{-1}) in upper altitudinal range compared to middle (156.55 individualha^{-1}) and lower altitudinal range (119.64 individualha^{-1}). Trees with a height of 1-4m were completely absent in lower and middle altitudinal ranges.

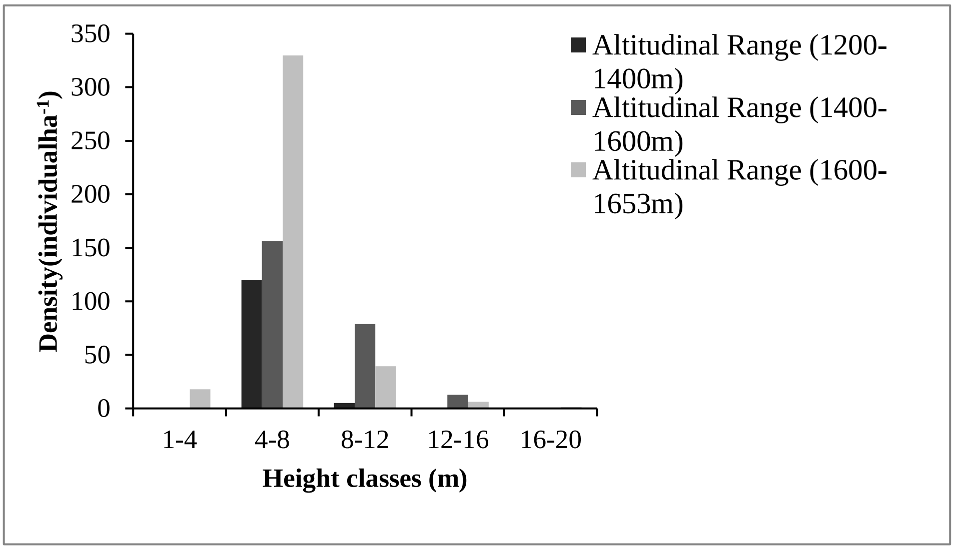


Figure 4.9. Density of *R. arboreum* with different height classes in different altitudinal ranges

4.4 Regeneration Pattern

4.4.1 Regeneration Patterns of Tree Species

The regeneration pattern of tree species in different altitudinal ranges within the forest is shown in Figure 4.10. The highest numbers of well-regenerating tree species were recorded in lower (1200–1400m) and middle (1400–1600m) altitudinal ranges where, the number was lowest in upper altitudinal range (1600-1653m). In all three altitudinal range, *Rhododendron arboreum* showed the highest regeneration as compared to other associated species (*C. indica*, *S. wallichi M. esculenta*, and *L. ovalifolia*).

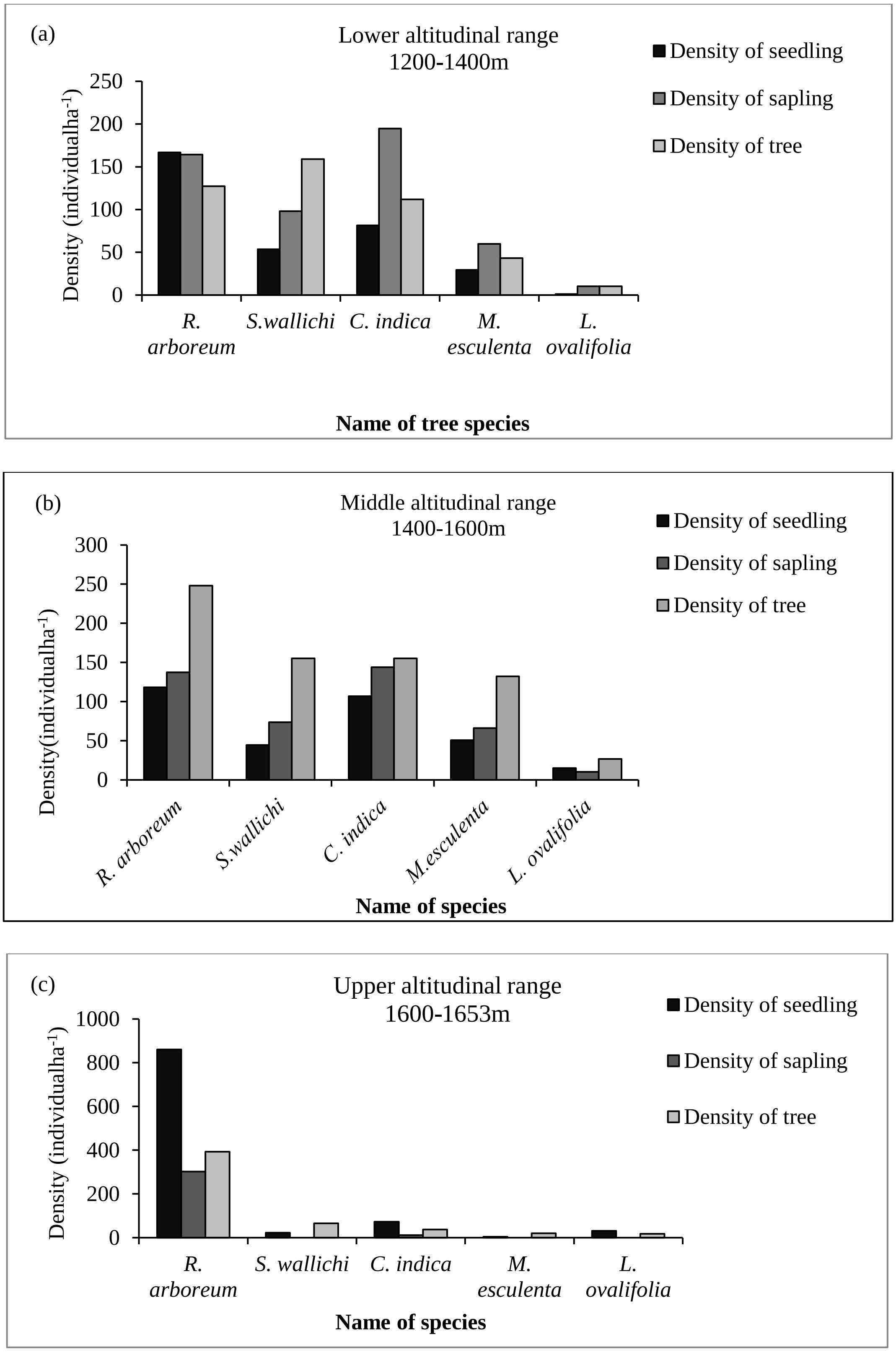


Figure 4.10. Distribution of trees, saplings, and seedlings along the different altitudinal ranges

