

VARIATION IN VEGETATION ALONG ALTITUDE AND ASPECTS IN WESTERN HIMALAYA

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis titled **“Variation in vegetation along altitude and aspects in western Himalaya”** submitted in partial fulfilment of the requirements for the award of degree of DOCTOR OF PHILOSOPHY (FORESTRY) in the discipline SILVICULTURE of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) 173 230 is a bonafide research work carried out by Ms. SONAM RAJPUT (F-2016-21-D) D/o Sh. Pramod Kumar Rajput under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE-II

This is to certify that the thesis titled, “**Variation in vegetation along altitude and aspects in western Himalaya**” submitted by Ms. Sonam Rajput (F 2016-21-D) to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) in partial fulfillment of the requirements for the award of degree of DOCTOR OF PHILOSOPHY SILVICULTURE has been approved by the Student’s Advisory Committee after an oral examination of the same in collaboration with the external examiner.

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Place: Nauni, Solan

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ABBREVIATIONS USED

%	:	Per cent
⁰ C	:	Degree Celsius
a.m.s.l	:	Above Sea Mean Level
AGB	:	Above Ground Biomass
Approx.	:	Approximately
BA	:	Basal Area
BD	:	Bulk Density
BEF	:	Biomass Expansion Factor
BGB	:	Below Ground Biomass
C ha ⁻¹	:	Carbon Per Hectare
C	:	Carbon
CD _{0.05}	:	Critical Difference at P = 0.05
CM	:	Centimeter
DBH	:	Diameter at Breast Height
e.g.	:	For Example
<i>et al.</i>	:	Co-Workers
etc	:	Etcetera
FCCC	:	Framework Convention on Climate Change
FSI	:	Forest Survey of India
g	:	Gram
ha	:	Hectare (10,000 m ²)
HB	:	Herb Biomass
i.e.	:	That is
ind.ha ⁻¹	:	Individual Per Hectare
IPCC	:	International Panel on Climate Change
IVI	:	Important Value Index
K	:	Potassium
kg	:	Kilogram
m	:	Meter
MAT	:	Mean Annual Temperature
mm	:	Millimeter
P	:	Phosphorus

pH	:	Puissance d' Hydrogen
pp.	:	Pages
ppm	:	Parts Per Million
RBA	:	Relative Basal Area
RD	:	Relative Density
RF	:	Relative Frequency
SB	:	Shrub Biomass
SOC	:	Soil organic carbon
Spp.	:	Species
SR	:	Species Richness
TB	:	Tree Biomass
TBA	:	Tree Basal Area
viz.	:	In Other Words

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Chapter-1

INTRODUCTION

The recorded forest area of Himachal Pradesh is 37,033 km² which constitute 66.52 per cent of the total geographical area (55,673 km²). The forest cover of the state based on satellite data (October-December, 2004) is 14,369 km², which constitute only 25.81 per cent of geographical area (Anonymous, 2005). Due to imposition of ban on green felling since 1985, the ecological significance of forest has increased to a greater extent (Nanda, 2005).

The managed forests are more productive than the unmanaged or mismanaged where the enhanced productivity advantages are gained through regulating the crop composition and structure. The growth, harvest and changing environment modifies the forest structure, composition and function. To illustrate, the basal area increment in young trees increase until their maximum usable growing space is reached (Assmann, 1970). However, Indian forests are neither uniformly stocked nor equitably distributed and only about 50 per cent of total area is having good forests with crown density of 40 per cent or above (Reddy *et al.* 2001).

Regeneration is the key feature of the forest dynamics, progress and restoration of degraded forest land. It depends on number of seedling, sapling and their distribution pattern in region. The Himalayan embodies diverse and characteristic vegetation distribution over a wide range of topographical variation. In the distant past, except for the high altitude mountain ranges, the entire Himalayan were covered within altitudes the cofactors like topography, aspect, and soil type effect of the forest composition. The Forest of mid hill zone of western Himalayan temperate region consists of Oak Forest, Moist deodar Forest, Western mixed coniferous Forest. Opposing slopes vary in their microclimate, especially the light intensity, soil and temperature, humidity, soil moisture and evaporation that these differences are closely associated with differences in vegetation composition and structure.

Regeneration of any species is confined to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution. The population structure of a species in a forest can convey its regeneration behaviour. The population structure, characterized by the presence of sufficient population of seedlings, saplings and adults, indicates successful regeneration of forest species, and the presence of saplings under the canopies of adult trees also indicate the future composition of a

community. Regeneration status of trees can be predicted by the age structure of their populations. Regeneration of a particular species is poor if seedlings and saplings are much less than the mature trees. The study of regeneration of forest trees has important implications for the management of natural forests, and is one of the thrust areas of forestry. Regeneration is the process of silvigenesis by which trees and forests survive over time. Research in this field contributes to planning, conservation and decision making in forest resources management programmes.

Altitude and aspects play an additional role in determining the temperature regime and atmospheric pressure of any site and as such within one altitude; the cofactors, like topography, aspect, inclination of slope and soil type affect the forest composition (Shank and Noorie 1950) and as well as the species richness and their dispersion behaviour (Ellu and Obua 2005). The distribution of species and their richness pattern are also largely regulated by physiographic factors (Sharma *et al.* 2009a, 2009b). This type of ecological knowledge can prove to be fundamental for conservation and sustainable utilization of forests, and may help policy makers for drafting management plans for fragile mountain ecosystems.

The pattern of biodiversity along altitudinal gradients is a well-dominated ecological phenomenon. Community composition and structure are important factors affecting diversity patterns in plant communities. Furthermore, species diversity along altitudinal gradient differs in different layers at different scales. The organization of biodiversity across space and time has long been a central concern of ecologists and bio-geographers (Brown and Lomolino 1998, Field *et al.* 2009).

A hill slope largely depends on the direction on the different types of aspects. Southerly aspects are comparatively warmer than the northern aspects. It often results in having different vegetation at higher altitudinal ranges on opposite aspects. Thus, the two slopes of the same valley running east to west may have deodar forest on the slope having southern aspects and fir spruce forest on the slope having northern aspects even when the altitude is the same. The Himalayan species grow on altitude lower than their normal range on cooler northern aspect and above the normal range on warmer southern aspect. So due to altitudinal variation and different aspects, the species composition and density varies from one altitudinal range to another altitudinal range. The biomass and carbon density of the forest area of a particular altitudinal range is different from another range (Anonymous, 1999).

Aspects of the form and structure of vegetation have always been used to identify and describe vegetation, as with deserts and rainforest. Within these groups floristic have generally been used to increase the differentiation between different forms of vegetation. The identifiers are often genera, as with eucalypt and acacia woodlands. However, the identifiers can also be other forms of species assemblages, such as softwood and hardwood forest.

Elevation, aspect, and slope are the three main topographic factors that control the distribution and pattern of vegetation in mountain areas (Titshall *et al.* 2000). Among these three factors, elevation is most important (Day and Monk 1974, Busing *et al.* 1992). Elevation along with aspect and slope in many respects determine the microclimate and thus large-scale spatial distribution and pattern of vegetation (Geiger 1966, Allen and Peet 1990).

Crown development is a major phenomenon of forest productivity and dynamics of both individual tree and stand level. General structural pattern of crown development such as ex-current or de-current branching are under genetic control and are determined by relative growth rates of branches in various positions of the crown. Tree crown development is also adaptive to environmental conditions such as light quality and growing space limitations. The canopy density alters the functions and services of the stand over a period of time, which regulates and determines the composition and structure of the stand. This also plays an important role in ground cover conditions, soil and water conservation, microclimate, fire spread, extent of wind damage, protection to young seedlings and photosynthetic ability of sub-layered species.

Soils are the productive potential of forests. Soil fertility, the ability of the soil to provide plants with the nutrients they require, is a complex phenomenon. It is determined by soil chemistry, organic matter content, aeration, microbial activity and temperature. All these variables interact and influence each related to the balance of different nutrients and to their rate of circulation within the ecosystem, than to the absolute levels of nutrients in the soil.

Solan District of the state falls under I and II zones, which include low and mid hill region. The District is situated between 76°42' to 72° 20' East longitude and 30° 30' to 30° 15' North latitude, with the geographical area of about 1936 km². This comprises of five development blocks viz., Nalagrah, Dharmpur, Solan, Kandaghat and Kunihar. Although, a number of micro-farming situation are being experienced in the district, in the recent studies carried out by Krishi Vigyan Kendra the district has been divided in to two major agro-

climatic zones viz., sub-tropical, sub-mountain and low hills as well as sub-temperate, sub-humid mid hills.

Kandaghat tehsil in the Solan district of Himachal Pradesh (India) is situated on the Kalka-Shimla National Highway No. 22. It is situated between 30.970⁰N latitude and 77.1054⁰E longitude. The recorded forest area of Kandaghat is 786.4 ha which constitute 366 ha reserved forest. Its slopes vary considerably and are generally moderate to slightly steep except in Karol tibba. The climate of the Kandaghat is moist and cool. The seasons are well marked with distinct summer, rainy, autumn and winter seasons. The minimum temperature goes down below -2⁰ C in high places during winter season and the maximum temperature exceeds 33⁰C in lower places during summer season. The highest peak in this area is Karol tibba. The major tree species of Kandaghat forest range are chirpine, ban oak and deodar along with toona, bihul etc.

This study is an attempt to understand the regeneration status and biomass production potential along altitudinal ranges and aspects at the Kandaghat hill. Vegetation plays an important role in soil formation. Plant tissues (from above ground litter and below ground root detritus) are the main source of soil organic matter, which influence physiochemical characteristics of soil (Johnston, 1986).

The present investigation entitled “**Variation in vegetation along altitude and aspects in western Himalaya**” was taken up with the following objectives:

OBJECTIVES:

- i) To study the phytosociological behaviour of vegetation and regeneration status of tree species at different altitudinal ranges and aspects.
- ii) To study the biomass production and carbon stock of vegetation at different altitudinal ranges and aspects.
- iii) To study the soil properties at different altitudinal ranges and aspects.

Chapter-2

REVIEW OF LITERATURE

In this chapter, the relevant information related to the present study entitled “**Variation in vegetation along altitude and aspects in western Himalaya**” has been reviewed under the following heads:

- 2.1 Phytosociological behaviour of vegetation and Regeneration status
- 2.2 Biomass and Carbon stock
- 2.3 Soil properties

2.1 Phytosociological behaviour of vegetation

Phytosociology is relates to the phenomenon of vegetation, and needs to be examined in a statistical framework from the very beginning. Statistical techniques in vegetation ecology e.g., multivariate statistical analyses, have emerged in the last few decades. In community ecology, multivariate analysis helps ecologists to discover structure in the data set and helps them to analyze the effects of environmental factors on whole groups of species (Clymo, 1980; Bergmeier, 2002; Anderson *et al.* 2006).

Floristic composition is a measure of species diversity in a community. Before diversity can be measured it is essential that we define precisely the collection of species that comprises a community. It is one of the fundamental prerequisites to classify the flora into different systematic types of any ecosystem e.g. forest, agriculture, rangeland, etc. It is long term process to give clear cut information on floristic composition of an area, as it is liable to change with season as well as the effect of biotic factors and their interactions in any community (Whittaker, 1970). The degree of diversity depends upon the adaptability of the species, micro climate and prevailing biotic factors.

In the mountainous regions, altitude has greater effect on temperature than latitude and the rate of decrease is much more rapid in summer than in winter that ultimately cause the altitudinal zonation of vegetation (Heaney, 1989; Tanner *et al.* 1998; Givnish, 1999). Precipitations and redistribution of water that decrease with the increase in altitude associated with low temperature are the main factors that control vegetation succession and existence in those mountains (Peer *et al.* 2007)

Dar and Sundarapandian (2016) suggested that biodiversity patterns of plant diversity in seven temperate forest types of Western Himalaya, India. They were analyzed Plant biodiversity patterns in seven temperate forest types [*Populus deltoids*, *Juglans regia*, *Cedrus deodara*, *Pinus wallichiana*, *mixed coniferous*, *Abies pindrow* and *Betula utilis*]. A total of 177 plant species (158 genera and 66 families) were recorded. Most of the species were herbs (82.5 per cent), while shrubs account for 9.6 per cent and trees represent 7.9 per cent. Species richness ranged from 24 (*Populus deltoids*) to 96 (*Abies pindrow*). Shannon, Simpson, and Fisher α indices varied: 0.17-1.06, 0.46-1.22, and 2.01-2.84 for trees, 0.36-0.94, 0.43-0.75, and 0.08-0.35 for shrubs, and 0.35-1.41, 0.27-0.95, and 5.61-39.98 for herbs respectively. The total stems and basal area of trees were 35,794 stems (stand mean 330 stem/ha) and 481.1 m² (stand mean 40.2m²/ha), respectively. The mean density and basal area ranged from 103 stem/ha (*Betula utilis*) to 1,201 stem/ha (*Populus deltoids*), and from 19.4m²/ha (*Betula utilis*) to 51.9m²/ha (*Abies pindrow*) respectively. Tree density decreased with increase in diameter class. Tree and shrub communities were homogenous in nature across the seven forest types, while herbs showed heterogeneous distribution pattern.

Kumar (2016) studied the floristic composition of Agrakhal-Kunjapuri area of District Tehri Garhwal, Uttarkhand, India. The area lies at the elevation from 1300 to 1800m in the montane zone of Garhwal Himalaya and is covered with dense oak forest. The plant diversity of the study area consisted of 439 species of angiosperms (343 dicots and 96 monocots) belonging to 293 genera (218 of dicots and 75 monocots) and 84 families (71 of dicots and 13 of monocots). *Pinus roxburghii* and *Cedrus deodara* represented the gymnospermous group. Among Pteridophytes 14 species belong to ferns and one to fern-allies. The minimum diversity on south and south-west slopes might be attributed to drier condition. South-east slope had the highest diversity because it consisted of scattered woody vegetation which caused the development of more herbaceous species.

Khail and Bhatt (2014) studied the community structure and effect of altitudinal gradient on structure and composition of the vegetation in Garhwal Himalaya, India. The study area was categorized into four forest types on the basis of vegetation analysis, plant association or plant composition surveys, viz., chir-pine forest, pine-oak forest, oak-pine forest and oak mixed forest. In the floristic study, a total of 58 species were recorded (58 plant species, 21 trees, 11 shrubs and 26 herbs).

Mandal and Joshi (2014) analyzed the vegetation dynamics and plant diversity from the dry deciduous forests of Doon Valley, *Shorea robusta* was as noticed the main dominant species, and *Mallotus philippensis*, *Syzygium cuminii*, and *Ehretia laevis* as the codominant tree species in all communities. The highest species richness and diversity rates were found to be increased with the decrease in the tree density and basal area, the high Importance Value Index in Thano (>150) indicated that the *Shorea robusta* forest is progressing toward the culmination stage, whereas the lower IVI values (100 and 150) in the other two sites (Selaqui – Jhajra and Asarori) signify the heavy disturbance on these sites and further establishment of alien invasive species such as *Cassia tora*, *Cassia occidentalis*, *Lantana camara*, *Urena lobata*, *Ipomoea carnea*, *Sida acuta*, and *Solanum torvum*.

Sharma and Raina (2013) studied the composition, structure and diversity of tree species along an elevational gradient in north-western Himalayas, Jammu and Kashmir. Community structure and composition were important factors affecting diversity patterns in plant communities. Thirteen community groups characterized by different dominants in the tree layer were distinguished. These include Himalayan subtropical scrub (580-885m asl), northern dry mixed deciduous forest (600-1100m asl), Himalayan subtropical pine forest (780-1450m asl), *Lyonia*/*Alnus*/*Rhododendron* forest (1250-1500m asl), Mixed Oak forest (1300-2150m asl), *Rhododendron*-Oak mixed forest (1600-2200m asl), Pine/Oak mixed forest (1400-1750m asl), Pure *Cedrus deodara* forest (1450-1700m asl), *Taxus wallichiana* forest (2000-2580m asl), Deodar/blue pine mixed forest (1900-2600m asl), Fir/Spruce mixed forest (2700-3250m asl), pure *Betula* forest (3100-3500m asl), and alpine scrub (above 3500m asl). Distribution of importance values of dominants explicitly indicated a vertical pattern of these forest types. The sub-tropical and temperate elements of vegetation reveal predominance of closed canopy forests, wherein the sub-tropical tree species outnumber the temperate tree flora. The community analysis was performed using stratified random sampling involving 0.01 per cent of the total area for each community. The pattern of plant diversity as observed by the values of species richness and diversity indices showed a decreasing trend from lower to higher altitudes. The study suggested that distribution and species richness were largely regulated by physiography (altitude, latitude, slope, aspect etc.) and climatic factors.

Dangwal *et al.* (2012) assessed the diversity of plants in relation to disturbances effects in subtropical Chir pine forest of the Western Himalaya. The high diversity of trees,

shrubs and herbs was found in Hill Base as compared to Hill Slope and Hill Top. The decreasing in the number of seedling and sapling in Hill Slope due to higher anthropological pressure on trees and another side increasing in the number of shrubs and herbs mainly *Parthenium hysterophorus* and *Cynodon dactylon* was report because opening of canopy and anthropological interference.