The differences in different life stages (tree, sapling, and seedling) of *R. arboreum* in three different altitudinal ranges were checked by performing one - way ANOVA test. The density of all trees (399.64 individualha^{-1}), saplings (384.37 individualha^{-1}) and seedlings (860.38 individualha^{-1}) was found to be higher in the upper altitudinal range. In the middle altitudinal range, the density of trees was 248.19 individualha^{-1}, saplings and seedlings had 137.46 individualha^{-1}and 118.37 individualha^{-1} respectively. The density of life stages was found to be lower in lower altitudinal range, i.e., about 124.73 individualha^{-1} of tree, 175.64 individualha^{-1} of sapling and 166.73 individualha^{-1}of seedling (Table 4.3).

Table 4.3. Variation in density of different life stages of *R. arboreum* among altitudes

Altitude (m)	**Tree density** (individualha^{-1})	**Sapling density** (individualha^{-1})	**Seedling density** (individualha^{-1})
Lower altitudinal range (1200-1400m)	124.73^{a}	175.64^{b}	166.73^{c}
Middle altitudinal range (1400-1600m)	248.19^{a}	137.46^{b}	118.37^{c}
Upper altitudinal range (1600-1653m)	399.64^{a}	384.37^{b}	860.38^{c}
F	24.549	2.025	6.881
P*	< 0.001	0.139	0.002

P values are based on one-way ANOVA. The values shared by the different alphabets in columns in superscript are significantly different.

One-way ANOVA analysis showed insignificant differences in sapling density between altitudes (P = 0.139). Similarly, there was a significant difference (P = 0.002) for seedlings and (P = < 0.001) for trees, along the altitude. Overall, life stages showed significant differences (P = 0.01) along with altitude.

4.4.2 Regeneration Status of *R. arboreum*

Figure 4.11 describes the regeneration status and variation in density (individualha^{-1}) of *R. arboreum* seedlings, saplings, and trees. The regeneration status of the forest was examined by comparing mature tree density with regenerating populations (seedlings and saplings) of species. The density of seedlings (860.38 individualha^{-1}) was high in upper altitudinal range, which shows fair (seedlings > or ≤ saplings ≤ adults) regeneration status. Regeneration status was good (seedlings > saplings > adults) in lower altitudinal range. Within the forest, the regeneration status of *Rhododendron arboreum* was found to be fair.

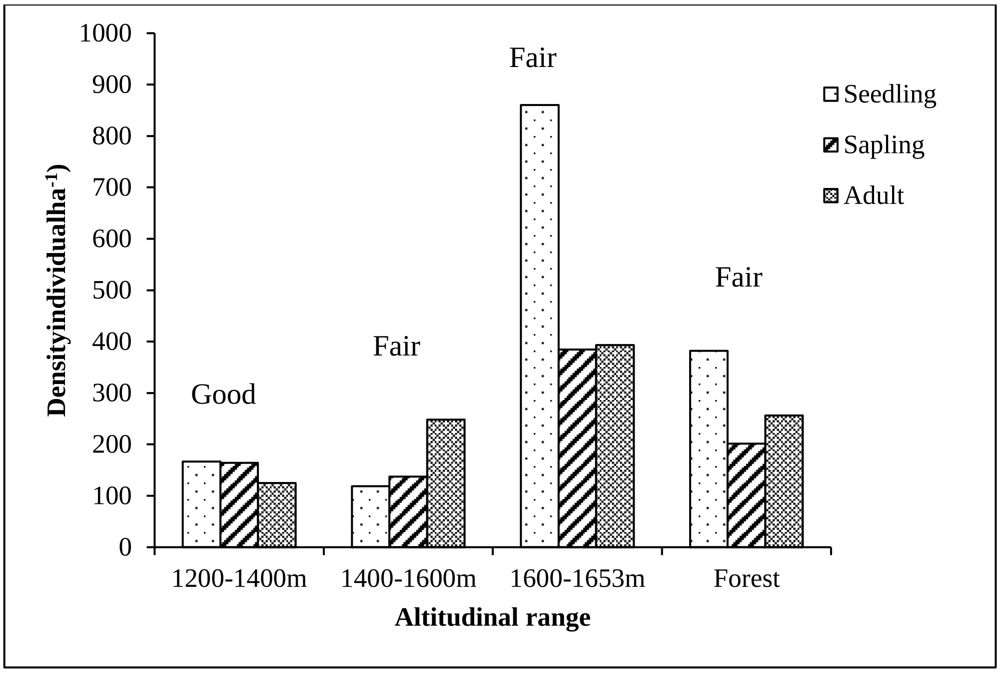


Figure 4.11. Variation in density (individualha^{-1}) of seedlings, saplings and trees and regeneration status of *R. arboreum* in the Forest and in three altitudinal ranges.

4.4.2 Litter Weight and Depth Analysis

The weight and depth of litter were found to be higher in middle altitudinal range, with an average value of 11kg and 0.57m, respectively. The lowest average value was recorded in lower altitudinal range, i.e., litter weight of 5.70kg and litter depth of 0.42m (Figure 4.12).