Raturi (2012) examined the forest community structure and their status in Rudraprayag district of Garhwal Himalaya. The district is mostly covered by temperate forests and partially by the sub-tropical forest. Temperate forests as dominant forest type of the district with a density of 1980,1550 plant ha⁻¹ and basal area cover 40.19, 20.94 m² ha⁻¹ in temperate mixed and temperate forest respectively.

Barali *et al.* (2011) studied species diversity and community structure of a rhododendron forest along an altitudinal gradient in eastern Himalaya. A total of 72 species representing 58 genera belonging to 35 families were recorded from the three study stands at different altitudes. The species richness index of tree and shrub species was highest in mid altitude while, for herb it was highest in lower altitude. The richness index of tree species showed a positive relation while, the shrub and herb species had a negative relation with the altitudinal gradient.

Dar *et al.* (2010) studied the variation of the vegetation along an altitudinal gradient in the Phakot watershed of Saklana range in Garhwal Himalaya and results revealed that aspect showed variation in density, diversity and richness of trees and shrubs cover varied significantly across different habitat type.

Majila and Kala (2010) studied the forest structure and regeneration along the altitudinal gradient in Binsar wildlife sanctuary viz., chir pine (*Pinus roxburghii*), oak-chir pine (*Quercus leucotrichophora* and *Pinus roxburghii*) and oak *Quercus floribunda* and *Quercus leuctichophora*). The oak forest had harder shrub population as compared to chir pine forest. *Myrica africana* was the dominant shrub across altitudinal gradient, whereas few shrubs species were restricted to a certain altitudinal range.

Kumar *et al.* (2009) reported on the forest structure and diversity along an altitudinal gradient in the temperate, sub-tropical and tropical regions of Garhwal, Himalayan. The structure and composition of the forests were greatly affected by the degree of disturbance.

A study conducted by Ceulla *et al.* (2009) revealed that altitudinal zonation was the main factor of difference in floristic diversity, composition and forest structure of seven different forest types. They found that structure of the forest become more compressed towards elevation while the basal area show different pattern against altitude.

Rana and Gairola (2009) studied the effect of altitudinal variation on structure and composition of the vegetation in natural Himalaya forest of Parshuram Kund area in Lohit district of Arunachal Pradesh. Three altitudinal zones viz., upper zone (550-850m asl), middle zone (500-700m asl) and lower zone (350-645m asl) were selected and the result revealed that shrub and herb species richness was higher on middle altitude, followed by lower and upper altitude.

Sharma *et al.* (2009) observed the characteristic of the structure, composition and diversity of Banj Oak (*Quercus leucotrichophora*) forests at different altitudes and slopes. Competing co-dominant tree layers comprised of *Persea duthiei* and *D. himalense* at the higher altitude (2100m asl) and steeper slope (45°); *D. himalense* and *Betula alnoides* at the middle altitude (1700m asl) and moderate slope (38°); and *Lyonia ovalifolia* and *Myrica esculenta* at lower altitude (1550m asl) and gentles slope (30°) were observed in these forests. Community diversity was highest (3.140) at the higher altitude (site-1) whereas the concentration of dominance followed the opposite trend of the diversity. Physico-chemical properties of soils have revealed that availability of higher average total nitrogen and moisture contents might have given birth to higher total basal cover values at middle altitude. The tree density was positively correlated with the tree diversity and tree richness ($P < 0.001$). The vegetational parameters A/F ratio, Shannon-wiener index, Species richness, Margalef index and soil parameters especially pH and available phosphate (kg/ha) were significant ($P < 0.05$ per cent) among the forest sites.

Sharma *et al.* (2009) compared different forest association along the altitudinal gradient based on species richness, species diversity and dispersion behavior in Himalayan temperate forest. They observed that the values of growth indices i.e. species diversity (0.99-2.34) and simpson's diversity index (1.49-8.73) were maximum at the lower altitude (1850-2600m asl) and the lowest at the higher altitude (2700-2800m asl). They also recorded significantly negative correlation of density and species along altitude are largely regulated by climate factors.

Devlal and Sharma (2008) examined the species composition, diversity and concentration of dominance of tree species and vegetational analysis was done identifying four forest stands along an altitude of (1200-1800m). *Quercus leucotrichophora* emerged as a dominant species on the Stand III (1600m), and Stand IV (1800m) with the highest importance value index values 138.79 & 74.49 respectively. The total density ranged from 1166 to 1828 trees/ha. Species diversity ranged from 1.00 to 2.07, maximum diversity was reported for Stand IV (1800m) and minimum diversity (1.00) recorded for Stand I (1200m).

A study conducted by Hussain *et al.* (2008) in the Kumaon forest, Himalaya, India found a total of 19 tree communities and 17 ground vegetation communities. Maximum tree species diversity and species richness were recorded at an altitudinal range of 2020-2440m asl. The distribution of tree species indicated influence of altitudinal gradient as well as of canopy cover and shrub diversity.

A study conducted on altitudinal gradient in forest vegetation of Mount Kilimanjaro by Hemp (2006) revealed that zonation was significantly related with altitude, temperature and pH of soil. Communities analyzed along the environmental gradient showed similar floristic composition, however differ in quantitative value (Ahmed *et al.* 2006).

The study conducted by Zhu and Li (2006) on species composition and biogeography revealed that the montane rain forest had similar diversity to the low land rain forest in southern Yunnan, China. They further contended that species richness was not reduced necessarily with the increasing altitude. Whereas, Soares *et al.* (2006) reported that graphical proximity and altitude were the main factors responsible for the floristic similarity of many area of Atlantic forest in Araponga MG, Brazil. Along the altitude of Indian Central Himalaya, the geographic and climatic conditions changed sharply. The total numbers of species were highest at low altitude to mid altitude of tropical/subtropical belt due to overlapping of climatic conditions but with further increase in altitude it decreased consistently (Kharakwal *et al.* 2005).

Slope and aspect particularly on hills, are expected to influence vegetation. Yadav *et al.* (2003) found that land slope facing eastward direction has higher organic carbon content as compared to other three aspects. Southern and eastern aspects have early sunshine of the day while northern and western aspects receive sun during the latter part of the day. As regards the slope positions, the low slope position is expected to contain high soil moisture

and available nutrients as compared to steep and very steep slopes because of the variable factors, so it was necessary to incorporate these factors into consideration while assessing impacts of slope and aspect on forest growth.

The study on regeneration was conducted on fourteen tree species at Hareenna forest, on the southern slopes of Bale Mountains, Ethiopia. Species showed variation in densities of their seedlings ranging from 1065 to only 58 seedlings per hectare. Frequency of distribution of species along altitudinal gradients varied between 15 and 69 per cent and their spatial distribution to the canopy light gradient, eight tree species were found growing under canopy shade while six exclusively in the open. Only few species had good representation of individuals at all size classes implying healthy or normal regeneration. Tree species with healthy regeneration or reserve “J” distribution included *Teclea nobilis*, *Ocotea kenyensis* and *syzygium guineense* sub sp. *guineense*, where *Podocarpus falcatus*, *Aningeria adolfi-friderici*, *Oleacapis*, *Croton macrostachyus* and *Prunus Africana* showed hampered regeneration (Tesfaye *et al.* 2002).

Pande *et al.* (2002) studied the vegetation composition, species diversity, distribution pattern and other parameters of vegetation analysis along population structure and regeneration of some tree species in Western Himalayan forests of Chakrata forest division (Uttaranchal). The density for tree species (plant 100m²) was 4.51-6.64, for shrubs was 23.56-41.62 and for herbaceous species was 7280-11920, while the range for total basal cover was 0.332-0.938m²/100m² for trees; 9.50-18.81cm²/100m² for shrubs and 235-323cm²/100m² for herbaceous species. The maximum diversity of trees was 12 (species richness) and minimum up to 1 for trees, 9-14 for shrubs, 20-23 for herbs.

The total tree density was higher at hilltop of eastern aspect and hill slope of western aspect. Total tree basal area varied from 4.5 m² ha⁻¹ (hill base) to 11.9 m² ha⁻¹ (hilltop) on the eastern aspect and from 9.3 m² ha⁻¹ (hilltop) to 16.8 m² ha⁻¹ (hill base) on the western aspect. The sapling and seedling density was lower on western aspect because higher anthropogenic disturbances may lead the removal of seedlings of most of the tree species. The shrub and herb diversity was higher on both the aspects as compared to tree diversity because opening of canopy provides greater opportunity for the recruitments of shrubs and herbs. A comparatively higher number of trees and shrubs were recorded on the western aspect where low erosion and greater anthropogenic pressure were present (Khera *et al.* 2001).

Bhandari *et al.* (2000) studied the impact of woody vegetation composition, dominance and diversity in a montane forest in the Garhwal Himalaya. Invasion of *Pinus roxburghii* is an indication of *Quercus leucotrichophora* replacement in the near future. Decreasing diversity indices from seedling to tree strata reflected the poor regeneration potential of these forests.

Aiba and Kitayama (1999) Studied forest structure, composition and tree species diversity of eight plots in altitudes (700, 1700, 2700 and 3100m) and two types of geological substrates (ultrabasic and non-ultrabasic rocks) on Mount Kinabalu, Borneo. The two forests on the different substrate series were similar at 700m in structure, composition and tree diversity, but became dissimilar with increasing altitude. Tree diversity was generally lower on ultrabasic substrates than on non-ultrabasic substrates at $\geq 1700\text{m}$. Forest with higher tree species diversity were characterized by greater biomass allocation to height growth under more productive environment than forests with lower tree species diversity.

Sundriyal *et al.* (1987) also reported variations in floristic composition of grassland along altitude in Garhwal Himalaya. They argued that grazing, cutting and burning had long term effects on species composition.

Singh *et al.* (1975) contended that the floristic composition of grasses varies greatly with altitude. They reported in their study on grasslands at different altitude in Himachal Pradesh that at 2360m altitude the dominant grasses were: *Heteropogon contortus*, *Arundinella camus*, *Bothriochloa pertusa*, *Chrysopogon gryllus* and *Arundinella nepalensis*, whereas, those at 2915m consisted of *Agrostis canina*, *A. stolonifera*, *Festuca gigantea*, *Dactylis glomerata*.

Without altitude the cofactors like topography, aspect, inclination of slope and soil type further affect the forest composition (Holland and Steyn 1975). Shank and Norrie (1950) found that the western Himalaya is comprised of a variety of forest type at various altitudes and within one altitude, the eco-factors such as topography, inclination of slope, aspect and soil types further affect the forest composition and vigour.

2.1.1 Growth

A study conducted on floristic diversity and regeneration status of *Cedrus deodara* stand under forest management systems in western Himalaya by Singh and Gupta (2009)

revealed the dominance of *Cedrus deodara* in all periodic blocks with maximum dominance in PB II. Among different PB's, maximum diversity in species was found in PB IV. Among shrubs, *Berberis aristata* showed maximum dominance in PB I followed by PBII and PB IV.

Gairola *et al.* (2008) described vegetation diversity along an altitudinal gradient in three sites of subalpine forests. The altitude of the study sites ranged from 2800-3600m asl and represented a transition from closed canopy temperate forests to open canopy sub-alpine forests. The results revealed that from low to high altitude strata, size and density of trees decline. The density of sapling and seedling do not follow the trend of trees and exhibit site/location specific trends. Shrub and herb also did not exhibit uniform patterns across altitudinal range of the sites. As sub-alpine forests are considered to be potentially prone to the adverse effects of climate change, present study will provide important baseline information for future evaluation of the impact of climate change on sub-alpine forest communities.

Konstantinidis *et al.* (2006) studied effect of aspect on the growth of *Arbutus unedo* L. resprouts. The results of the study revealed that aspect has an important effect on both diameter and height of resprouts.

Sharma (2006) studied stand parameters of silver fir and spruce in Bashla, Jubbal and Kotkhai forest range District Shimla, Himachal Pradesh. The result obtained for various fir and spruce parameter viz., average diameter, average height, average crown width showed increasing trend from lower to higher diameter classes in all sites. Total basal area, volume and crown cover also showed increasing trends lowest elevation to highest elevation class. Maximum basal area ($90.65\text{m}^2/\text{ha}$) and volume ($1044.53\text{m}^3/\text{ha}$) was found in highest elevation class of Jubbal forest in PB I.

Nawa (2005) conducted a study to assess the growth performance of chir pine at four sites based on density, altitude and aspect. Results showed that maximum average collar diameter and crown development were recorded at site IV while minimum values were recorded at site I. Average height was also maximum at site IV but was minimum at site II. Results also showed that the number of growing shoots and their dimension was recorded maximum at site IV and minimum at site I.

Liang *et al.* (2005) analyzed the influence of slope on growth of *Fraxinus mandshurica* and *F. manshurica*. The results showed that the soil moisture was higher on the

lower slope site than on middle or upper slope sites, and the soil temperature was higher on the upper slope site than on middle or lower slope sites. The growth of *F. mandshurica* was better on the lower or middle slope sites than on the upper slope site. But in *F. mandshurica* plantation the growth was better on the middle slope sites than on the lower or upper slope site.

Li and Yang (2004) examined the growth in *Pinus cembra* across the tree line ecotone from 1900-2100m asl elevation in the Austrian Alps. Over the range of altitude studied, elevation and steepness had influences on growth depending on tree size. Elevation and steepness had little effect on growth as long as trees were very small (<0.5 m in height). Both elevation and steepness affected tree growth significantly when the tree height was between 0.5 and 3m.

Singh (2004) studied the growth parameter viz., average dbh, average bole height, average height and average crown width, observed that growth parameters showed increasing trend from lower to higher diameter class under different PB. However, maximum values were obtained in higher diameter class. The number of trees per hectare was found maximum in PB III (399.99). The presence of tree in different PB was in decreasing trend in order of PB III > PB II > PB I > PB IV. There was regular decrease in total basal area (50.709 to 7.995 m²/ha) and standing volume (463.114 to 60.027m³/ha) PB I to PB IV.

Zade *et al.* (2003) investigated response in diameter at breast height and height growth of 34 year old *Pinus elderica* trees to slope and aspects variations in 57 sample plots at four main geographical aspects and two slopes of 0-15 and 16-40 per cent. The results indicated that slope affected DBH; aspect affected DBH contrary to slope, aspect affected DBH and height and the interaction of aspect and slope was marginally significant on height. Without considering slope, the highest trees were found on the eastern aspect, and the thickest tree on the eastern and southern aspect.

Sharma and Baduni (2000) studied the effect of aspect, altitude and slope on growth attributes in the moist temperate forests of *Abies pindrow* in Garwal Himalaya Uttar Pradesh. The total basal cover found to be highest (5099.6cm²/100m²) on the northeast facing slopes, and lowest (3092.7cm²/100m²) on the southeast facing slopes. It was suggested that cooler condition with regards to aspect and exposure, including the solar radiation, moderate soil pH, higher amount of carbon directly favor the growth in terms of total basal area cover of

Abies pindrow forest along with companion species on northeast and northwest facing slope and also at the comparatively higher altitude in the Himalayan moist temperate forest.

Chandra *et al.* (1999) reported that average tree density increased even with the altitude whereas average basal area and species diversity decreased with increase in altitude. They attributed low density 288 trees/ha and high basal area 49.7 m²/ha to high biotic pressure in the area. Stand structure has been defined as the horizontal and vertical distribution of components of a forest stand including the height, diameter, crown layers and stems of trees, shrubs, herbaceous under storey, snags and coarse woody debris (Helms, 1998).

Suri (1975) had given the regression analysis of data on 97 trees on *Cedrus deodara* (dbh 2 to 38 inches) and 55 trees of *Abies pindrow* (dbh 2 to 24 inches) in Himachal Pradesh and found positive relation between stem diameter and crown projection area of each species. The curves of number of stem per acre over diameter as prescribed by the regression equation and those taken from yield tables were compared for each species and for *Shorea robusta*. The use of the relation between the variables as guide to thinning and initial spacing was described and their values for purpose of aerial survey were noted.

Singhal and Soni (1992) studied vegetation type of *cedrus deodara*, *Pinus roxburghii* and *Quercus leucotrichophora* on eight sites in Massoorie for quantitative characters viz., frequency, density, abundance, mean basal area/tree and total basal area of ten major tree species and data was correlated with soil characteristics and mean annual increment calculated from yield and volume table for each forest types. Deodar forest had a highest mean annual increment than chir and oak forests.

A study was conducted by Lata and Bisht (1991) at eight forest patches varying in altitude (1700-2500m asl) and slope in moist temperate forest at Pauri in the Garhwal Himalaya. Four sites were dominated by *Quercus leucotrichophora* and two sites each by *Cupressus torulosa* and *Pinus roxburghii*. The Maximum number of species and total basal cover of forest (7125.02cm²/100m²) were recorded at 2500m altitude (site VIII). Concentration of dominance varied from 0.2139 to 0.5478 and 0.2148 to 0.5845 in the basis of total basal cover and density, respectively. Rubus and Berberis were the most common among seven shrub species.