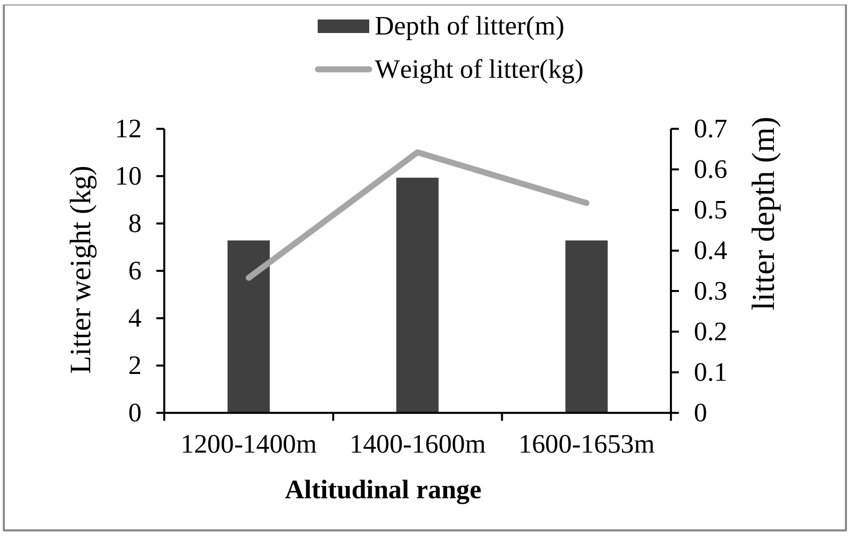


Figure 4.12. The weight (kg) and depth (m) of litter among three altitudinal ranges

4.4.3 Regeneration and Environmental Factor

The chemical properties of the forest soil were tested in laboratory and major soil properties along with the studied altitudinal ranges are shown in Figure 4.13 and 4.14.

The soil pH of a forest was found to be acidic with an average value of 6.35. Among three studied altitudinal ranges, the lower altitudinal range had pH value of 6.58, whereas the middle altitudinal range and upper altitudinal range had pH value of 6.24. The soil pH value has decreased with increasing altitude, which showed negative correlation with altitude. However, the correlation test was found to be insignificant. The study area soil texture was discovered to be sandy loam, silty loam, sand clay loam, silty clay, and sandy clay. The soil texture of the lower altitudinal range was found to be sandy loam and silty loam. In middle altitudinal range, sandy clay loam and silty loam were found, and in the upper altitudinal range, sandy clay texture was found. The favorable soil texture for the growth of *R. arboreum* was sandy loam.

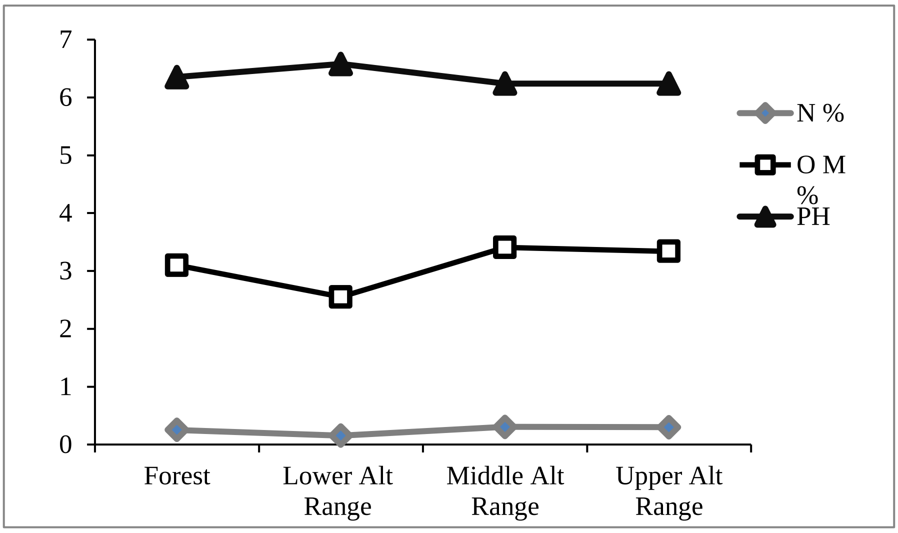


Figure 4.13. Soil pH, nitrogen (%), organic matter (%) of soil samples collected from three altitudinal range.

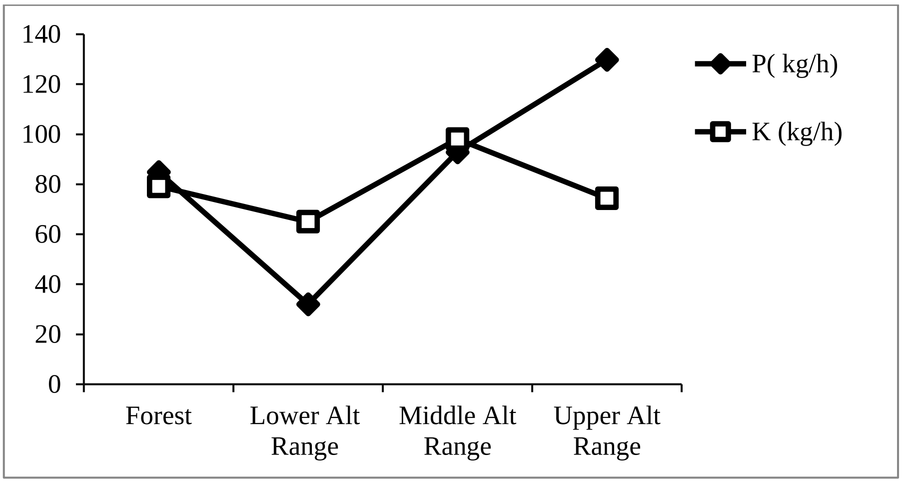


Figure 4.14. Phosphorus (kgha^{-1}), and potassium (kgha^{-1}) of soil samples collected from three altitudinal range.

The altitude, nitrogen, organic matter, phosphorus, potassium, seedling, sapling, adult (trees), canopy coverage, liter weight, and liter depth were negatively correlated with soil pH values. Among these, only nitrogen (N) and organic matter (OM) were found to be statistically significant, whereas the others were insignificant, as shown in Table 4.4.

The total organic matter contained in the soil ranged from 2.55% to 3.41%, available nitrogen from 0.15% to 0.31%, available phosphorus from 32 $kgha^{-1}$ to 129.84 $kgha^{-1}$ and available potassium from 65.02 to 98.12 $kgha^{-1}$. Altitude has a positive correlation with nitrogen, organic matter, phosphorus, potassium, seedlings, saplings, adults (trees), canopy coverage, litter weight, and litter depth except pH (Table 4.4). The correlation of altitude with P and ADT was significant at 0.05 and 0.01 levels of significance, respectively. Adults had a positive correlation with all parameters except pH, canopy cover, and litter depth. Seedling had positive correlation with all parameters except pH, potassium, canopy cover, and litter depth. The correlation of seedling with sapling was significant at 0.05 level.

Table 4.4. Correlation of seedling and sapling density with climatic as well as soil factors

	ALT	N	OM	pH	P	K	SED	SAP	ADT	CC	LITW
ALT	1										
N	0.888	1									
OM	0.872	0.999*	1								
pH	-0.904	-0.999*	-0.997*	1							
P	0.998*	0.913	0.898	-0.927	1						
K	0.352	0.743	0.766	-0.718	0.405	1					
SED	0.787	0.415	0.384	-0.449	0.751	-0.300	1				
SAP	0.727	0.329	0.297	-0.364	0.686	-0.387	0.996*	1			
ADT	0.991**	0.818	0.798	-0.839	0.982	0.223	0.863	0.813	1		
CC	0.070	0.522	0.550	-0.490	0.128	0.959	-0.559	-0.634	-0.064	1	
LITW	0.722	0.959	0.968	-0.948	0.761	0.902	0.142	0.050	0.622	0.741	1
LITD	0.010	0.470	0.499	-0.437	0.068	0.940	-0.608	-0.679	-0.124	0.998*	0.700

**correlation is significant at the 0.01 level.

*correlation is significant at the 0.05 level.

ALT=Altitude, N=Nitrogen, OM=Organic matter, pH= Potential of Hydrogen, P=Phosphorus, K=Potassium, SED=Seedling, SAP=Sapling, ADT=Adult, CC=Canopy coverage, LITW=Liter weight, LITD=Liter Depth

Sapling also had positive correlation with all parameters except pH, potassium, canopy cover and litter depth. Nitrogen had a positive correlation with all parameters except pH. Organic matter had a positive correlation with all parameters except pH. Organic matter had significant negative correlation with pH at 0.05 level. Potassium had positive correlation with all parameters except pH, seedling, and sapling. Canopy had a positive correlation with soil parameters (N, P, K, and OM), litter weight and depth. The canopy and litter weight correlation was significant at the 0.05 level, and the canopy had a negative correlation with soil pH, seedling, sapling, and adult. Litter depth had positive correlation with soil parameters (N, P, K, and OM), whereas litter depth had negative correlation with soil pH, seedling, sapling, and adult. Its weight had positive correlation with all parameters except pH.

CHAPTER 5

5. DISCUSSION

5.1 Vegetation Structure

The total population density of Rainaskot forest was found to be 612.60 individualha^{-1}. Slightly higher results were reported by Tiwari and Tiwari (2012) in the subtropical montane forests of India, where the total density value for tree species ranged from 619 - 687 individualha^{-1}. The current study found that total tree density (745.83 individualha^{-1}) was highest in the middle altitudinal range. This might be due to better association of *Rhododendron arboreum* with other tree species. A similar result was observed by Chauhan *et al*. (2017) in temperate broad-leaved forest of Uttarakhand, India, where maximum density was recored at Pharakhal site might be due to better association and combination of *R. arboreum*, *Quercus leucotrichophora*, *Myrica esculenta* etc. The lowest density (459.46 individualha^{-1}) was recorded in lower altitudinal range, might be due to the dominant tree being *Schima wallichi* in association with *R. arboreum*, so that species does not support other species. Population density of *R. arboreum* was found to be 257.52 individualha^{-1} in the forest. This result was more or less similar to population density value (344.70 individualha^{-1}) of *R. arboreum* reported by Sharma and Kala (2016) in Dhauladhar Mountain range of Himachal Pradesh, India. The density of *R. arboreum* was found to be less in lower altitudinal range. It was expected that vegetation destruction caused by human may impact on vegetation structure and distribution in low altitudinal area. Major disturbances like human settlement, cattle grazing, construction etc. were common in lower altitudinal area. Human mostly collected *R. arboreum* flower for different purposes like medicinal, beauty and aesthetic, juice and offering in worship.

The IVI value of tree species represents the dominance of species in a mixed forest, and it gives a clear picture of the social structure or ecological significance of species in a community. It is also useful to form an association of dominant species (Parthasarathy and Karthikeyan, 1997; Abunie and Dalle, 2018). In this study, it was found that *R. arboreum* was recorded with the highest IVI value, emerging as the dominant tree species in all altitudinal ranges except the low altitudinal range, which was followed by the associated tree species like *S. wallichi*, *Castanopsis indica*, *Myrica esculenta*, and *Lyonia ovalifolia* in the overall forest. The abundance and dominance of these species in the forest was considered as the establishment sign of early succession (Ghanbari and sefidi, 2020). In the present study, the total basal area of the forest was found to be 33.42 m^2ha^{-1}. Slightly lower value (31.8 m^2ha^{-1}) was reported by earlier study in subtropical forests of Eastern Himalayan Forest of Nepal (Carpenter and Zomer, 1996). The basal area of *R. arboreum* was relatively higher in upper altitudinal range that might be due to old growth forest of *R. arboreum* were reported. Gairola *et al*. (2011) also reported similar result for *Abies pindrow*, which had high basal area in the old growth forest in Grawhal Himalaya, India.