Genys and Harman (1990) noticed that in *Robinia psuedaacacia* high altitude geographic sources recorded more rapidly growing population than those from low altitudes. Silas *et al.* (1987) analyzed the pine oak communities for structure changes and composition of vegetative cover at different altitudes in Pauri Garhwal. The species distribution was markedly distinct, which followed the normal Raunkier's pattern with slight variation in the species, but the number of species in different forest was different. Joshi *et al.* (1986) and Kharkwal *et al.* (2005) argued the factors such as altitude, topography, climate and human interferences affect the vegetation. They reported lower altitude and greater diversity of species than that of higher altitude between Kotdwara and Doggada in Garhwal Himalaya. A marked irregularity in diversity of flora of Nanga Prabat in Western Himalaya at about 3300m asl was related to relief features and climatic factors (Dickore and Nusser 2000). Plant species and functional group richness improved establishment of plant assemblages and mean vegetation cover increased with diversity (Spehn *et al.* (2000).

2.1.2 Canopy Analysis

Forest canopy architecture delineates the spatial distribution of position, size and orientation of each and every woody and leafy element above the ground. Canopy can be defined as the combination of all leaves, twigs and small branches in a stand of vegetation (Parker, 1995). This is the aggregate of all the crowns. As an interface between forests and atmosphere, canopies receive and release energy through photosynthesis, respiration and evapotranspiration and thereby create microclimate regime within a canopy that drives understory processes.

Crown sizes and centricity of oak crowns is a consistent indicator of competitive conditions (Miller, 1990). Crown studies can help in setting a limit to minimum number of trees per hectare required to stock an area. Also, the density of crop greatly influences crown development, its study may serve guide for thinning.

Long and Smith (1992) while studying volume increment and crown dynamics in *Pinus contorta* at USA reported that the degree of abrasion and crown shyness was a function of relative slenderness and the distance between the boles of interacting trees and crown radius increased with increasing distance between trees and decreased with greater slenderness.

Gratini (1997) while studying the canopy structure, vertical radiation profile and photosynthetic function in a *Quercus ilex* evergreen forest observed that high LAI drastically modified the quality and quantity of solar radiation on the forest understory/ground vegetation.

2.1.3 Regeneration status

Chacko (1965) reported that for the assessment of regeneration plot size was the determining factor in negative and positive correlation of species. It was, therefore, essential to use higher intensity of sampling to get accurate results.

Regeneration is a critical phase of forest management because it maintains the desired number of a species in a community. For healthy regeneration, it is important that a large number of seedlings should survive. The presence of adequate number of seedlings, saplings and distribution of boles reveal good regeneration potential (Pande, 2000). Hole (1914) probably was the first person to carry out first systematic study on regeneration. Since then the problem of regeneration was studied by many workers. Ralhan *et al.* (1985) and Singh *et al.* (1990) had studied seed characteristics of a number of Himalayan conifers (*Pinus roxburghii*, *Cedrus deodara*, *Cupressus torulosa* and *Abies pindrow*).

Regeneration status of trees can be predicted by the age structure of their populations (Marks, 1974; Veblen *et al.* 1979). Presence of sufficient number of seedlings and young trees in a given population indicates successful regeneration (Saxena and Singh 1984). Regeneration of tree species was greatly influenced by the interaction of biotic and abiotic factors (Boring *et al.* 1981; Lange and Graham 1983; Akshamit and Irving 1984; Khan *et al.* 1986). These factors might affect the recruitment, survival and growth of tree seedlings and sprouts.

Singh *et al.* (2018) investigated the community structure and regeneration status of tree species in Eastern Himalaya. The area was grouped into three altitudinal zones viz., lower, middle and upper temperate and tree species were sampled at three life stages (seedlings, saplings and mature trees). The mean density of seedlings ($32278.6 \pm 3713.13 \text{ ha}^{-1}$) > saplings ($840 \pm 141.07 \text{ ha}^{-1}$) > trees ($248.5 \pm 22.79 \text{ ha}^{-1}$). Basal area ranged from $9.36 \text{ m}^2 \text{ ha}^{-1}$ to $29.95 \text{ m}^2 \text{ ha}^{-1}$ for trees, from $1.34 \text{ m}^2 \text{ ha}^{-1}$ to $2.07 \text{ m}^2 \text{ ha}^{-1}$ saplings and from $1.92 \text{ m}^2 \text{ ha}^{-1}$ to $5.75 \text{ m}^2 \text{ ha}^{-1}$ for seedlings at different study sites. It was observed that majority of the tree species at all life stage showed contiguous distribution pattern. Good regeneration status was

recorded for maximum species at all the sites. Density-diameter distribution exhibited decrease in tree densities towards higher DBH classes.

Singh *et al.* (2014) studied two dominant forest types identified along elevational gradient in Nainital Forest Division. They found that the dominant tree species were *Quercus leucotrichophora* and *Pinus roxburghii*, followed by *Acer oblongum*, *Rhododendron arboretum*, *Quercus floribunda*, *Cedrus deodara*, *Myrica esculenta*, *Ficus nerifolia*, *Cupressus torulosa* and *Prunus cerasoides*. Tree and sapling species richness, density and diversity were high in *Quercus leucotrichophora* dominated forest and total basal area and concentration of dominance were maximum in *Pinus roxburghii* dominated forest. Maximum seedling species richness was found in *Pinus roxburghii* dominated forest and maximum density, diversity and concentration of dominance found in *Quercus leucotrichophora* dominated forest.

Gairola *et al.* (2012) observed the regeneration of dominant tree species along an altitudinal gradient in moist temperate valley slopes. The present study was undertaken in moist temperate forest of Mandal-Chopta area in the Garhwal region of Uttarakhand, India. Most of the native canopy and under canopy dominants had frequent reproduction and expanding populations, which suggests the stability of forest structure/composition and further expansion of dominant species. The overall regeneration of trees in the forest had a greater contribution of middle and understorey species. Because of infrequent reproduction and declining populations of some of the dominant native species viz., *Abies pindrow*, *Alnus nepalensis* and *Betula alnoides*, structural/compositional changes in the future are expected in respective forests dominated by them. *Abies pindrow* and *Taxus baccata* need immediate attention by forest managers for their survival in the area. Seedlings were found to be more prone to competition from herb and shrubs than saplings.

Pant and Samant (2012) studied diversity and regeneration status of tree species in Khokhan wildlife sanctuary. Sixty five sites were selected between 1640-2400m asl and seventeen forest communities were recorded. *Cedrus deodara* community was the most widely distributed, followed by *Quercus semecarpifolia* communities. *Cedrus deodara* community had maximum density of trees (1468 Ind ha⁻¹), seedlings (1290 Ind ha⁻¹) and saplings (1172 Ind ha⁻¹) while *Picea smithiana* community recorded the maximum total basal area (186.2 m² ha⁻¹). In seventeen forest tree communities identified, eight showed maximum regeneration of the dominant species, six showed maximum regeneration of the co-dominant

species and three communities showed poor or no regeneration of the dominant species indicating a total replacement of the dominants in the coming years.

A study was conducted in Tara Gedam and Abebaye forests northwestern Ethiopia to investigate the diversity, regeneration status. A total of 143 woody species belonging to 114 genera and 57 families were found, and of all the species 44 (30.8 per cent) were trees, 57 (39.9 per cent) trees/shrubs, 33 (23.1 per cent) shrubs and 9 (6.3 per cent) lianas. The diversity and evenness of woody species in Tara Gedam forest were 2.98 and 0.65, respectively and in Abebaye forest the values were 2850 individuals ha⁻¹ and 49.45 m² ha⁻¹, respectively (Zegeye *et al.* 2011).

Anitha *et al.* (2010) revealed that structure, function, and ecosystem services of any forest depend on its species richness, diversity, dominance, and the patterns of changes in the assemblages of tree populations over time. The data on species diversity, community composition, and regeneration status of tropical forests in a human-dominated landscape in the Western Ghats of southern India and the enumeration of 40 plots (50m × 20m) results a total of 106 species of trees, 76 species of saplings and 79 species of seedlings. Detrended Correspondence Analysis (DCA) ordination of the tree populations yielded five dominant groups, along disturbance and altitudinal gradients on the first and second axes, respectively. Abundant species of the area such as *Albizia amara*, *Nothopegia racemosa* and *Pleiospermum alatum* had relatively few individuals in recruiting size classes. Our data indicate replacement of rare, localized, and old growth ‘specialists’ by disturbance-adapted generalists, if the degradation is continuing at the present scale.

Sharma *et al.* (2009) described the impact of altitude on the species richness, species diversity and dispersion behavior. Maximum Margalef’s index (0.17 to 1.14), Menheink’s index (0.27 to 0.80), species diversity (0.99 to 2.34) and simpson’s diversity index (1.49 to 8.73) were found at lower altitudes (2250-1850m asl), medium at mid-altitudes (2600-2400m asl) and lowest at higher altitudes (2800-2700m asl). The distribution and species richness pattern of different tree species were largely regulated by the altitude and climatic factors.

A study was made around Almora town, Uttar Pradesh, on 12 forest sites on south, north and west slopes along an altitudinal gradient of 1600-2000m. *Pinus roxburghii* was the dominant species at lower altitudes and *Quercus leucotrichophora* at higher altitudes. Regeneration status was good, although regeneration of *Q. leucotrichophora* was better on

the north and west aspects and that of *P. roxburghii* was better on the south aspect (Tripathi *et al.* 1987).

Singh (2004) studied regeneration of *Cedrus deodara* in different periodic blocks in Koti forest and found maximum established regeneration of 1388.8/ha, maximum established stocking per cent (55.54) in PB I, followed by PB IV whereas, PB II was devoid of regeneration, with maximum value on northern aspect at about 2100m msl. Grazing affected the distribution pattern by inhibiting regeneration. Gupta (2007) studied the natural regeneration status of silver fir and spruce in Kullu, Rajgarh and Kotgarh Forest Divisions of Himachal Pradesh and reported that over all regeneration success was better at Kullu (91.68 per cent), followed by Kotgarh (74.69 per cent) and Rajgarh (72.47 per cent) forests.

In the high elevation evergreen forests of Talakavery wildlife sanctuary, regenerates in the classes II, III and IV were deficient and the storey was dominated by life forms other than tree species. Whereas in medium elevation evergreen forests the understory was dominated by regenerates of tree species, which could be attributed to higher disturbance in high altitude evergreen forests (Santhosha, 2005).

Raghu (2003) had reported 191 plant species distributed over 58 families in evergreen forests of Gerusoppa region of Uttarakhand district. Among the different altitudinal zones, altitude between 250-350m asl was found to be richest in species composition followed by the second altitudinal gradient between 150-250m asl. Members of Lauraceae, Rubiaceae, Euphorbiaceae, Fabaceae, Ebenaceae, Myrtaceae, and Rutaceae families were the most dominant floristic elements in this region.

Quercus leucotrichophora in the Central Himalayas is used for fuelwood, fodder and as an agricultural mulch which results in large canopy openings and exposed topsoil widely reported to promote stands of chir pine (Quazi *et al.* 2003).

Gupta (1996) investigated the regeneration of fir and spruce and reported that regeneration of fir (687.5/ha) on an average was more as compared to the spruce (312.50/ha) in Narkanda (Theog Forest Division) forest. In contrast, however, the regeneration of spruce (1875.00/ha) was found to be more than fir (833.33/ha) at Chhachpur (Jubbil Forest Division) forest. The investigation also revealed that regeneration decreased with the increase in elevation from 1250/ha to 208.33/ha for fir and from 625/ha to 156.25/ha for spruce at

Narkanda, while it increased with increase in elevation in fir from 625/ha to 1041.67/ha, and decreased for spruce from 2083.00/ha to 1666.67/ha at Chhachpur.

Inayatullah and Tick (1965) investigated the plant communities in the Kashmir valley and coniferous forest zone. In the valley, regeneration was hampered by a dense undergrowth of *Parrotia*, while in the outer ranges, regeneration was generally satisfactory. Whenever conditions become drier, *Pinus wallichiana* regenerate and eventually the young crop of *Pinus wallichiana* create conditions conducive to *Cedrus deodara* regeneration and a mixed crop of *C. deodara* and *Pinus wallichiana* results.

Conservation and management of the Himalayan subtropical chir pine (*Pinus roxburghii*) forests are discussed on the basis of work done in Rajgarh Forest Division, Himachal Pradesh and suggested that artificial regeneration was required to supplement natural regeneration, and forests had to be protected against fires (Shrivastava, 1994). A phytosociological analysis was undertaken in forest communities distributed along an altitudinal gradient (1190-2610m asl) in the Kumaun Himalaya. Regeneration and size class data indicated that *Pinus roxburghii* and *Q. floribunda* reproduced frequently whereas, *Q. leucotrichophora* and *Q. semecarpifolia* reproduced infrequently (Rikhari *et al.* 1991).

Tripathi *et al.* (1991) highlighted the regeneration status of distributed forest sites in the oak zone in and around Naini Tal in between 1930-2200m elevation. Regeneration status was fairly good on all the forest sites, though the number of seedlings were comparatively low on the site dominated by *Acer oblongum*.

2.2 Biomass and carbon stock

2.2.1 Biomass

Rai *et al.* (2018) studied biomass and carbon stock emission of Khangchendzonga National Park, Eastern Himalaya, India, along 3800 to 4000m asl, in Dzungri landscape. They assessed nine major timberline sites for the estimation of total basal area, aboveground biomass, belowground biomass, total carbon and stem density. The total basal area varied between 99.55 ± 1.90 and $4.50 \pm 2.41 \text{ m}^2 \text{ ha}^{-1}$. The total above ground biomass differed between 279.25 ± 3.04 and $15.35 \pm 7.38 \text{ Mg ha}^{-1}$, while the total below ground biomass ranged between 144.76 ± 8.10 and $9.85 \pm 4.82 \text{ Mg ha}^{-1}$. The total carbon content was estimated between 195.03 ± 2.32 and $11.59 \pm 5.61 \text{ Mg ha}^{-1}$. Among the studied environmental factors, elevation

and humus were observed the determining factors for the tree growth and forest composition in the study area.

Thokchom and Yadava (2017) assessed the aboveground biomass and carbon stock along an altitudinal gradient in the forest of Manipur. Stand density varied from 128 to 168 trees ha⁻¹ across the study sites with the highest stand density at higher altitude. The aboveground biomass varied between 124.56 to 254.99 t ha⁻¹ and carbon stock ranged from 60.09 to 121.43 t C ha⁻¹. There was a significant positive correlation of stand density, aboveground biomass and carbon stock with increasing altitude. This positive relationship could be attributed to less disturbance and the dominance of larger trees at higher altitudes as compared to lower altitudes. This result could be helpful to devise appropriate strategies in the restoration of degraded forest ecosystems to enhance carbon sequestration and to mitigate climate change.

Chowdhuri *et al.* (2016) studied the change in the above ground biomass and carbon stock for a period of 10 years for three major forest types (Deodar, Oak, and Pine) in Shimla district as a consequence to land use dynamics using NDVI based approach. Non-destructive sampling techniques had been used for preparing the forest inventory for two time periods (2003 and 2013). The correlation between carbon stock and NDVI values was found to be significant ($r = 84$ per cent for 2003 and 80 per cent for 2013) and was used for the spatial interpolation of carbon values in order to generate carbon map for the two time periods and the results of the analyses were presented. The carbon pool of the tropical and temperate forests in India is largely affected by land use change and deforestation. The land use changes directly influence the amount of carbon stored in vegetation and soil releasing carbon dioxide in the atmosphere.

Girardian *et al.* (2014) studied the forest structure, species richness and composition from six elevations transect in the Andes ranging from lowland Amazonian rain forest to high-elevation forest in Ecuador, Peru and Bolivia. They reported that aboveground woody biomass stocks in forest ranged from 247 Mg ha⁻¹ (Peru, 210m) to 86 Mg ha⁻¹ (Peru, 3450m) with significant decreasing trends of tree height and biomass, no trend in basal area and an increasing trend of stem density with increasing elevation. They also observed an increase in forest richness at three taxonomic levels viz., trees, shrubs and herbs at mid-elevation, followed by a decrease in richness at higher altitudes.

Sharma *et al.* (2011) assessed the stem density, tree diversity, biomass and carbon stocks in subtropical to temperate zones (350 to 3100m asl) of Garhwal Himalaya. Stem density ranged between 295 and 850Nha⁻¹, while total biomass ranged from 129 to 533 Mg ha⁻¹. Total carbon storage ranged between 59 to 245 Mg ha⁻¹ and range of Shannon-Wiener diversity between 0.28 and 1.75. Most of the conifer-dominated forest types had higher carbon storage than broadleaf-dominated forest types.