5.2 Species Richness and Diversity

In present study species richness gradually increased along with increase in altitude. This might be due to study was carried out in short range of middle altitudinal gradient i.e., 1200 m to 1653 m which is recognized as a part of a ‘‘humped’’ distribution curve. Similar result was reported by Brinkmann *et al*. (2009) in Jabal al Akhdar Mountain range of northern Oman. According to Fossa (2004) generally species richness gradually decreases with increasing altitude of vascular plant in mountain vegetation.

The species richness in Himalaya's increases from low altitude then reaches saturation at middle altitude and decline further up and forming a unimodal pattern (Baniya *et al*., 2010; Bhattarai *et al*., 2014). In this study statistically the tree species richness significantly varied among the three altitudinal ranges were observed. The highest species richness was recorded in upper altitudinal range. This result indicates greater diversity, and which leads to a higher community stability according to the study of MacArthur (1955). However, species richness alone is an incomplete representation of biological diversity, because it does not account for differences in species evenness. This statement was supported by Bock *et al*. (2007) who studied in southeastern Arizona, USA.

Diversity of species is an important feature of forest composition and structure, and its changes are widely used as an indicator of forest dynamics (Muhumuza and Byarugaba, 2009). In the present study, the values of the Simpson index decreased with increasing diversity, i.e., the highest in upper altitudinal range and the lowest in middle altitudinal range. This result was supported by Simpson (1949), which indicates the value of the Simpson index decreases with increasing diversity. The value of the Shannon-Weiner Index was ranges from 1.34 to 1.60, i.e., the highest in middle altitudinal range and the lowest in lower altitudinal range. Similar results were observed by Zhang and Shao (2015) in which altitude and slope position were the most important factors affecting species diversity and reported that the value of Shannon-Wiener index ranged from 1.129 to 2.114, Similarly, Paudyal (2015) also reported Shannon-Weiner Index values 1.676 in the subtropical forest of Central Nepal. The variation in diversity between the three different altitudinal ranges might be due to physiographic, climatic, and edaphic factors (Rosbakh *et al*., 2014). The lower diversity was found to be in upper altitudinal range this may be because of human disturbances as they cause the soil and water erosion and make the site poor in terms of resources (Lodhiyal *et al*., 2013). This altitudinal range also had the lowest value for evenness which shows that the species are not equally abundant. This might be due to a single species or a few species dominating (Sharma *et al*., 2018).

The highest index of similarity was recorded in altitudinal range (lower & upper and middle & upper) with more than 65% similarity. Chao *et al*. (2006) already reported that communities with less than 65% similarity are regarded as dissimilar. Higher similarities between the altitudinal ranges could be due to the similarity of the nutrients and the proximity of the stands to each other, which had almost similar habitat conditions in terms of edaphic conditions such as soil moisture, degree of erosion, organic matter, and nutrients to be created, a uniform habit (Khan *et al*., 2018). The lowest similarity was recorded between the lower and middle altitudinal ranges. This might be due to change in altitude, landscape, edaphic conditions such as erosion, soil differences from silty to sandy loam, pH and biotic factors (Shah *et al*., 1991; Malik and Hussain, 2008; Badshah *et al*., 2010; Khan *et al*., 2016).

5.3 Population Structure of Dominant Tree Species

The population structure of selected tree species (*Rhododendron arboreum*, *Castanopsis indica*, *Schima wallichi* and *Myrica esculenta*) with the highest IVI value showed a reverse J-shaped DBH-density distribution curve with higher density in the lower DBH class (10-25) and a gradual decrease in the higher classes. The reverse J-shaped population curve of tree species indicates an evolving or expanding population, a stable type of population in the forest ecosystem, suggests that the forest showed growing and healthy populations (Parthasarathy and Karthikeyan, 1997;

Mishra *et al*., 2005; Sahu *et al*., 2012). The basal area of all dominant species, i.e., *R. arboreum, C. indica, S. wallichi* and *M. esculenta* found to be the highest in DBH class (25-40cm) but their density of individuals was higher in DBH class (10-25cm) and *C. indica* had highest value of basal area in DBH class (55-70cm). Current results suggested that the nature of the plants not to grow to higher Basal area. This result also indicates that species with the highest basal area do not necessarily have the highest density, indicating size difference between species (Shibru and Balcha, 2004; Dereje, 2006). *C. indica* showed a little higher density of individuals in DBH class 55-70cm than in class 40-55cm. This might be due to the effect of disturbances on the density of individuals in DBH classes (Vetaas, 2002). Similar result was observed by Neelo *et al*. (2013) in dry woodlands adjacent to Molapo Farms in Northern Botswana, according to them pole-sized and mature individuals may have been cut by the local people for various purposes.

5.3.1 Population Structure of *R. arboreum*

The population structure of *Rhododendron arboreum* in the forest showed reverse J-shaped DBH-density distribution curves. A similar result was observed by Khadka (2013) in the Manaslu conservation area of Nepal. The reverse J-shaped population curve of trees suggests that the population structure was stable with good regeneration (Tesafye *et al*., 2010; Malik and Bhatt, 2016). Looking towards the altitudinal ranges wise d-d curve, in overall forest and upper altitudinal range showed reverse J-shaped d-d curve, whereas in middle altitudinal range had little higher density of individuals in DBH class 25-40cm than 10-25cm, this might be due to disturbance in this DBH class and the disturbance could be anthropogenic activities such as firewood extraction, grazing, charcoal burning, removal of poles for construction and cottage industries (Neelo *et al*., 2013; Sarkar and Devi, 2014). In altitudinal range, the number of individuals were present only in two DBH classes i.e., 10-25cm and 25-40cm, in higher DBH classes number of *R. arboreum* was completely absent this might be due to disturbance in the forest. The lower altitudinal range was near to the human settlement, so people collected firewood from the nearest area and also grazed.