Gairola *et al.* (2011) studied total live tree biomass density along an altitudinal gradient (1500-2850m) in moist temperate valley slopes of the Garhwal Himalaya and reported that it varied from 215.5 to 468.2 mg ha⁻¹. Sharma *et al.* (2011) reported that the variation in carbon stocks on different slope aspects in seven forest types of temperate region of Garhwal Himalaya. This study was undertaken in seven major forest types of temperate zone (1500m asl to 3100m asl) of Garhwal Himalaya. We assessed soil organic carbon (SOC) density, tree density, biomass and soil organic carbon (SOC) on four aspects, viz., north-east (NE), north-west (NW), south-east (SE) and south-west (SW) in forest stands dominated by *Abies pindrow*, *Cedrus deodara*, *Pinus roxburghii*, *Cupressus torulosa*, *Quercus floribunda*, *Quercus semecarpifolia* and *Quercus leucotrichophora*. Total carbon density ranged between 77.3 C Mg ha⁻¹ on SE aspect (*Quercus leucotrichophora* forest) and 291.6 C Mg ha⁻¹ on NE aspect (moist *Cedrus deodara* forest). SOC varied between 40.3 C Mg ha⁻¹ on SW aspect (Himalayan *Pinus roxburghii* forest) and 177.5 C Mg ha⁻¹ on NE aspect (moist *Cedrus deodara* forest). Total C density (Soil organic carbon+ total carbon density) ranged between 118.1 C Mg ha⁻¹ on SW aspect (Himalayan *Pinus roxburghii* forest) and 469.1 C Mg ha⁻¹ on NE aspect (moist *Cedrus deodara* forest). Soil organic carbon and total carbon density were significantly higher on northern aspect as compared with southern aspect. It was recommended that for C sequestration, the plantation silviculture be exercised on northern aspect, and for C conservation purposes, mature forest stands growing on northern aspects be given priority.

Chandra *et al.* (2010) analyzed the vegetational diversity along an altitudinal range of 1900-2200m. A total of 209 plant species were recorded out of which 29 were trees, 50 shrubs, 102 herbs, 11 climbers, 7 epiphytes, 4 pteridophytes, 3 bryophytes and 3 parasites. Minimum tree species were recorded on ridge site (12) and maximum tree species were recorded on moist site (22). Maximum shrub species were present both on stream bank and dry site (31 at each site). Most of the herb and climber species were present on dry and moist

site (62 and 8), respectively. Species relationship between the sites indicated that 11 trees, 20 shrubs, 41 herbs, 4 climbers, 2 pteridophytes, 1 bryophyte and 2 parasites were common in stream bank and dry site. The mean tree, shrub and herb species richness was maximum on stream bank (6.3 ± 0.2), moist (6.1 ± 0.3) and dry (10.3 ± 0.4) and minimum on ridge site (4.6 ± 0.3), (5.5 ± 0.4), (7.6 ± 0.5), respectively. Comparison similarity between the sites revealed maximum similarity among stream bank and moist sites (70 per cent) for trees and minimum between ridge and moist site (32.43 per cent) for herbs. The high similarity index between moist and stream bank site may be due to similar environmental conditions on both the sites.

Kharkwal and Rawat (2010) made a vegetational analysis in different forest sites between 1600 to 2600m asl. In this study *Quercus leucotrichophora* A. Campus, *Quercus floribunda* Lindl. ex Rehder, *Quercus semecarpifolia* J.E. Smith and *Pinus roxburghii* Sarg. were the dominant tree species in banj-oak, tilonj-oak, kharsu-oak and chir-pine forests, respectively. Among the sampling sites, total density of tree, shrub and herb species was ranged from 10 to 28.6 individuals ($\text{indv}/100 \text{ m}^2$) 1.8 to 21.7 $\text{indv}/25 \text{ m}^2$, and 28.1 to 103.7 indv/m^2 , respectively. The total abundance-frequency (AF) ratio of tree, shrub and herb species across the sampling sites varied from 0.23 to 1.25, 0.25 to 1.79 and 3.4 to 27.3, respectively. The abundance-frequency ratio in the present study showed contagious distribution pattern in tree, shrub and herb species.

Sharma (2009) studied the distribution of biomass in different land uses viz., Chir pine, ban oak, deodar, other broadleaves, culturable and unculturable land uses, distributed in five forest ranges along altitudinal gradient from 900 to 2100m of Solan Forest Division (H.P.). The study revealed that out of 1.07 Mt of total biomass in the division, Chir pine land use contributed 36.63 per cent, ban oak 32.94 per cent, deodar 1.15 per cent and culturable land 0.48 per cent. Along altitudinal gradient, it was 44.89 per cent in 1500-1800m, 42.38 per cent in 1200-1500m, 10.35 per cent in 1800-2100m and 2.36 per cent in 900-1200m elevation.

Sanneh (2007) indicated that in wet temperate north western Himalaya at different altitudinal gradients maximum aboveground biomass (308.96 t ha^{-1}), belowground biomass (62.09 t ha^{-1}) and total biomass (371.06 t ha^{-1}) occurred in the forest land use system and was

followed by silvi-pasture, agri-silvipasture, agri-horticulture, agriculture and grassland systems, respectively.

Gupta and Bhardwaj (2005) studied the aboveground biomass production of black wattle in mid hills of Himachal Pradesh. Some easily measurable attributes such as plant height and DBH were used to develop allometric relationship which showed that DBH was the best predictor variable for the total aboveground biomass (controlling more than 80 per cent variability) and the inclusion of height as variable in the model slightly improved the adequacy of the model.

Kharkwal *et al.* (2002) examined plant species richness at altitudes between 200 to 5800m asl in Himalaya. A total of 2487 species were recorded, of which 276 were tree, 355 shrubs, 112 climbers and 1744 herbs. The deciduous trees were maximum at 600-800m asl elevation and evergreen trees were maximum at 1200-1400m elevation. Shrubs species occurred in the altitude range of <200 to 4800m asl and total number of shrubs species varied from 2 (4600m asl) to 35 (1400m asl). Along the altitude, the geographic and climate conditions change sharply. Distribution and species richness pattern in this region largely depend on the altitude and climatic variables like rainfall, temperature.

Rana *et al.* (1989) studied plant biomass and net primary productivity of a series of forests located along an altitudinal gradient (300-2200m) in the central Himalayans. The biomass ranged between 199 and 787 t ha⁻¹ with lower values being for early successional forests, such as Chir pine forest. The net primary productivity was in range 12.8-27.9 t ha⁻¹ year⁻¹ which was not related to the elevation. In fact, the entire elevation range seemed to have the potential to support high biomass and productivity values.

2.2.2 Carbon stock

Mahato *et al.* (2016) conducted the study on tree carbon and soil organic carbon stock in district Pauri (1800-2300m asl) of Garhwal Himalaya. *Quercus leucortichophora* was dominated tree species in this selected area. The highest values for above ground biomass density 78.20±17.41 t ha⁻¹ was found in *Quercus leucotrichophora*, which was followed by *Pinus roxburghii*. Overall calculated values of total biomass density and total carbon density were 132.74 Mg ha⁻¹ and 66.36 Mg ha⁻¹, respectively. As far as Soil Organic carbon (SOC %) was concerned; the mean value of organic carbon was 1.28 per cent, while the highest SOC percentage was found in depth 0-10 cm (2.29±0.42 per cent).

Kumar and Sharma (2015) estimated the carbon stock of tree species of Balganga Reserved Forest (BRF) in district Tehri Garhwal, Uttarakhand, India. The highest total biomass density (TBD) and total carbon density (TCD) were estimated at site III in the altitudinal range of 1800-2600m as 108.26 and 53.45 Mg ha⁻¹, followed by site II in the range of 1600-1800m as 83.92 and 41.96 Mg ha⁻¹ and the least at site I in the altitudinal range of 1000-1400m as 57.22 and 28.61 Mg ha⁻¹. They also found that the C stock increased with increasing altitude due to fine root area, fine root length growth, and decreasing temperature. The study also revealed that oak, devdar, and fir had greater C sequestration capacity compared to other species found in BRF.

Carbon stock estimation was conducted in tree species of Sem Mukhem sacred forest in district Tehri of Garhwal Himalaya, Uttarakhand, India. *Quercus floribunda*, *Quercus semecarpifolia* and *Rhododendron arboretum* were dominated tree species in this sacred forest. The highest values of below ground biomass density, total biomass density and total carbon density were 34.81±1.68 Mg ha⁻¹, 168.26±9.04 Mg ha⁻¹ and 84.13±4.18 Mg ha⁻¹ for *Pinus wallichiana*. Total value of growing stock volume density for all species was 732.56 m³ ha⁻¹ and ranged from 144.97±11.98 m³ ha⁻¹ for *Pinus wallichiana* to 7.78±1.78 m³ ha⁻¹ for *Benthamidia capitata*. Total biomass density and total carbon density calculated were 1549.704 Mg ha⁻¹ and 774.77 Mg·ha⁻¹, respectively (Pala *et al.* 2013).

Verma *et al.* (2012) investigated the carbon storage capacity of high altitude of oak forest between 2400-2750m and the timber line areas. These forests have large reserves of carbon in their biomass (above and below ground parts) and soil. These forests had carbon ranging between 210.26 and 258.02 t ha⁻¹ in their biomass in 2009 and mean carbon sequestration rates between 3.7 and 4.8 t ha⁻¹ yr⁻¹. The litter production in both the sites ranged from 5.63 to 7.25 t ha⁻¹ yr⁻¹. The leaf litter decomposition of species took more than 720 days for approximately 90 per cent decomposition. Even at 1m soil depth soil organic carbon was close to 1.0 per cent.

Sharma *et al.* (2010) studied carbon stock of some major forest types of Garhwal Himalaya, India. Four forest stands each of twenty major forest types in sub-tropical to temperate zones (350m asl-3100m asl) of Garhwal were studied. Total carbon storage ranged between 295 and 850 Mg ha⁻¹, while total biomass ranged between 59 to 245Mg ha⁻¹. Most of the conifer-dominated forest types had higher carbon storage than broadleaf-dominated forest

types. Protecting conifer-dominated stands, especially those dominated by *Abies pindrow* and *Cedrus deodar*, would have the largest impact, per unit area, on reducing carbon emission from deforestation.

Zhu *et al.* (2010) studied the altitudinal changes in C storage in different components (vegetation, detritus and soil) of forest ecosystems. They measured C stocks of vegetation, detritus and soil of 22 forest along an altitudinal gradient of 700-2000m to quantify altitudinal changes in carbon storage of minor forest ecosystems (*Pinus koraiensis*) and broad leaf mixed forest, 700-1100m Picea and Abies forest, 1100-1800m and *Betula ermanii* forest, 1800-2000m on Mt Changbai, Northeast China. Total ecosystem C density averaged 237 t C ha⁻¹ (ranging from 112 to 338 t C ha⁻¹) across all the forest stands, of which 153 t C ha⁻¹ (52-245 t C ha⁻¹) was stored in vegetation biomass, 141 t C ha⁻¹ (2.2-48 t C ha⁻¹), in forest detritus (including standing dead trees, fallen trees, and floor material) and 70 t C ha⁻¹ (35-113 t C ha⁻¹) in soil organic matter. Among all the forest types, the lowest vegetation and total C density but the highest soil organic carbon (SOC) density occurred in *Betula ermanii* forest, whereas the highest detritus C density was observed in Picea and Abies forest. The C density of the three ecosystem component showed distinct altitudinal pattern: with increasing altitude, vegetation C density decreased significantly, detritus C density first increased and then decreased, and SOC density exhibited increasing but insignificant trends. The results suggested that carbon storage and partitioning among different in temperate forest on Mt Changbai vary greatly with forest type and altitude.

The study conducted by Minj (2008) in low and mid hills of western Himalaya during year 2004-2006 revealed that mean biomass carbon stock and CO₂ sequestration in zones I(sub montane low hills) was found to be 2.09 times higher than zone II (mid hills). Maximum mean total carbon stock (107.00 t ha⁻¹) was observed in pure plantation system of popular at an average density of 1066 trees/hectare. It was 2.68-4.86 times higher than other perennial plant based land use system and about 12.40-22.57 times higher than annual crops or pure grassland systems.

Chauhan *et al.* (2004) compared carbon stock in plant communities viz., pure pine, pine *Michelia champaca*, mixed pine, pure *Cinnamomum camphora* at FRI Dehradun and observed maximum carbon stock in mixed pine community, followed by pine-M.*champaca*, pure pine and pure camphora.

2.3 Soil properties

Whittaker (1965) observed that the distribution of tree, shrub and herb diversities has been found to be affected by the presence of different soil moisture regimes and in fact site quality has been related primarily to soil moisture and nutrients (Lowry, 1975).

Saha *et al.* (2018) analyzed the soil characteristics in different seasons at varying altitudes in temperate region of Garhwal Himalayan. The values of nitrogen ranged between 0.01 to 0.012 per cent (upper altitude), 0.009 to 0.011 per cent (middle altitude) and 0.007 to 0.011 per cent (lower altitude). The effects of altitudes and seasons in nitrogen showed significant variation. Potassium ranged between 102.29 and 206.22 kg ha⁻¹. The combined effect of season and soil depth also showed significant variation in level of potassium. The soil organic carbon values were between 0.14 and 0.19 per cent and pH values ranged between 6.33 and 6.75 which was slightly acidic in nature.

Maurya *et al.* (2014) described the impact of altitude on soil characteristics of Almora District. Altitude was one of the major topographical, which influenced the fertility status of soil. Content of organic carbon, nitrogen, phosphorus and potassium were high in range and increased with altitudes. Average content of total nitrogen, phosphorus and potassium in forest was 2115.39, 111.89 and 2189.36 kg ha⁻¹, respectively.

Kumar *et al.* (2013) described the soil properties of Banj Oak and Chir Pine dominated forests. The higher accumulation of litter and presence of moisture in Banj oak forest favors higher nutrient level of nitrogen, phosphorus and potassium compared to Chir pine forest. The soil organic carbon also reduced with increasing altitude. While bulk density had reverse trend with soil organic carbon in both the forests at different peaks of same region. In Banj oak forest, the highest density and total basal cover was reported 1,100 tree ha⁻¹ and 58.86 m² ha⁻¹, respectively. However, the highest values of density and total basal cover of Chir pine forest was 560 tree ha⁻¹ and 56.94 m² ha⁻¹, respectively. The total density and basal cover of both the forests reduced with increasing altitude. The study concluded that Banj oak forest had better nutrient cycling ability, well developed forest floor had a greater protective and productive features compared to the Chir pine forest.

Singh *et al.* (2009) carried out a study in a pine forest along altitudinal gradients in Garhwal Himalaya and observed that the soil pH of pine forest is slightly acidic and SOC content decreased with increasing altitudes. Nitrogen also decreased with increasing altitudes

but the trend was reverse for phosphorus. Physical and chemical properties of soils have been used to evaluate the ecological functioning of the forest soils. Forest soils are important for maintaining the normal cycling and make soil physicochemical conditions favorable for plant growth (Bargali *et al.* 1998).

2.3.1 pH

Tiwari *et al.* (2013) recorded soil pH of different forest tree species. Highest values (5.76) were recorded in *Abies pindrow*, followed by *Cedrus deodara* (5.33), Mixed Forest (5.50) and *Pinus wallichiana* (5.09 per cent). Drohan and Sharp (1997) also reported reduction in forest soil pH due to acid deposition. They reported 3 times greater pH ions flux beneath larch than that of Sitka spruce indicating larch was more acidifying than spruce. Inter species difference in soil pH in a mixed forest were also reported by Finzi *et al.* (1998); Matsuura *et al.* (2001). Gupta (1980) reported that the pH range of Koyhikerh and Mecleodganj soil profiles from northwest Himalaya of Kangra reflecting good growth of *Cedrus deodara* was 4.8 to 5.3 and 6.2 to 8.2, respectively. They found that in case of *Pinus roxburghii*, it was from 7.1 to 8.3 for Bankhandi and 5.5 to 6.0 for Norpur soil profile and had also reported that *Cedrus deodara* and *Pinus roxburghii* had been found to grow well even on clay and sand clay-loam soil of northwest Himalaya.

The soils on hill tops and hill side are slightly acidic with pH varying from 6.11 to 6.50, whereas those on the ravenous area, piedmont plain and alluvial plain were slightly alkaline to alkaline with range of 7.55 to 8.57 (Sitanggang *et al.* 2006). Slightly acidic to alkaline pH was observed in karewa soils of Kashmir region (Kirmani, 2004). Takahashi *et al.* (2001) found that soils in the coniferous forests of Japan were mostly acidic. Similarly, pH in the range of 5.5 - 6.5 was reported by Bisht and Lodhiyal 2005 in coniferous forests of central Himalaya. In an experiment soil pH of alpine sites ranged 4.0 to 6.0, which were lower than that reported for oak and pine forest sites (6.0 to 6.3) in the lower elevations (Singh and Singh 1987).