5.3.2 Height Class Distribution of *R. arboreum*

The height class distribution of *R. arboreum* was found to be the highest number of individuals at class 4-8m in all altitudinal ranges and declined toward the highest height classes which, suggests the dominance of small sized individuals in the forest (Tesfaye *et al*., 2002). Endris *et al*. (2017) reported similar results in the Hallideghie wildlife reserve of Northeast Ethiopia and reported that this could be due to high rate of regeneration and/or high rate of mortality in large-sized individual, which was also characteristics of the stable size distribution common in natural forests. Similarly, Girma *et al*. (2015) observed the lowest number of individuals at higher height classes might be due to removal of trees caused by anthropogenic disturbances such as illegal logging and charcoal burning in Nandi Forest of western Kenya.

5.4 Regeneration Pattern

The highest number of well-regenerating species was recorded in lower altitudinal range (1200-1400m) and middle altitudinal range (1400-1600m), whereas the lowest was in upper altitudinal range (1600-1653m). This variation in regeneration might be due to a significant difference in associated species density, which was higher in low and middle altitudinal ranges but lower in upper altitudinal range. The density of seedlings and saplings of *R. arboreum* was found to be higher in lower and upper altitudinal range. This might be due to availability of enough light through open canopy and nutrient availability, whereas it was lowest in middle altitudinal range with more adults than the young which might be due to dense canopy in forests, the light becomes a limiting factor (Sharma, 2016; Paul *et al*., 2019). Similar result was reported by Pokhriyal *et al*. (2010) in Garhwal Himalaya, India, They reported the forest having good canopy cover may have affected the survival of seedlings under good canopy. In upper altitudinal range density of sapling was lower than seedlings and adults. Current results could impacts on developing stages of saplings before reaching the canopy level. Shrestha (2003) also reported similar results for *Quercus semecarpifolia* in the Himalayan region of Nepal. The *R. arboreum* had the highest total seedling density (860.71 individualha^{-1}) in upper altitudinal range compared to the middle and lower altitudinal ranges. The similar density of *R. arboreum* was recorded by Chauhan *et al*. (2017) in the Garhwal Himalaya, Uttarakhand, India, they found that seedling density of *R. arboreum* was 900 individualha^{-1}. It was observed that maximum sapling density of *R. arboreum* was 302.91 individualha^{-1} from upper altitudinal range. The highest density of seedlings and saplings were reported in upper altitudinal range that might be because of maximum seed-bearing trees in this altitudinal range, which was encouraging the regeneration and producing more seedlings and saplings (Chauhan *et al*., 2017).

5.4.1 Regeneration Status of *R. arboreum*

Regeneration profile can be presented by the pattern of population dynamics of seedlings, saplings, and trees of plant species, which is useful in determining their regeneration status (Malik and Bhatt, 2016). The present study showed that regeneration status of *Rhododendron arboreum* was fair in whole forest. In altitudinal ranges wise study all the altitudinal ranges showed fair regeneration status except of lower altitudinal range which showed good regeneration. Similar regeneration status was reported by Paul *et al*. (2019) in the temperate mixed broad-leaved forest of western Arunachal Pradesh, India, Where they reported population structure and regeneration status of *Rhododendron* tree species. About 77% of the species demonstrated fair regeneration, 8% of the species indicated good regeneration, and 15% of the species displayed no regeneration. Bharali (2012) also reported fair regeneration of *Rhododendron* species in all the study stands, with a higher number of seedlings compared to saplings, in the temperate broad-leaved forest of Arunachal Pradesh, India. *R. arboreum* had a good number of seedlings and saplings in all three altitudinal range, these results might suggest the number of seedling and sapling represent the dominant species along each altitudinal range in the forest (Khadka, 2013).

5.5 Soil Analysis

The findings of this study suggested that the soil pH of forest was found to be acidic with average value 6.35. The similar result with pH value ranged from (6.33-6.47) was reported by Kumar *et al*. (2006), in subtropical forest of the Garhwal Himalaya. *R. arboreum* prefer acidic soil and sandy loam soil texture for its growth. This result was supported by Pathak *et al*. (2021) studied on *Rhododendron arboreum* propagation through seeds cultivation in Nawalparasi District. Karki *et al*. (2018) studied on an analysis of hydraulic properties of soil in Chiti areas of Lamjung District, and they reported pH value was ranges from 4.69 to 6.69. The pH range of 5.5 to 6.5 provide the most satisfactory plant nutrient and is the best for most plants (Brady and Well, 1984).

The lowest value of organic matter was found to be in lower altitudinal range that might be due to anthropogenic disturbances. According to Srivastav and Singh (1989), in dry tropical forest of India, the clearing of natural vegetation and intensive cultivation causes an enormous loss of organic matter from the soil. The higher organic matter content was found in middle altitudinal range this might be due to the presence of matured forest stands with closed canopy, which facilitated rapid decomposition, and checked soil moisture. Similar result was reported by Kunwar *et al*. (2008) in *Castanopsis hystrix* forests (CH) eastern Nepal. The density of seedlings sapling of *R. arboreum* found to be lower in middle altitudinal range this might be due to the stands with high organic matter associated with poor regeneration (Seth and Bhatnagar, 1959), ultimately reduce species richness.

There was positive correlation of organic matter with nitrogen which was statistically significant. This result was similar with the finding of Kunwar *et al*. (2008) in *Castanopsis hystrix* forests (CH) of eastern Nepal and Gupta *et al*. (1989) in Dhankuta Nepal. The value of nitrogen ranges from (2.55 - 3.41%) which is similar with the value range (0.281 - 0.438 %) reported by Kunwar *et al*. (2008). Higher level of nitrogen was reported in middle altitudinal range might be due to the presence of close tree canopy combined with dense forest. Similarly, highest value of phosphorus was reported in upper altitudinal range which was with good plant regeneration and species richness. Bhatnagar (1965) also observed higher Phosphorus in good regeneration areas. The value of potassium also found to be highest in middle altitudinal range which might be due to higher organic matter and its input from the tree cover. Similar result was reported by Malla *et al*. (2001) in community forest at Kabhrepalanchok District, Nepal.

The seedling, sapling and adult density were positively correlated with the nutrients such as nitrogen (N), phosphorus (P) and organic matter (OM). Whereas canopy cover had negative correlation with seedling, sapling, adult, and soil pH. Although soil nutrients were found to be higher in middle altitudinal range, which was favorable for plant growth and development, but middle altitudinal range had lowest regeneration compared to lower and upper altitudinal ranges. This might be due to the closed canopy in middle altitudinal range. Bharali (2012) in the temperate broad-leaved forest of Arunachal Pradesh, India, recorded the very few *Rhododendron* seedlings beneath the canopy, but they were abundant in open places. Koirala (2004) in Tinjure-Milke region, east Nepal, also reported that an open canopy caused by mild disturbance to the forest allows the growth of seedlings and saplings, which ensures sustainable regeneration. Litter depth had negative correlation with soil pH, seedlings, saplings, and adults. The litter weight and litter depth were found to be higher in middle altitudinal range this might be due to dense forest with closed canopy. Inadequate light intensity, closed canopy, quality, and thickness of litter generally reduces the establishment of seedlings and saplings in the forest (Facelli and pickett, 1991; Shrestha, 2003; Paul *et al*., 2019)

CHAPTER 6

6. CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

The present study encountered altogether 13 tree species from 11 families. The forest was mixed forest of *Rhododendron arboreum*, *Schima wallichi*, *Castanopsis indica*, *Myrica esculenta* and *Lyonia ovalifolia*, with some other tree species.

1. *R. arboreum* was found to be dominant tree in middle and upper altitudinal range but in lower altitudinal range *S. wallichi* was the dominant tree. Tree species richness increased with increasing altitude whereas species diversity was found to be higher in middle altitudinal range this might be due to species richness alone is an incomplete representation of biological diversity, because it does not account for differences in species evenness.
2. The population structure of *Rhododendron arboreum* and associated tree species (*Castanopsis indica*, *Schima wallichi* and *Myrica esculenta*) with the highest IVI value showed a reverse J-shaped DBH-density distribution curve with higher density in the lower DBH class (10-25cm) and a gradual decrease in the higher classes. In lower altitudinal range, the number of individuals of *R. arboreum* were present only in two DBH classes(10-25cm, 25-40cm),in higher DBH classes number of individuals were completely absent.
3. The highest number of well-regenerating tree species was recorded in lower and middle altitudinal ranges, whereas the lowest was in upper altitudinal range. The seedlings population in all three altitudinal ranges was dominated by *R. arboreum.* The regeneration status of *R. arboreum* was fair, with a higher number of seedlings compared to saplings in the overall forest and also in the middle and upper altitudinal range. But in the lower altitudinal range, regeneration status was found to be good (seedlings > saplings > adults).
4. The soil of the forest was found to be acidic; the soil pH is decrease with increasing altitude. The seedlings, saplings and adults density were positively correlated with the nutrients such as nitrogen, phosphorus and organic matter except pH, potassium, canopy cover.

5. The weight and depth of litter were found to be higher in middle altitudinal range. Seedlings, saplings and adults density were positively correlated with litter weight but negative with litter depth.

6.2 Recommendation

Rhododendron arboreum has multispectral uses and significant to the nature and human beings. So, its population structure and regeneration pattern reveal the future scenario of *R. arboreum* in the Rainaskot Forest. Rainaskot is being developed as a historical, cultural and tourism hub more in recent year. The forest with *R. arboreum* glorifies its natural beauty especially in flowering season. It is necessary to preserve the natural habitat and diversity of Rainaskot Forest. On the basis of this present study the following recommendations are made for the perseveration of *R. arboreum* and natural habitat of entire forest.

- In lower altitudinal range, seasonal grazing by cattle and human attraction on *Rhododendron arboreum* forest are main causes of forest destruction and encroachments. Thus, it should be controlled.
- In upper altitudinal range, there were good numbers of seedling and sapling but due to human encroachment, tree density was not adequate. So, this range should be managed properly for the preservation of *R. arboreum* forest.

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ANNEXES

Annex I. Temperature and rainfall data for Khudi Bazzar station from 1990 to 2020 A.D (Source: Department of Hydrology and Meteorology, Government of Nepal)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Rainfall (mm)	290.0	271.4	222.3	271.8	266.1	286.0	370.5	277.2	295.8	286.3	295.4	261.7
Temp (° C)	21.3	21.1	21.2	22.0	21.5	22.2	21.9	20.1	21.8	22.7	20.7	22.0
Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Rainfall (mm)	275.4	323.3	326.9	282.0	237.2	281.1	303.2	220.1	273.4	278.2	258.3	222.4
Temp (° C)	21.8	21.4	20.9	21.8	22.2	21.7	21.0	21.1	22.3	21.3	21.7	22.1
Year	2014	2015	2016	2017	2018	2019	2020					
Rainfall (mm)	258.8	189.9	313.1	296.0	284.6	244.3	388.2					
Temp (° C)	23.3	23.8	21.7	21.6	20.0	21.5	21.2					
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
T_{max} (° C)	21.8	24.3	28.6	30.4	32.0	31.8	31.3	31.8	30.1	27.4	23.7	20.0
T_{min} (° C)	7.6	10.6	13.9	15.7	18.5	22.4	22.1	20.6	17.5	12.4	8.8	6.0
Rainfall (mm)	29.4	47.9	84.7	113.7	224.4	547.0	861.2	815.7	477.4	82.4	8.3	13.3
Temp=Temperature, T_{max}= Maximum Temperature and T_{min}=Minimum Temperature												

Annex II. Important Value Index (IVI*) R. arboreum* and associated species Tree Species in the forest