2.3.2 Bulk density

Tiwari *et al.* (2013) who recorded bulk density of different forest tree species and the values observed were 1.74, 1.58 and 1.72 (*Pinus wallichiana*), 1.37, 1.58 and 1.49 (*Cedrus deodara*) and 1.34, 1.49 and 1.79 (Mixed Forest) gm cm⁻³ at 0-15, 15-30 and 30-45 cm soil

depth, respectively. But, soil bulk density values of temperate forests of Nanda Devi Biosphere Reserve ranged between 1.14 to 1.91 g cm⁻³. Zarin *et al.* (1998) found that median bulk density values were lowest for the 0-10 cm depth in coniferous forest soils and highest for the 10-40 cm depth in moorland soils. Bisht and Lodhiyal (2005) reported soil bulk density values in the range of 0.95-1.20 g cm⁻³ in the coniferous forest of central Himalaya (Kumaon). Bulk density of forest soils reported by Page-Dumroese *et al.* (1999) was 1.10 and 1.24 mg m⁻³ at 0 to 10 cm and 1.11 to 1.21 mg m⁻³ at 10 to 20 cm. However, low average values (1.05 mg m⁻³) of bulk density were reported by DeLong *et al.* (2011).

Semwal *et al.* (2009) determined the physical and chemical features of soils of Uttarakhand in the Central Himalayas. The values ranged from 1.78-2.83 per cent for organic carbon, 0.15-0.24 per cent for phosphorus and 1.53-3.66 per cent for potassium. Maximum organic carbon (2.83 per cent) was observed in winter season under undisturbed oak forest as compared to cedar and pine forest and lowest carbon content (1.4 per cent) was estimated in cedar forest in spring season. Maximum phosphorus content (2.41 per cent) was observed in soil depth 0-10 cm of pine undisturbed forest as compared to oak cedar forest. More accumulation of potassium (3.66 per cent) was found in mid-layer (10-20 cm) in cedar forest as compared to oak and pine forest. Disturbed forests exposed to high degree of biotic stress had comparatively low mineral content in their soils. The stresses were more pronounced in the forests of low elevations.

Tate *et al.* (2004) observed that soil surface bulk density was 16 to 22 per cent lower under canopy cover compared to open grasslands, and was greater at grazed sites than at non grazed sites. Soil bulk density and acidity were found to recover completely to those found under forest covers after reestablishment of high elevation grassland by *Acacia koa* in Hawaii (Scowcroft *et al.* 2004).

Neeraj *et al.* (2001) studied the effect of altitude and aspect on bulk density in mid elevation forests of Central Himalaya (India) and the values recorded were 1.0 and 1.2 (1300-1500m asl), 1.0 and 1.2 (1500-1800m asl) and 1.1 and 1.3 g cm⁻³ on East and West aspects respectively. Dalai (1997) analyzed the soil for its chemical properties under chir pine forest and found that the soil had average pH values 5.87 and 5.74, organic carbon 1.34 and 1.05.

Sharma (1991) analyzed the soil under chir pine forest of Solan Forest Division for its chemical properties and found that the soil had 5.0 to 8.4 pH, 0.17 to 3.37 per cent organic carbon, 94.0 to 223 ppm available N, 10.0 to 25.0 ppm available P and 87 to 112 ppm

available Kaushal (1992) found positive and significant correlation of organic matter with increase in altitude.

2.3.3 Organic Carbon

In the study, Chaturvedi and Melkania (2013) reported that soil organic carbon (SOC) stock and soil characteristics were measured in mixed oak and mixed pine forest for two years (2008-10) at different altitudinal ranges of Kumaon Himalaya. The study revealed that soil texture at selected sites varied from loam to sandy loam and soil pH ranged from slightly acidic to neutral. The SOC stock was found to be higher in mixed oak forests than mixed pine forests. The average SOC stock ranged from 110.37 to 125.03 ton/ha at non-degraded mixed oak forest site and 43.81 to 53.47 ton/ha at degraded mixed pine forest site. P_2O_5 , K_2O , and C:N ratio were also found to be higher in mixed oak forest than mixed pine forest.

Pande *et al.* (2012) described the A study was for determining the impact of biotic disturbance on physical and chemical characteristics in mixed oak forest zone of Nainital catchment (Uttarakhand) in the Kumaun Himalaya. Three sites viz., undisturbed, moderately disturbed and highly disturbed were selected in a mixed oak forest and each site was further divided into three sub sites viz., Hill Base, Hill Slope and Hill Top. The findings indicated that there was more accumulation of nutrients in the undisturbed site as compared to moderately and highly disturbed sites. Maximum organic carbon (2.19 per cent) was detected in surface soil (0-10cm) at hill top of undisturbed forest and minimum (1.01 per cent) in deep soil (20-30cm) at hill base of highly disturbed site. Maximum nitrogen (0.36 per cent) and organic matter content (3.78 per cent) was detected in undisturbed forest as compared to moderately and highly disturbed sites.

Raina and Gupta (2009) studied the soil characteristics in relation to forest vegetation and parent material in Kempty range of Mussorie forest (Uttarakhand) they found that the organic matter and available nitrogen contents in the surface horizons increased with increase in altitude.

Sheikh *et al.* (2009) estimated the stocks of soil organic carbon along altitudinal gradients in coniferous subtropical and broadleaf temperate forests of Garhwal Himalaya. The stocks of SOC were found to be decreased with altitude from 185.6 to 160.8 t C ha⁻¹ and from 141.6 to 124.8 t C ha⁻¹ in temperate (*Quercus leucotrichophora*) and subtropical (*Pinus roxburghii*) forests, respectively.

Soil properties change with the overgrowing vegetation, which was reported by Singh *et al.* (2009) along altitudinal gradients in the oak and pine forest forests of Garhwal Himalaya. The soil organic carbon (SOC) was higher in oak forest. The SOC content decreased with increasing altitudes in both pine and oak forests. They found soil organic carbon availability with reduced trend in both the forests. They concluded that SOC availability with reduced trend in both the forests and altitudes might be due to reduced density and total basal cover of the trees with altitudes.

Chauhan *et al.* (2004) studied soil organic carbon of *Pinus roxburghii* community at Forest Research Institute, Dehradun, India and they reported 48 t ha⁻¹ organic carbon from the site. Whereas Sharma *et al.* (2011) reported SOC varied between 40.03 cmg/ha on SW aspect (*Pinus roxburghii*) and 177.5 cmg/ha on NE aspect (*Cedrus deodar*) forest in temperate region of Garhwal Himalaya.

According to Patil and Prasad (2004) organic carbon varied from 33 to 2 g kg⁻¹ with depth, being higher in surface than in sub-surface horizons. Topography, slope and type of vegetation showed a definite relationship. The organic carbon content of Kiar-Nagali Micro watershed in Himachal Pradesh varied from 11.7 to 23.5 g kg⁻¹ in surface and 4.5 to 16.2 g kg⁻¹ in sub-surface soils, respectively (Tripathi *et al.* 2006).

The nature and amount of organic carbon produced after decomposition of litter depend on the dominating tree species (Vogt *et al.* 1986 and Fu *et al.* 2004) and the characteristics of the area (Liski and Westman 1997; Zhong and Qigua 2001; Cauteaux *et al.* 2001; Koch and Makeschin 2004), which regulate the physical, chemical and biological properties of soils. According to Lal (2005) the soil organic carbon values in forest soils may range from 0.00 per cent in very young soils to as much as 50 per cent (w/w) in some organic or wetland soils, with most soils containing between 0.3 and 11.5 per cent in the surface 20 cm of mineral soil.

2.3.4 Nitrogen

Nitrogen is an essential element for forest growth, and usually acts as a limiting factor for the productivity of forest ecosystems. It was estimated that more than 90 per cent of the soil nitrogen reserves were in the soil organic pool and acts as a potential source of soil available nitrogen through mineralization. The processes of nitrogen uptake by vegetation and return to soils as litter periodically is one of the basic features of forest ecosystems (Chen

et al. 2000). Soil nitrogen availability and net nitrogen mineralization and nitrification rates had been found to vary with tree species composition in temperate and boreal forests (Bargali *et al.* 1998; Zhong and Makeschin 2004).

Verma *et al.* (1990) reported that the available nitrogen content ranged from 36.0 to 205.0 ppm with a mean value of 118.0 ppm in some alluvial soils of Kashmir. Sharma and Bhandari (1992) observed that available nitrogen content ranged from 92 to 231 and 27 to 210 ppm with a mean value of 158 and 138 ppm in the surface and sub-surface soils, respectively in Himachal Pradesh. The available nitrogen content of some apple orchard soils of valley varied from 56 to 140 and 22 to 118 ppm in the surface and sub-surface horizons, respectively. Mushki (1994) observed that available phosphorus in some apple orchard soils of Kashmir ranged from 10 to 20 and 9 to 26 ppm in the surface and subsurface layers, respectively.

Vogt *et al.* (1986) reported that evergreen forests had higher root mass and turnover and greater circulation of nitrogen in the forest floor. According to them one annual litter fall input of nitrogen may be retained in the forests in floor for more than 20 years in boreal and 10 years in cold temperate forests in contrast to less than 2 years for tropical forests. The potential nitrogen mineralization and nitrification linearly increased with field age, and standing crop of plant biomass had been reported to be highly correlated to pools and rates of N-cycling (Zak *et al.* 1990).

2.3.5 Phosphorus

The available phosphorus content varied from 12.0 to 42.6 kg ha⁻¹. The highest mean phosphorus of soil was found in Kiar and Nagali-II (Tripathi *et al.* 2006). Sharma *et al.* (2008) noticed a range of 9.38 to 84.9 kg ha⁻¹ averaging to 37.3 kg ha⁻¹ for available phosphorus in Amritsar, Punjab. Singh and Bansal (2009) reported that available phosphorus in Barpur alluvial soil series of Indo-Gangatic Plains ranged from 9.0 to 153 mg ka⁻¹ in surface soil samples.

Antoo (2000) while studied the physico-chemical properties of soils of Zangir found that phosphorus content ranged from 12.90 to 16.70 ppm with a mean value of 15.01 ppm. The available phosphorus content in the surface and sub-surface layers of karewa soils ranged from 12.0 to 19.10 ppm and 8.0 to 17.20 ppm, respectively reported by Najjar (2002). The

available phosphorus content of forest soils of Kashmir ranged medium to high (Amarjit 2004).

Farida (1997) observed that the available phosphorus content varied from 16.8 to 19 ppm in karewa soils of Kashmir. Khan *et al.* (1997) reported that available phosphorus was high in the surface and decreased downwards in the soil profiles. Neeraj *et al.* (2001) studied the effect of altitudinal ranges and aspects on water holding capacity in mid elevation forests of Central Himalaya (India) and the values recorded were 43.7 per cent and 29.8 per cent (1300-1500m asl), 37 per cent and 40 per cent (1500-1800m asl) and 25.1 per cent and 28.3 per cent (1800-2000m asl) on east and west aspects, respectively.

Mandal *et al.* (1990) studied the forest sites of the eastern Himalaya, reported the distribution of phosphorus followed no definite trend, though soils at higher altitude showed higher available phosphorus content. They found that the content of easily soluble or available phosphorus (P_2O_5) varied in virgin forest soils from 10ppm-200ppm.

2.3.6 Potassium

Mehraj *et al.* (2010) analyzed the physico-chemical properties and an economic analysis of the soil of two forest types viz., oak (*Quercus leucotrichophora*) and pine (*Pine roxburghii* Sargent). The collected soil samples were analysed for texture, water holding capacity, pH, potassium, phosphorus and nitrogen. The available phosphorus in oak forest was higher 17.99 kg ha⁻¹ than in pine forest 16.88 kg ha⁻¹. The potassium for oak and pine forests was 188.92 kg ha⁻¹ and 166.43 kg ha⁻¹. Oak forest was rich in nutrients than pine forest. The oak forest should be preferred to protect, enhanced their nutrients level for enhanced the forest ecosystem services.

Tsui *et al.* (2004) clarified the relationships between soil properties and the landscape in a lowland rain forest of southern Taiwan. Soil samples were taken at 0-5 and 5-15 cm in contiguous 10×10m quadrates along an altitudinal ranges from 300 to 480m with three slope position viz., summit, back slope and foot slope position, each with a different floristic composition and structure. Organic carbon, available N, available K, extractable Fe and exchangeable Na were highest on the summit, while pH, available P, exchangeable Ca and Mg were significantly higher on the foot slope at 0-5 cm soil. The organic carbon increased with increasing altitude due to the quality of litter fall present in that forest and lower rate of decomposition in summit forest.

Kaushal *et al.* (1997) observed that soils under deodar forests in northwest Himalaya (HP) were high in available K, Na, Ca and Mg. They reported increase in potassium values with increase in altitude in the Garhwal Himalaya (Jha *et al.* 2002 and Dimiri *et al.* 2006). A study was conducted in foot hills of Pir Panjal and Siwalik (Rajouri) Range of Jammu and Kashmir Himalaya and available Potassium was recorded on different altitudinal ranges of northern aspect, the values obtained at Hill base 102, 126 and 136 (500-700m asl), Hill slope 98, 110 and 127 (700-900m asl) and Hill top 136, 121 and 153 (900-1200m asl) kg ha⁻¹ at 0-10, 10-20 and 20-30 cm soil depth, respectively. The results depicted that increased trend was found in the values with respect to soil depth and altitude except in Hill top where decreased trend 10-20 cm was recorded (Dangwal *et al.* 2012). Similar trend were also recorded in temperate forests of Uttarakhand and values of available Potassium were 224, 174 and 280 (Undisturbed site), 174, 205 and 224 (Moderately disturbed site) and 173, 224 and 207 (Highly disturbed site) kg ha⁻¹ at 0-10, 10-20 and 20-30 cm soil depth, respectively (Bisht and Bhatt 2010).

The mineral potassium (exchangeable potassium) is found in soluble form in all parts of plants, and is responsible for the carbohydrate and protein formations. Potassium activates the enzymes of the plants, which in turn help in the metabolism of the plants, starch synthesis, nitrate reduction, and also plays a role in sugar degradation. Potassium performs very vital processes like regulating transpiration and respiration, influencing enzyme action, and synthesis of carbohydrates and proteins, etc. (Brady, 1996). The decrease of potassium is caused by leaching and drainage, which result in the destruction of vegetation (Basumatary and Bordoloi 1992).

Chapter-3

MATERIALS AND METHODS

The present study entitled “**Variation in vegetation along altitude and aspects in western Himalaya**” was undertaken in the year of 2018-2019 in purposely selected natural forests of Kandaghat Forest Range of Solan district of Himachal Pradesh, western Himalaya. For this three different altitude viz., <1800m, 1800-2100m and >2100m ranges were selected. At each altitude three replications were randomly laid out with plot size of 0.1 ha in four different aspects viz., North, South, West and East, respectively. The details of the experimental site, sampling technique, methodologies adopted and material used for the investigation are as under:

3.1 EXPERIMENTAL SITE

3.1.1 Location

The Solan district lies between longitudes 76°56' and 77°12' East and latitudes 30°46' and 31°10' North. The geographical area of division is 721.30 sq. km. It is surrounded on the North by the Shimla Forest Division, on the East by the Rajgarh Forest Range, on the West by Kunihar Forest Division and South by Haryana State. The Northern and North-Western slopes of Sutlej catchment, North Eastern and Eastern slopes of Ghaggar catchment of the erst while Pepsu State now Kandaghat Range are having good forests of Ban-Oak. The important peak in the tract are Karol (2253 meters), Rajgrah (2100 meters), Monkey Point (1907 meters) Basha top (1900 meters) and Banasar top (1664 meters).

Table 1: Coordinates of the study site

Altitudinal ranges (m a.s.l.)/ Coordinates	Latitude				Longitude			
	North	South	West	East	North	South	West	East
E ₁ (<1800m)	33°50'33'' to 30°75'86'' N	30°56'16'' to 33°95'20'' N	33°57'42'' to 30°57'82'' N	33°055'26'' to 33°55'41'' N	77°04'17'' to 77°05'81'' E	77°05'46'' to 77°08'78'' E	77°05'41'' to 77°05'72'' E	77°05'57'' to 76°61'13'' E
E ₂ (1800-2100m)	30°56'43'' to 30°94'13'' N	30°95'21'' to 30°56'62'' N	33°95'34'' to 33°95'99'' N	33°55'50'' to 30°56'32'' N	77°06'55'' to 77°10'99'' E	77°08'87'' to 77°05'49'' E	77°08'86'' to 77°09'84'' E	70°06'08'' to 70°06'11'' E
E ₃ (>2100m)	30°56'49'' to 33°56'63'' N	30°94'33'' to 30°94'37'' N	33°56'53'' to 33°56'72'' N	30°55'04'' to 30°56'05'' N	77°12'08'' to 77°12'41'' E	77°09'39'' to 77°09'64'' E	77°05'56'' to 77°05'96'' E	77°06'16'' to 77°06'29'' E

3.1.2 Climate

In lower reaches the climate is sub-tropical and moist temperate in the upper range. The seasons are well marked and there are distinct summer, rainy, autumn and winter season. Precipitation is received both during the rainy and winter season, but the bulk of it is received during rainy season from the southeast monsoon. The rainy season commences from the first week of July and continues up to the last week of August but sometime extends up to mid of September. Winter rains generally commence from the last week of December and continue up to end of February. Precipitation in the form of snow is received during January, February. Due to variation in this division, the temperature also varies considerably.

Table 2: Mean monthly meteorological data of the study area for the year 2018-2019

Month	Temperature (°C)		Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum		
January	21.5	10.5	45.13	45.5
February	23.5	12.3	42.57	78.15
March	28.3	15.5	34.07	38.05
April	32.35	17.25	48.75	38.2
May	35.4	23.75	44.70	38.1
June	35.7	25.95	57.10	143.85
July	31.7	21.85	80.95	278.45
August	30.75	23	82.10	221.2
September	30.1	19.5	79.10	187.85
October	28.6	22.5	59.10	2.80
November	22.75	17.75	53.23	23.6
December	22.75	12.25	58.08	20.9

Source: Meteorological observatory, Department of Environment Science, Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan

3.2 TREATMENT DETAILS

A) Aspect: 4

A₁ - Northern

A₂ - Southern

A₃ - Western

A₄ - Eastern

B) Elevational ranges: 3

E₁ - <1800m

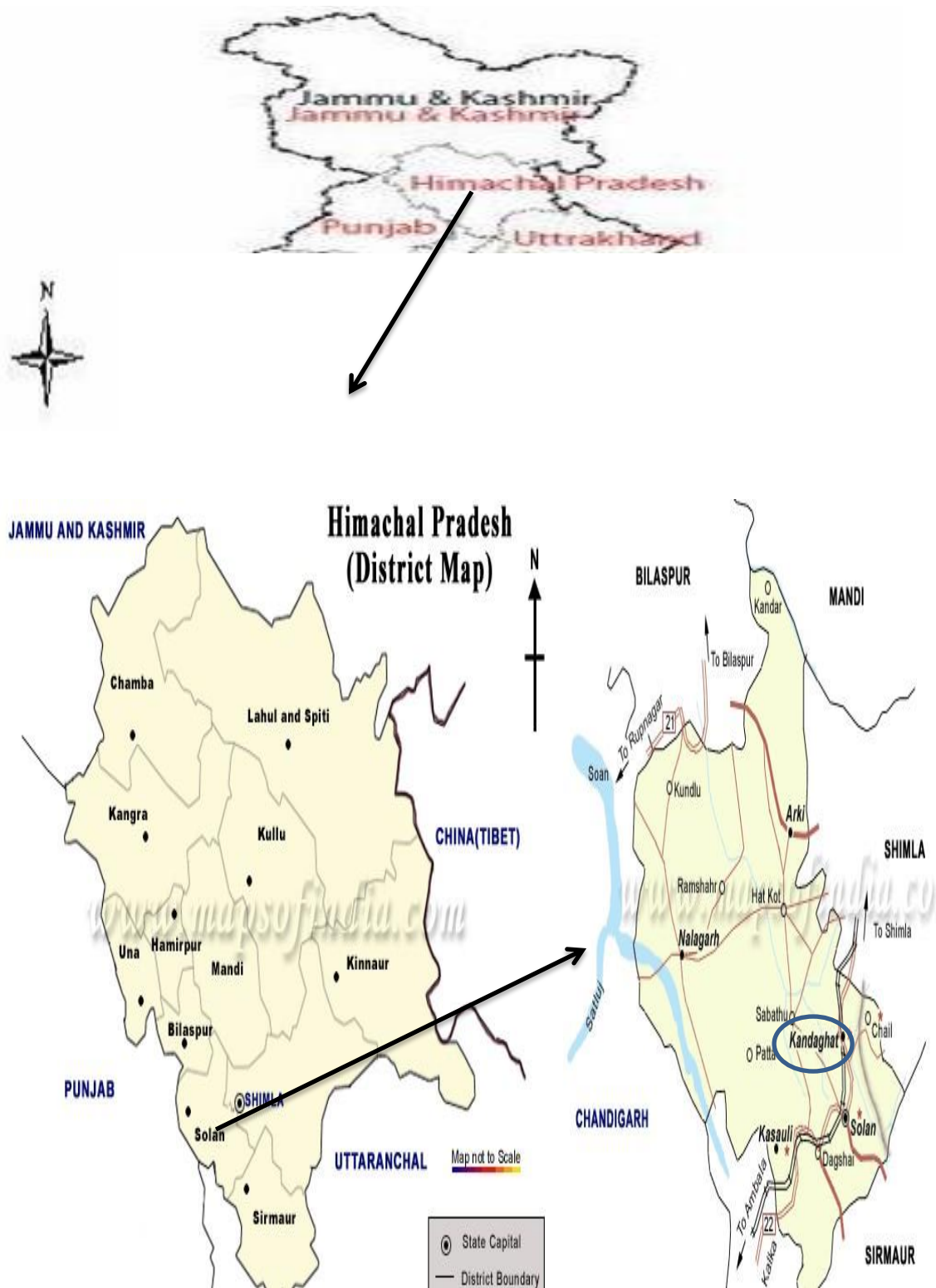
E₂ - 1800-2100m

E₃ - >2100m

Statistical Design: RBD (Factorial)

Replication: 3

Total number of treatments: 12 [4(aspect) × 3(altitude)] = 36



Map of the study area

3.3 EXPERIMENTAL METHODOLOGY

Experiment 1: Phytosociological behaviour and regeneration status of vegetation at different altitudinal ranges and aspects

3.3.1 VEGETATION ANALYSIS

a. Tree

The plots of 0.1 ha ($31.62 \times 31.62 \text{m}^2$) were marked in each elevation and aspects for analyzing structural and functional parameters of tree vegetation. Density of the trees was calculated by counting trees in each sample plot. Basal area of each tree in the sample plot was determined by tree caliper and height was measured by Spiegel Releskope.

b. Shrubs

The shrub characteristics at each altitude and aspect were studied by laying out five quadratic sub-plots of size $5\text{m} \times 5\text{m}$ in each sample plots of selected for trees. Density of shrub was calculated by counting plants of different species in each sub-plot. Stratified sampling of each shrub species was done by grouping them in to three categories by visual appearance viz., a) large b) medium and c) small on the basis of size and number of stems in each of them. In each category, numbers of plants were counted. Basal area of stem was determined by vernier caliper.

c. Herbs

Herbaceous vegetation in different elevation and aspects was studied at the time of its peak growth in month of September by harvesting one quadrat of size $1\text{m} \times 1\text{m}$ each from each sample plot at every elevation and aspect. The vegetation from each quadrat was segregated species wise and identified with the help of herbarium in the university, expert, journals and research books. The numbers of tiller in each herb species were counted to find out their density. Collar diameter of bundle of tillers of each herb species was measured to determine basal area of each species. Frequency of a species was determined by its presence in different quadrates sampled.

Basal area

The cross sectional area of shrubs, herbs and trees falling in the recording unit was determined by the formula as:

$$\text{Basal area} = \frac{\pi d^2}{4}$$

Where,

d = diameter in 'm'

Density

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrates is divided by the total number of quadrates studied. Density is calculated by the formula as:

$$\text{Density (D)} = \frac{\text{Total number of individuals of a species in all quadrate}}{\text{Total number of quadrates studied}}$$

Frequency

It is the indicator of samples in which given species occurs, thus expresses the distribution of various species in community.

$$\text{Frequency} = \frac{\text{Number of sample units in which species occurred}}{\text{Number of sampling units studied}}$$

Relative basal area, Relative Density, Relative Frequency and Importance value index

These relative parameters were calculated from the per cent frequency, density and basal area according to procedure given by Phillips (1959).

a. Relative basal area (RBA) $= \frac{\text{Total basal area of the species}}{\text{Total basal area of all the Species}} \times 100$

b. Relative Density (RD) $= \frac{\text{Number of individuals of the species}}{\text{Total number of individuals of all the species}} \times 100$

c. Relative Frequency (RF) $= \frac{\text{Quadrates of occurrence of the species}}{\text{Total number quadrates of occurrence of all the species}} \times 100$

d. Importance value index (IVI): The IVI is an integrated measurement of the relative frequency, relative density and relative basal area which calculated for trees and shrubs separately.

$$\text{IVI} = \text{Relative basal area (RBA)} + \text{Relative density (RD)} + \text{Relative frequency (RF)}$$

3.3.2 VEGETATION INDICES

Species richness

The species richness was calculated by using the method ‘Margalrf’s index of richness’ (Magurran, 1988).

$$D_{mg} = (S-1)/\ln N$$

Where, S =Total number of species

N =Total number of individual

Shannon’s Index (H)

Shannon’s index of diversity was calculated by using Margalef formula (Odum, 1971).

$$H = -\sum (n_i/N) \ln (n_i/N)$$

Where,

n_i = Importance Value Index of each species

N = Total Importance Value Index

Simpson’s index of dominance (D)

The formula used to determine Simpson’s index was

$$D = \sum (p_i)^2$$

$$p_i = \frac{n_i}{N}$$

Where,

D = Simpson’s index of dominance

P_i = The proportion of important value index of i^{th} species

n_i = the important value index of the i^{th} species

N = the important value index of all the species

Similarity Index (SI)

It expresses the ratio of the common species to all the species found in the vegetation and was determined by the method given by Sorenson 1948.

a. **Index of Similarity (SI)** =
$$\frac{2C}{A+B}$$

Where, A = Number of species in community A

B = Number of species in community B

C = Number of common species in both the communities

b. **Index of dissimilarity (D)** = 1-S

3.3.3 STAND CHARACTERISTICS

Tree identification

Trees within each sample plot were identified and counted to determine density and species composition of the stand. Plant specimens were collected for all the plants that occurred in the plots and sub-sub-plots of each study site. These specimens were identified with the help of experts, herbarium and literature from Dr. Yaswant Parmar University of Horticulture and Forestry.

Tree diameter

The diameter was measured at DBH viz., 1.37 m above ground level with the help of caliper and expressed in centimeters.

Tree height

The height of the tree was measured with the help of Spiegel Relaskop and expressed in Meters.

Form factor (FF)

The form factor was calculated separately for each diameter class using the formula given by Bitterlich (1984).

$$ff = \frac{2}{3} \times \frac{h_1}{H}$$

Where,

ff - Form factor,

h_1 - Height (m) at which diameter is half of the dbh,

H - Total height (m) of the tree.

Volume of standing trees

Volume of standing trees was calculated by Pressler formula (1865) and was expressed in cubic meters.

$$V = \frac{\pi d^2}{4} \times h \times ff \times \frac{1}{100 \times 100}$$

Where,

V - Volume (m^3)

d - Diameter at breast height (cm)

h - Tree height (m)

ff - Form factor

Further, the volume per hectare was calculated by multiplying the mean volume with number of trees in respective diameter classes per hectare.

3.3.4 Canopy Analysis

Crown width

The crown width (m) was measured in two directions (north-south and east-west) and average was calculated as suggested by Assmann (1970); Chaturvedi and Khanna (1982).

$$CW = \frac{D_1 + D_2}{2}$$

Where,

CW = Crown width (m)

D_1 = Crown diameter in north-south

D_2 = Crown diameter in east-west direction

Crown height

It is the height of the crown as measured vertically from the ground level to the point half way between the lowest green branches forming green crown all round and was measured with the help of Spiegel Relaskop and expressed in meters.

Crown length

It is the vertical measurement of the crown of a tree from the tip to the point half way between the lowest green branches forming green crown all round and the lowest green branch on the bole and was measured with the help of Spiegel Relaskop and expressed in meters.

The below discussed crown ratios were estimated as per the descriptions of (Assmann, 1970).

Crown Basal Area

Crown Basal Area is calculated by the following formula:

$$\text{Crown Basal Area} = \pi/4 \times (\text{Crown width})^2$$

Crown Surface Area

Crown Surface Area is calculated by the following formula:

$$\text{Crown Surface Area} = \pi/4 \times (b \sqrt{4I^2 + b^2})$$

Where,

b = crown width

I = crown length

Crown Volume

Crown Volume is calculated by the following formula:

$$\text{Crown volume} = \pi/12 \times (b)^2 \times l$$

Where,

B = crown width

l = crown length

Crown per cent

Crown per cent is calculated by the following formula:

$$\text{Crown per cent} = \text{Crown length} \times 100 / \text{Tree height}$$

Crown spread

$$\text{Degree of crown spread} = \text{Crown width} / \text{Tree height}$$

Crown fullness ratio

Crown fullness ratio is calculated by the following formula:

$$\text{Crown fullness ratio} = \text{Crown width} / \text{Crown length}$$

Crown projection ratio

Crown projection ratio is calculated by the following formula:

$$\text{Crown projection ratio} = \text{Crown width} / \text{Tree diameter}$$

Crown quotient to ground cover area

Crown quotient to ground cover area is calculated by the following formula:

$$\text{Crown quotient to ground cover area} = (\text{Crown width})^2 / (\text{Tree diameter})^2$$

Crown Index

Crown Index is calculated by the following formula:

$$\text{Crown Index} = \text{Crown length} / \text{Crown width}$$

3.3.5 Solar Radiation (Influx)

Light transmission ratio in selected sample plots was recorded by HTC LX-101 Digital Luxmeter under trees of different diameter classes and outside the canopy during day time and the value in percentage of light intensity under the canopy to that in the open was calculated as under (Rao, 1998). The readings were recorded every after 15 days and average value was calculated.

$$\text{Solar radiation (\%)} = \frac{\text{Total solar radiation below the canopy}}{\text{Total solar radiation in the open}} \times 100$$

3.3.6 Regeneration Status

The study was conducted for recruits (defined as current year's seedlings), un-established regeneration (seedling other than recruits which has not yet established and the height was less than 2 m). Four un-established plants taken equivalent to one established plant and established regeneration having height of more than 2m. The height of un-established plants was also measured for the assessment of regeneration (Champion, 1935). The collected data was analyzed using the formulae given by Chacko (1965).

$$\text{Recruits (r) /ha} = \frac{2500 \sum_{i=1}^n r_i}{m}$$

$$\text{Un-established regeneration (u)/ha} = \frac{2500 \sum_{i=1}^n u_i}{m}$$

$$\text{Established regeneration (e)/ha} = \frac{2500 \sum_{i=1}^n e_i}{m}$$

Where,

n = Number of sampling units

m = Total number of recording units in survey

r_i = Total number of recruits in each sampling unit

u_i = Total number of un-established plants in each sampling unit

e_i = Total number of established plants in each sampling unit

$$\text{Weighted Average height (cm)} = \frac{\text{Total height of un-established regeneration} + (\text{Number of established plants} \times \text{establishment height})}{\text{Total un-established plants} + \text{Total established plants}}$$

On the basis of above estimates following indicators were calculated

$$\text{Establishment index (I}_1\text{)} = \frac{\text{Weighted average height}}{\text{Establishment height}}$$

$$\text{Stocking index (I}_2\text{)} = \frac{1}{2500} \times \frac{\text{Un-established regeneration/ha}}{4} + \frac{\text{Established regeneration/ha}}{1}$$

$$\text{Established stocking per cent} = 100 (I_1 \times I_2)$$

$$\text{Regeneration success (\%)} = \text{Stocking index (I}_2\text{)} \times 100$$

Experiment 2: Biomass production and carbon stock of vegetation at different altitudinal ranges and aspects

3.4 Tree biomass: Tree biomass was calculated by adding above ground tree biomass and below ground tree biomass.

a. Shrub biomass

Shrub biomass was estimated using 5m×5m quadrates. All the shrubs occurring within the borders of the quadrates were enumerated. The diameter of all tillers was measured at base with the help of caliper according to the method given by Chaturvedi and Khanna (1982). The fresh weight of the shrubs was taken using spring balance. A sub sample of the shrubs was taken to the laboratory for drying to obtain the dried weight of shrubs.

b. Herb biomass

Grass/herb biomass was estimated using 1m×1m quadrates. The total herb biomass occurring within the borders of the quadrate was cut at ground level and collected samples was weighed, sub sampled and oven dried at 65±5°C to a constant weight. The grass biomass was converted into carbon by multiplying with a factor of 0.5 (IPCC default value).

3.4.1 Aboveground biomass

a. Volume estimation

The diameter at breast height (dbh) was measured with the help of tree caliper and height measured with Ravi's altimeter. Local volume equation developed for specific tree species and region was used for calculating the volume of the forest trees of the sample plot (Table 3).