S. N	Name of species	Family	Density (Stemha^{-1})	Basal Area(m^2)	IVI
In lower altitudinal range (1200-1400m)					
1	*Schima wallichi* (DC.) Korth.	Ericaceae	159.09	0.03	77.56
2	*Rhododendron arboreum* Sm.	Theaceae	124.73	0.033	68.11
3	*Castanopsis indica* (roxb.ex Lindl).A. DC	Fagaceae	112	0.024	60.92
4	*Myrica esculenta* Buch. Ham.ex D.Don	Myricaceae,	43.27	0.018	35.97
5	*Albizia lebbek* (L.)	Fabaceae	2.55	0.047	27.51
6	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae	10.18	0.02	16.03
7	*Madhuca longifolia* var.latifolia	Sapotaceae	5.09	0.018	13.95
In middle altitudinal range (1400-1600 m)					

S. N	Name of species	Family	Density (Stemha^{-1})	Basal Area(m^2)	IVI
1	*Rhododendron arboreum* Sm.	Ericaceae	248.19	0.079	70.02
2	*Castanopsis indica* (roxb.ex Lindl).A. DC.	Fagaceae	155.28	0.124	63.77
3	*Schima wallichi* (DC.) Korth.	Theaceae	155.28	0.079	58.43
4	Myrica esculenta Buch. Ham.ex D.Don	Myricaceae,	132.37	0.039	45.73
5	*Lyonia ovalifolia* (Wall.)Drude	Ericaceae	26.73	0.033	17.06
6	*Mallotus tetracoccus(*Roxb.), Kurz.	Euphorbiaceae	16.55	0.029	14.01
7	*Falconeria insignis* Royle.	Euphorbiaceae	2.55	0.057	12.45
8	*Phyllanthus emblica* Linn,	Phyllanthaceae	1.27	0.053	11.46
9	*Litsea doshia*	Lauraceae	7.64	0.021	7.7
In upper altitudinal range(1600-1653m)					
1	*Rhododendron arboreum* Sm.	Ericaceae	393.27	0.064	105.52
2	*Schima wallichi* (DC.) Korth.	Theaceae	66.18	0.04	33.2
3	*Castanopsis indica* (roxb.ex Lindl).A. DC.	Fagaceae	36.91	0.044	28.35
4	*Mallotus tetracoccus(*Roxb.), Kurz.	Euphorbiaceae	36.91	0.03	22.87
5	Myrica esculenta Buch. Ham.ex D.Don	Myricaceae,	20.36	0.04	21.41
6	*Alnus nepalensis D.Don*	Betulaceae	42	0.019	21.23
7	*Madhuca longifolia* var.latifolia	Sapotaceae	1.27	0.066	16.34
8	*Litsea doshia*	Lauraceae	14	0.033	15.47
9	*Luculia gratissima*(kaiyo)	Rubiaceae	2.55	0.042	12.11
10	*Albizia lebbek* (L.)	Fabaceae	1.27	0.045	11.61
11	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae	17.82	0.012	11.16
In Overall Forest (1200-1653 m)					
1	*Rhododendron arboreum* Sm.	Ericaceae	256.24	16.31	77.78
2	*Schima wallichi* (DC.) Korth.	Theaceae	126	6.31	50.57
3	*Castanopsis indica* (roxb.ex Lindl).A. DC.	Fagaceae	101.82	6.97	47.97
4	*Myrica esculenta* Buch. Ham.ex D.Don	Myricaceae,	65.33	2.2	33.14
5	*Mallotus tetracoccus (*Roxb.), Kurz.	Euphorbiaceae	17.82	0.53	13.94
6	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae	18.24	0.41	12.68
7	*Falconeria insignis* Royle.	Euphorbiaceae	0.85	0.05	11.08
8	*Phyllanthus emblica* Linn,	Phyllanthaceae	0.42	0.02	10.24
9	*Albizia lebbek* (L.)	Fabaceae	1.27	0.06	9.51
10	*Litsea doshia*	Lauraceae	7.21	0.21	9.22
11	*Alnus nepalensis* D.Don	Betulaceae	14	0.27	9.01
12	*Luculia gratissima*(kaiyo)	Rubiaceae	0.85	0.04	8.52
13	*Madhuca longifolia* var.latifolia	Sapotaceae	2.12	0.05	6.44

Annex III. Comparison of species richness among the different altitudinal ranges

Between Altitude	**Mean differences**	**Lower bound**	**Upper bound**	**Adjusted P-value**
1200-1400 &1400-1600	-0.8	-1.66	0.06	0.072
1200-1400 & 1600-1653	0.08	-0.78	0.94	0.973
1400-1600 & 1200-1400	0.8	-0.06	1.66	0.72
1400-1600 & 1600-1653	0.88*	0.2	1.74	0.042
1600-1653 & 1200-1400	-0.08	-0.94	0.78	0.973
1600-1653 & 1400-1600	-0.88*	-1.71	-0.02	0.042

*The mean difference is significant at the 0.05 level.
Altitude used as a factor and species richness as a response variable

Annex IV. Elevation wise frequency of *R. arboreum* based on life stages

S. N	**Elevation Range(m)**	**Frequency of Tree**	**Frequency of Sapling**	**Frequency of Seedling**
1	1200-1400	88	92	64
2	1400-1600	92	88	72
3	1600-1653	100	60	92
4	Forest	93.33	70.66	85.33

Annex V. Sorenson similarity index between different altitudinal ranges

S. N	**Altitudinal range**	**Sorenson similarity index**
1	Lower altitudinal range and Middle altitudinal range	62.50%
2	Lower altitudinal range and Upper Altitudinal range	77.70%
3	Middle altitudinal range and Upper altitudinal range	70%

Annex VI: Basal area of *R. arboreum* at different altitude and in whole forest

S. N	Altitudinal range (m)	Basal Area (m2/ ha)
1	1200-1400	4.2
2	1400-1600	19.85
3	1600-1653	26.74
4	Forest	16.4035

Annex VII. Selected field Photographs from the study area

 Rainaskot Forest viewing towards west	 *R. arboreum* tree at site
 A flower of *R. arboreum*	 DBH measuring at field
 Soil sampling at site	 Air drying of soil sample

Measuring tree height using clinometer

Weighing litter

Seedlings of *R. arboreum*

Sapling of *R. arboreum*