Table 3: Equations for volume estimation of different woody tree species

Sr. No.	Name of species	Volume equation
1	<i>Acer oblongum</i>	$V = 0.05026 + 0.296846 \times D^2 \times H$
2	<i>Bauhinia variegata</i>	$V = -0.04262 + 6.09491 \times D^2$
3	<i>Cedrus deodara</i>	$V = -0.0017 + 8.2098 \times D^2$
4	<i>Grewia optiva</i>	$V = 0.007606/D^2 - 0.033037/D + 1.868567 + 4.483454 \times D$
5	<i>Myrica esculenta</i>	$V = -0.002 + 0.256 \times D^2 \times H$
6	<i>Pinus roxburghii</i>	$V = 0.034529 + 0.284662 \times D^2 \times H$
7	<i>Populus deltoids</i>	$V = 0.193297 - 2.267002 \times D + 10.679492 \times D^2$
8	<i>Punica granatum</i>	$V = 0.007602/D^2 - 0.0033037/D + 1.868567 + 4.48345D$
9	<i>Pyrus pashia</i>	$V = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.48345D$
10	<i>Pistacia integerrima</i>	$V = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 \times D$
11	<i>Quercus leucotrichophora</i>	$V = 0.68238 + 5.049937 \times D - 2.770924 \times D$
12	<i>Rhododendron arboreum</i>	$V = 0.06007 - 0.21874 + \sqrt{D} + 3.6342 \times D^2$
13	<i>Toona ciliata</i>	$V = 0.12483 + 0.28446 \times D^2 \times H$

b. Biomass estimation

The estimation of aboveground biomass of woody trees by using expansion factors and specific gravity, which were developed for estimation of above ground biomass of trees by non-destructive method.

$$\text{Aboveground biomass density (t ha}^{-1}\text{)} = \text{VOB} \times \text{ASG} \times \text{BEF}$$

Where,

VOB = Volume over bark

ASG = Average wood Specific gravity

BEF = Biomass expansion factor

c. Biomass expansion factor (BEF)

The ratio of total aboveground oven-dry biomass density of trees with a minimum dbh of 10cm or more to the oven-dry biomass density of the inventoried volume. Some expansion factors developed for various tree species is given in the Table (4).

Table 4: Biomass expansion factor of some important woody species

Sr. No.	Name of species	Expansion factor
1	<i>Acer oblongum</i>	1.40
2	<i>Bauhinia variegata</i>	1.40
3	<i>Cedrus deodara</i>	1.40
4	<i>Grewia optiva</i>	1.91
5	<i>Myrica esculenta</i>	1.91
6	<i>Pinus roxburghii</i>	1.91
7	<i>Populus deltoids</i>	1.58
8	<i>Punica granatum</i>	1.50
9	<i>Pyrus pashia</i>	1.50
10	<i>Pistacia integerrima</i>	1.40
11	<i>Quercus leucotrichophora</i>	1.91
12	<i>Rhododendron arboretum</i>	1.40
13	<i>Toona ciliata</i>	1.40

d. Specific gravity

Specific gravity for biomass estimation of different tree species were taken from available literature (Table 4). Wherever the specific gravity values were not available, in that case the stem cores taken to find out specific gravity, which was used further to determine the biomass of the stem using maximum moisture method (Smith, 1954).

$$\text{Gr} = \frac{1}{\frac{\text{Mn}-\text{Mn} + 1}{\text{Mo} \times \text{GSo}}}$$

Where,

Gr = Specific gravity based on grass volume

Mn = Weight of saturated volume sample

Mo = Weight of oven-dried sample

GSo = Average density of wood substances equal to 1.53

Thus the weight of wood was estimated using formula i.e. mass per unit volume.

Table 5: Average specific gravity of stem wood of different tree species

Sr. No.	Name of species	Specific gravity
1	<i>Acer oblongum</i>	0.48
2	<i>Bauhinia variegata</i>	0.67
3	<i>Cedrus deodara</i>	0.46
4	<i>Grewia optiva</i>	0.51
5	<i>Myrica esculenta</i>	0.70
6	<i>Pinus roxburghii</i>	0.49
7	<i>Populus deltoides</i>	0.40
8	<i>Punica granatum</i>	0.99
9	<i>Pyrus pashia</i>	0.71
10	<i>Pistacia integerrima</i>	0.59
11	<i>Quercus leucotrichophora</i>	0.82
12	<i>Rhododendron arboreum</i>	0.57
13	<i>Toona ciliata</i>	0.42

3.4.2 Belowground biomass

Belowground biomass of tree was calculated by multiplying aboveground biomass with a factor of root: shoot ratio of particular tree as per the guidelines of IPCC (1996) Cairns *et al.* (1997). The data pertaining to root: shoot of trees was estimated by:

Belowground biomass = above ground biomass $\times$ Root: Shoot ratio

Table 6: Root: shoot ratio of stem wood of different woody tree species

Sr. No.	Name of species	Root: shoot ratio
1	<i>Acer oblongum</i>	0.26
2	<i>Bauhinia variegata</i>	0.27
3	<i>Cedrus deodara</i>	0.27
4	<i>Grewia optiva</i>	0.50
5	<i>Myrica esculenta</i>	0.21
6	<i>Pinus roxburghii</i>	0.21
7	<i>Populus deltoids</i>	0.50
8	<i>Punica granatum</i>	0.50
9	<i>Pyrus pashia</i>	0.25
10	<i>Pistacia integerrima</i>	0.21
11	<i>Quercus leucotrichophora</i>	0.39
12	<i>Rhododendron arboreum</i>	0.27
13	<i>Toona ciliata</i>	0.27

3.4.3 CARBON STOCK

Above and belowground carbon stock in vegetation was determined by multiplying vegetation biomass with default value 0.5 IPCC (1996)

$$\text{Carbon stock} = \text{Biomass} \times 0.5 \text{ (IPCC default value)}$$

3.4.4 Vegetation carbon density (t ha^{-1})

Vegetation carbon density = tree biomass carbon (t ha^{-1}) + Shrub biomass carbon (t ha^{-1}) + Herb biomass carbon (t ha^{-1})

Experiment 3: Soil physico-chemical properties along different altitudinal ranges and aspect

3.5 Soil analysis

Soil samples were collected from each quadrat at different elevation and aspect. The soil samples for each sub plot area were obtained by digging two profiles up to 30cm deep viz., 0-15, 15-30 cm. Composite samples from all sub areas were obtained at each depth. Samples were air dried in shade, grinded with wooden pestle, passed through 2mm sieve and stored in cloth bags for further laboratory analyzed in a laboratory of the department of Silviculture and Agroforestry. The following physico-chemical attributes of soil were determined by standard methods given below:

3.5.1 Soil humus depth

To record the depth of humus layer, a horizontal cut with the help of sharp knife through the humus layer was made and thickness of the humus recorded on a graduated scale placed in front of the sharp cut.

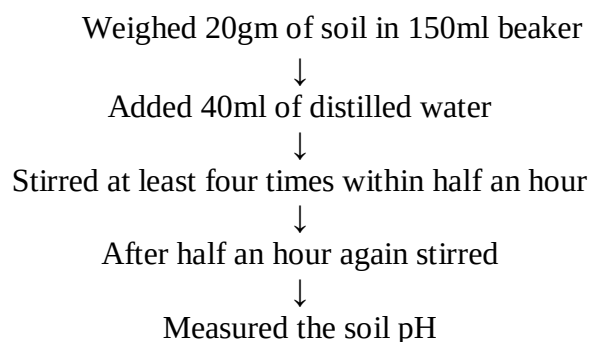
3.5.2 Soil pH

The pH of soil samples was measured at 20°C with the help of a digital pH meter (model AP x 175 E/C). Twenty five gram (25g) of air dry soil sample was thoroughly mixed with 50ml of distilled water (1:2 w/v) and pH of the soil samples was taken after 30 minutes. The pH meter was calibrated before use with standard pH buffers (pH 4 and pH 7).

$$\text{Soil pH} = \frac{\log 1}{H^+} = -\log(H^+)$$

H^+ is expressed as g ions/lit.

The detailed procedure for estimation of available P is as under:



3.5.3 Bulk density

Bulk Density is the ratio of the oven-dry mass of the solids to the volume (the bulk volume includes the volume of the solids and of the pore space) of the soil. Core tube method for undisturbed soil was used to determine the bulk density of soil.

$$\text{Bulk Density (g/cm}^{-3}\text{)} = \frac{\text{weight of oven Dry soil in core (g)}}{\text{Volume of the core (cm}^3\text{)}}$$

Volume of the core was calculated, the using the core length and the diameter of the cutting edge of the sampler.

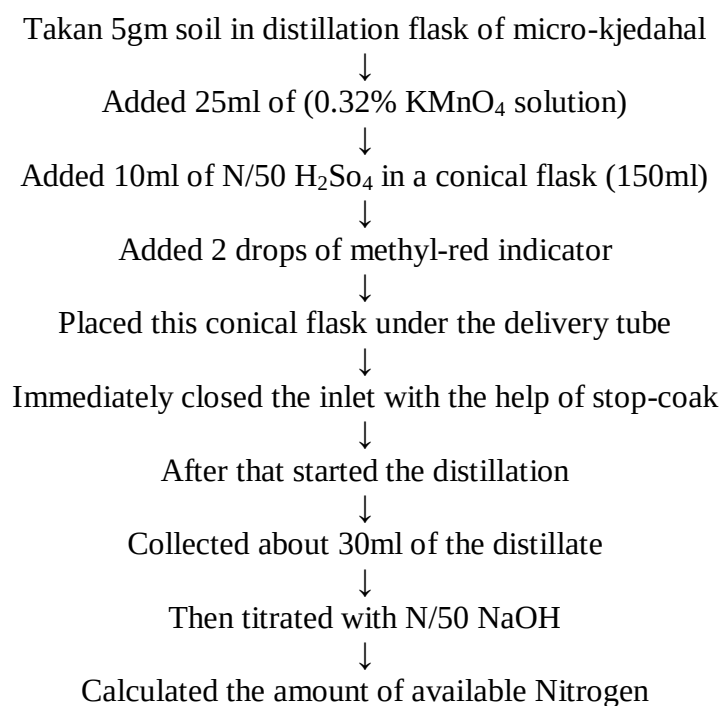
3.5.4 Soil Organic carbon

Weight out of 2gm of soil in a 250ml conical flask. Added 10ml of 1N $K_2Cr_2O_7$ solution to it and mixed. Then added 20ml of concentrated H_2SO_4 , swirling the flask during addition. Left the flask as such, so as to cool the contents and to make the reaction complete. Then added approximately 2gm of NaF powder (NaF is flocculation agent), 100ml of distilled water and shaken vigorously. Added 10 drops of diphenylamine indicator, which gave a violet colour to the suspension. Titrated the contents of the flask with 0.5N ferrous ammonium sulphate solution. The end point in this titration was change of the colour from blue violet to bright green. Noted the volume of the ferrous ammonium sulphate solution

used and calculated the results. Ran a blank titration also in the similar way (Walkley and Black 1954).

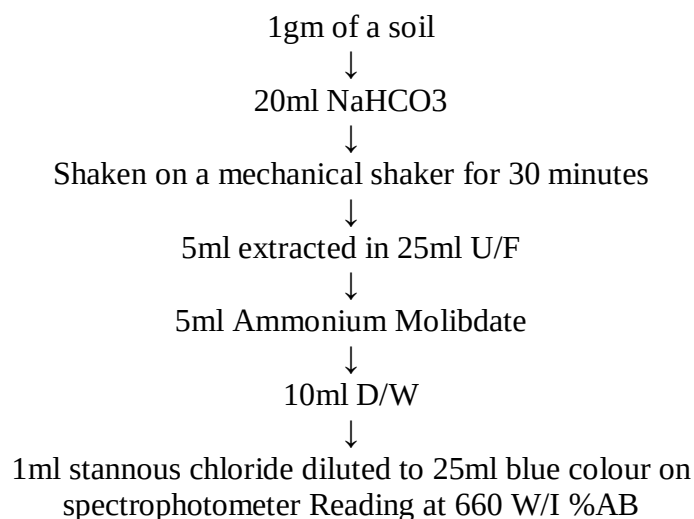
3.5.5 Available Nitrogen (kg ha^{-1})

Subbiah and Asija method was used to determine available phosphorus in soil samples (Subbiah and Asija 1956). The detailed procedure for estimation of available P is as under:



3.5.6 Available Phosphorus (kg ha^{-1})

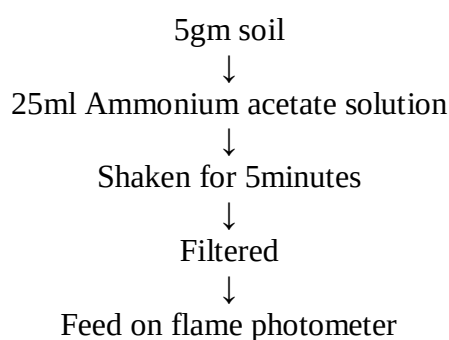
Olsen's method was used to determine available phosphorus in soil samples (Olsen *et al.* 1954). The detailed procedure for estimation of available P is as under:



The concentrations of available phosphorus were calculated by reference to a calibration graph plotted from the standard phosphorus (KH_2PO_4) solution. Blanks were run in the same manner without soil.

3.5.7 Available Potassium (kg ha^{-1})

The available potassium was estimated by N-Ammonium Acetate Method using Digital Flame Photometer by Merwin and Peech (1951). The detailed procedure for estimation of available P is as under:



3.6 Statistical Analysis

The data obtained were subjected to statistical analysis using OPSTAT and SPSS for the Randomized Block Design (RBD) of the experiment. Wherever the experimental effects exhibited significance at 5 per cent level probability, the critical difference (CD) was calculated.

ANOVA for RBD shall be as follows:

Source of variation	Degree of freedom	Sum of square	Mean sum of squares	Fcal
Treatments	(t-1)	S_t	$M_t = S_t/(t-1)$	M_t/M_e
Replications	(r-1)	S_r	$M_r = S_r/(r-1)$	M_r/M_e
Error	(r-1) (t-1)	S_e	$M_e = S_e/(r-1) (t-1)$	
Total	(rt-1)	S_T		

Where,

- r = Number of replication
- t = Number of treatments
- S_r = Sum of square due to replications
- S_t = Sum of square due to treatments
- S_e = Sum of square due to error

S_t	=	Total sum of square
M_r	=	Mean sum of square due to replications
M_t	=	Mean sum of square due to treatments
M_e	=	Mean sum of square due to error

The replication and treatment mean sum of square shall be tested against Mean sum of square due to error by 'F' test at (r-1), (r-1) (t-1) and (t-1), (r-1) (t-1) degree of freedom for RBD at 5% level of significance.

The calculated F-values shall be compared with tabulated F-value. When F-test will be found significant, critical difference will be calculated to find out the superiority of one treatment over the others.

Critical difference (CD) shall be calculated as follows:

For RBD:

$$CD_{0.05} = S.E. (d) \times t_{(0.05)} (r-1) (t-1) df$$

$$SE (d) \pm = \frac{\sqrt{2Mg}}{r}$$

$$SE (m) \pm = \frac{\sqrt{Mg}}{r}$$

Where,

$SE (m) \pm$ = Standard error of mean

$SE (d) \pm$ = Standard error of difference of mean

$CD_{0.05}$ = Critical difference at 5 per cent level of significance

Chapter-4

RESULTS AND DISCUSSION

The results emerging out of the present investigation entitled “**Variation in vegetation along altitude and aspects in western Himalaya**” was carried out at different altitudes and aspects in Kandaghat range of Solan Forest Division of Himachal Pradesh. Phytosociological behaviour of vegetation, regeneration status, biomass production and soil physico-chemical properties of soil at different aspects along an altitudinal gradient have been described in this chapter under the following major heads and sub heads:

- 4.1 Floristic composition
- 4.2 Phytosociological behaviour of vegetation
- 4.3 Vegetation indices
- 4.4 Stand characteristics
- 4.5 Canopy analysis
- 4.6 Solar radiation
- 4.7 Regeneration status
- 4.8 Biomass and carbon stock
- 4.9 Soil physico-chemical properties
- 4.10 Correlation studies

4.1 Floristic composition

4.1.1 Floristic composition of tree species

The altitude and aspects play a key role in determining the temperature regime of any site. Within one altitude the cofactors like topography, slope, aspects and soil type also affect the forest composition (Shank and Noorie 1950). The relationship between vegetation and altitude has been studied since the early 19th century (Kala and Mathur 2002).

The floristic composition of tree species at different altitudinal gradients and aspects are summarized in Table (7). In this present study, at the altitudinal range of <1800m, maximum number of tree species (6) were recorded on the western aspect, followed by the northern aspect (5) and minimum number of tree species (3) found on eastern aspect, respectively. The maximum number of tree species (4) at 1800-2100m altitudinal range were

recorded on the western aspect, followed by the northern (3) and southern aspects (3) and least tree species (2) were found on eastern aspect. *Quercus leucotrichophora* was recorded at 12 sites, followed by *Pinus roxburghii* at 10 sites and *Cedrus deodara* at 9 sites. Minimum number of tree species (2) were recorded at higher altitude (>2100m) on the western aspect. *Quercus leucotrichophora* was dominant tree species, followed by *Pinus roxburghii* and least dominant tree species were *Populus deltoides*, *Punica granatum* and *Acer oblongum* at different altitudinal ranges and aspects.

Table 7: Presence or absence of tree species at different altitudinal ranges and aspects

Sr. No.	Tree species	Family	Altitudinal ranges (m a.s.l)												Total
			E ₁ (<1800m)				E ₂ (1800-2100m)				E ₃ (>2100m)				
			A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	
1.	<i>Acer oblongum</i>	Sapindaceae	-	-	+	-	-	-	-	-	-	-	-	1	
2.	<i>Bauhinia variegata</i>	Fabaceae	+	-	-	-	-	-	-	-	-	-	-	1	
3.	<i>Cedrus deodara</i>	Pinaceae	+	-	+	-	+	+	+	-	+	+	+	9	
4.	<i>Grewia optiva</i>	Malvaceae	-	-	-	+	-	-	-	-	-	-	-	1	
5.	<i>Myrica esculenta</i>	Myricaceae	-	+	-	-	-	-	-	-	-	-	-	1	
6.	<i>Pinus roxburghii</i>	Pinaceae	+	+	+	+	-	+	+	+	-	+	-	9	
7.	<i>Populus deltoides</i>	Salicaceae	-	-	-	+	-	-	-	-	-	-	-	1	
8.	<i>Punica granatum</i>	Lythraceae	-	-	+	-	-	-	-	-	-	-	-	1	
9.	<i>Pyrus pashia</i>	Rosaceae	+	-	-	-	+	-	-	-	-	-	-	2	
10.	<i>Pistacia integerrima</i>	Anacardiaceae	-	+	-	-	-	-	-	-	-	-	-	1	
11.	<i>Quercus leucotrichophora</i>	Fagaceae	+	+	+	-	+	+	+	+	+	+	+	11	
12.	<i>Rhododendron arboreum</i>	Ericaceae	-	-	-	-	-	-	+	-	-	-	-	1	
13.	<i>Toona ciliata</i>	Meliaceae	-	-	+	-	-	-	-	-	-	-	-	1	
Total			5	4	6	3	3	3	4	2	2	3	2	3	

A₁ (Northern aspect), A₂ (Southern aspect), A₃ (Western aspect), A₄ (Eastern aspect)

The biological diversity of the Himalaya is severely threatened by natural, as well as anthropogenic disturbances, such as, tree cutting, grazing, lopping, fuel wood, fodder and litter removal etc. There are large number of environmental factors which influence the species richness and composition, such as elevation and habitat (Chandra *et al.* 2010). The occurrence of *Quercus leucotrichophora* on almost all the sites along the temperate altitude suggest their tolerance to biotic pressure and wider ecological amplitude. *Pinus roxburghii* is an early succesional species and oak a climatic climax alluded by Champion and Seth (1968).

4.1.2 Floristic composition of shrub species

The shrub species examined at different altitudinal ranges and aspects are given in Table (8). Maximum number of shrub species (13) were found at lower altitudinal range (<1800m) on southern aspect while minimum number of species (4) were found at higher altitudinal rangess (1800-2100m) on eastern aspect, followed by western aspect. The prominent species were *Berberis aristata* and *Rubus ellipticus* where as, the least prominent

shrub species were *Cassia floribunda*, *Woodfordia fruticosa*, *Artemisia vulgaris* and *Adhatoda vasica*. At altitudinal range of <1800m, the maximum species (13) were recorded on southern aspect, followed by northern aspect (11). The middle altitudinal range (1800-2100m) was represented by maximal (7) shrub species on northern and southern aspects and minimal shrub species (5) were found on eastern aspect. The highest number of shrub species (7) were found at higher altitudinal range (>2100m) on northern aspect, followed by southern aspect (6) and lowest number of species (4) observed on eastern aspect, respectively. Kharkwal *et al.* (2005) reported that along the altitudinal ranges, the geographic and climatic conditions change sharply. Marcelo (2001) and Alan (2001) explained that the vegetation structure within a site changed significantly despite the short distance due to the north and south aspects irrespective of climate and edaphic characteristics. Variation in topography, altitude, soil and climatic condition are responsible for sustaining specific type of plants peculiar to Himalayas Gaur *et al.* 1995).

Table 8: Presence or absence of shrub species at different altitudinal ranges and aspects

Sr. No.	Shrub species	Family	Altitudinal ranges (m a.s.l)												Total
			E ₁ (<1800m)				E ₂ (1800-2100m)				E ₃ (>2100m)				
			A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	
1.	<i>Adhatoda vasica</i>	Acanthaceae	-	+	-	+	-	-	-	-	-	-	-	-	2
2.	<i>Artemisia vulgaris</i>	Asteraceae	-	+	-	-	-	-	-	-	-	-	-	-	1
3.	<i>Berberis aristata</i>	Berberidaceae	+	+	-	-	+	+	+	+	+	+	+	+	10
4.	<i>Berberis vulgaris</i>	Berberidaceae	+	+	-	-	-	-	-	-	-	-	-	-	2
5.	<i>Boenninghausenia albiflora</i>	Rutaceae	+	-	-	+	-	+	-	-	-	-	-	-	3
6.	<i>Carissa carandes</i>	Apocynaceae	-	+	-	-	-	-	-	-	-	-	-	-	1
7.	<i>Cassia floribunda</i>	Fabaceae	+	-	-	-	-	-	-	-	-	-	-	-	1
8.	<i>Coriaria nepalensis</i>	Coriariaceae	+	-	-	+	-	-	-	+	-	-	-	-	3
9.	<i>Daphne cannabina</i>	Thymelaeaceae	+	+	-	+	+	-	-	-	+	+	-	-	6
10.	<i>Hypercium ablongifolium</i>	Hypericaceae	-	+	-	-	-	-	-	-	-	-	-	-	1
11.	<i>Indigofera pulchella</i>	Fabaceae	-	-	-	-	+	+	-	-	+	+	+	-	5
12.	<i>Lantana camara</i>	Verbenaceae	-	-	-	+	-	-	-	+	-	-	-	+	3
13.	<i>Myrsine africana</i>	Primulaceae	+	+	-	-	-	+	+	-	+	+	+	-	7
14.	<i>Osyris arborea</i>	Santalaceae	+	-	+	-	-	-	-	-	-	-	-	-	2
15.	<i>Prinsepia utilis</i>	Rosaceae	-	+	+	-	-	+	-	-	-	-	-	-	3
16.	<i>Rabdosia rubescens</i>	Lamiaceae	-	+	+	+	-	-	+	-	-	-	-	-	4
17.	<i>Randia tetrasperma</i>	Rubiaceae	-	+	-	+	-	+	-	+	-	-	-	+	5
18.	<i>Rubus ellipticus</i>	Rosaceae	+	+	+	-	+	-	+	-	+	+	+	-	8
19.	<i>Rubus niveus</i>	Rosaceae	+	-	-	-	+	-	+	-	+	-	-	-	4
20.	<i>Sarcococca saligna</i>	Buxaceae	+	+	-	-	+	+	+	+	+	+	+	+	10
21.	<i>Woodfrordia floribunda</i>	Lytharaceae	-	-	+	+	+	-	-	-	-	-	-	-	3
22.	<i>Woodfordia fruticosa</i>	Lytharaceae	-	-	+	-	-	-	-	-	-	-	-	-	1
Total			11	13	6	8	7	7	6	5	7	6	5	4	

4.1.3 Floristic composition of herb species

Herbaceous vegetation recorded at different altitudinal ranges and aspects are given in Table (9). At the lower altitudinal range (<1800m), the maximum number of herb species (6) recorded on northern aspect whereas, the minimum number of species (4 each) were recorded on southern and eastern aspects. At altitudinal range of 1800-2100m, high diversity of herb species (8) were recorded on northern aspect and least species (5) were found on western and eastern aspects. At higher altitudinal range (>2100m), the maximum number of herb species (9) were reported on northern aspect, followed by southern aspect and minimum number of species (6) were found on western aspect. The maximum number of herb species (9) were recorded on northern aspect at higher altitudinal range (>2100m), followed by southern aspect (8) at same altitudinal range and southern aspect (8) at middle altitudinal range (1800-2100m). The dominant species were *Viola serpens* and *Cyperus rotundas* whereas, least dominant herb species were *Arisaema sp.*, *Artemisia roxburghiana* and *Dioscorea esculenta* at different altitudinal ranges and aspects. Rawal and Pangtey (1994); Singh *et al.* (2009) alluded that altitude is one of the most significant factor, which examined the distribution of tree species due to its direct effect on the microclimatic conditions of the habitat. Muller and Ellenberg (1974) explained that plant community can be defined as a collection of plant species growing together in a particular site that show a definite association with each other.

Table 9: Presence or absence of herb species at different altitudinal ranges and aspects

Sr. No.	Herb Species	Family	Altitudinal ranges (m a.s.l)												Total
			E ₁ (<1800m)				E ₂ (1800-2100m)				E ₃ (>2100m)				
			A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	
1.	<i>Artemisia roxburghiana</i>	Asteraceae	-	-	-	-	-	+	+	-	+	-	-	-	3
2.	<i>Arisaema sp.</i>	Araceae	-	-	-	-	-	+	-	-	+	-	-	-	2
3.	<i>Bidens pilosa</i>	Asteraceae	-	+	+	+	-	-	-	-	-	-	-	-	3
4.	<i>Cyperus rotundas</i>	Cyperaceae	+	-	+	+	+	+	-	+	+	+	-	+	9
5.	<i>Dioscorea esculenta</i>	Dioscoreaceae	+	+	-	+	-	-	-	-	-	-	-	-	3
6.	<i>Fragaria indica</i>	Rosaceae	-	-	+	-	+	+	+	+	-	+	+	+	8
7.	<i>Micromera bilflora</i>	Lamiaceae	-	+	-	-	-	+	-	-	-	+	-	-	4
8.	<i>Polystichum discretum</i>	Dryopteridaceae	+	-	-	-	+	-	+	-	+	+	-	+	6
9.	<i>Rubia cardifolia</i>	Rubiaceae	+	-	+	-	+	-	-	+	+	+	+	-	7
10.	<i>Strobilanthus wallichii/alstata</i>	Acanthaceae	-	-	-	-	+	-	+	-	+	-	+	-	4
11.	<i>Thalictrum foliolosum</i>	Ranunculaceae	+	-	-	+	+	+	-	-	+	+	+	+	8
12.	<i>Viola canescens</i>	Violaceae	-	-	-	-	+	-	+	+	+	+	+	+	7
13.	<i>Viola serpens</i>	Violaceae	+	+	-	-	+	+	-	+	+	+	+	+	9
Total			6	4	5	4	8	7	5	5	9	8	6	6	

4.1.4 Biodiversity of trees, shrubs and herbs at different altitudinal ranges and aspects:

It is evident from data persented in Table (10) that the maximum number of tree species (6) were reported at lower (<1800m) altitude on western aspect, followed by northern aspect at same altitudinal range. The minimum number of tree species were found on eastern aspect at higher altitude (>2100m).

In case of shrub species, the highest number of species (13) were recorded at middle 1800-2100m altitude on sothern aspect whereas, the least number of shrub species (4) were recorded at higher (>2100m) altitude on eastern aspect. 9 herb species belonging to 8 families wise were found at higher altitude (>2100m) on northern aspect whereas, minimum number of species (4) found on eastern aspect at lower altitude (<1800m), followed by southern aspect at same altitude, respectively.

Table 10: Biodiversity of trees, shrubs and herbs at different altitudinal ranges and aspects

Aspects	Altitudinal ranges (m a.s.l.)								
	E ₁ (<1800m)			E ₂ (1800-2100m)			E ₃ (>2100m)		
	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species
	Tree Species								
A ₁	5	6	5	4	5	4	2	3	2
A ₂	4	5	4	3	5	4	2	4	3
A ₃	5	7	6	3	6	4	2	3	2
A ₄	3	3	3	3	4	3	2	4	3
	Shrub Species								
A ₁	9	12	11	6	8	7	6	8	7
A ₂	11	14	13	7	7	7	6	7	6
A ₃	4	7	6	5	7	6	5	6	5
A ₄	8	8	8	5	5	5	4	4	4
	Herb Species								
A ₁	6	6	6	7	8	8	8	9	9
A ₂	4	4	4	7	7	7	7	8	8
A ₃	5	5	5	5	5	5	5	6	6
A ₄	4	4	4	4	5	5	5	6	6

A₁ (Northern aspect), A₂ (Southern aspect), A₃ (Western aspect), A₄ (Eastern aspect)

4.2 Phytosociological behaviour of vegetation

Mountains are the most remarkable land forms on earth surface with prominent vegetation zones based mainly on altitudinal and cliamtic variations. Variations in aspects

and altitude also enhance habitat heterogeneity and bring micro-environmental variation in vegetation pattern (Clapham 1973 and Khan *et al.* 2011).

4.2.1 Phytosociological behavior of tree species

4.2.1.1 Relative density, Relative frequency, Relative basal area and IVI of tree species at lower (<1800m) altitudinal range and aspects

The importance value index (IVI) was determined as the sum of relative frequency, relative density, and relative basal area/dominance (Curtis, 1959; Curtis and Intosh 1950; Phillips, 1959). *Pinus roxburghii* showed highest importance value index (179.29) at eastern aspect whereas lowest IVI (11.73) was exhibited at northern aspect by *Bauhinia variegata* followed by *Punica granatum* (12.89) on western aspect. On northern aspect, the maximum IVI (143.98) was reported by *Quercus leucotrichophora* and minimum (11.73) by *Bauhinia variegata*. *Pinus roxburghii* was completely dominant at lower altitudinal range (<1800m) and *Bauhinia variegata* showed least dominance in this altitudinal range (Table 11).

Table 11: Relative density, Relative frequency, Relative basal area and IVI of tree species at lower (<1800m) altitudinal range and aspects

Parameter			Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
Sr. No.	Tree species	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	
1.	<i>Acer oblungum</i>	-	-	2.10	-	-	-	9.75	-	-	-	0.19	-	-	-	12.04	-	
2.	<i>Bauhinia variegata</i>	1.30	-	-	-	10.00	-	-	-	0.43	-	-	-	11.73	-	-	-	
3.	<i>Cedrus deodara</i>	22.80	-	38.58	-	20.00	-	29.26	-	29.18	-	72.71	-	71.98	-	140.55	-	
4.	<i>Grewia optiva</i>	-	-	-	7.89	-	-	-	26.67	-	-	-	26.27	-	-	-	60.83	
5.	<i>Myrica esculenta</i>	-	13.20	-	-	-	17.25	-	-	-	12.12	-	-	-	42.57	-	-	
6.	<i>Pinus roxburghii</i>	8.10	48.87	38.41	84.10	20.00	47.25	7.48	43.35	21.87	33.50	9.99	51.84	49.97	129.62	55.88	179.29	
7.	<i>Pistacia integerrima</i>	-	8.24	-	-	-	12.94	-	-	-	30.57	-	-	-	51.75	-	-	
8.	<i>Populus deltoides</i>	-	-	-	8.01	-	-	-	29.98	-	-	-	21.89	-	-	-	59.88	
9.	<i>Punica granatum</i>	-	-	2.13	-	-	-	9.75	-	-	-	1.01	-	-	-	12.89	-	
10.	<i>Pyrus Pashia</i>	1.80	-	-	-	20.00	-	-	-	0.80	-	-	-	22.60	-	-	-	
11.	<i>Quercus leucotrichophora</i>	66.00	29.69	16.02	-	30.00	22.56	31.26	-	47.72	23.81	15.15	-	143.72	76.06	62.43	-	
12.	<i>Toona ciliata</i>	-	-	2.76	-	-	-	12.50	-	-	-	0.95	-	-	-	16.21	-	
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	300.0	300.0	300.0	300.0	

4.2.1.2 Relative density, Relative frequency, Relative basal area and IVI of tree species at middle (1800-2100m) altitudinal range and aspects

Among different aspects, the maximal IVI (199.54) was shown by *Quercus leucotrichophora* on southern aspect, followed by the same species (176.61) on northern

aspect at middle altitudinal range (1800-2100m) whereas, *Rhododendron arboreum* showed minimal IVI (32.78). On western aspect, the highest IVI (176.55) was observed again for *Quercus leucotrichophora* and lowest IVI (32.78) for *Rhododendron arboreum* in Table 12. Lyon and Gross (2004) described the grouping of different communities based on frequency values. Tree species like *Quercus semicarpifolia* and *Sorbus cuspidata* did not share their habitats with any other tree species and exhibited uniqueness and individually. Puri (1960) alluded that the temperate forests of western Himalaya represent climatic climax of one or other species of *Quercus* in upper altitudinal gradient. The lower altitudes of temperate forests are occupied by oak-pine mixed forests with other coniferous species at higher altitudes, normally from the climatic vegetation. Other species of oak are found above the oak-pine mixed forests of Garhwal Himalaya reported by Osmaston (1992).

Table 12: Relative density, Relative frequency, Relative basal area and IVI of tree species at middle (1800-2100m) altitudinal range and aspects

Parameter			Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
Sr. No.	Tree species	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	
1.	<i>Cedrus deodara</i>	24.73	13.00	21.87	-	33.45	27.50	14.28	-	27.54	9.95	2.49	-	85.72	50.45	38.64	-	
2.	<i>Pinus roxburghii</i>	-	10.55	9.89	52.01	-	32.00	28.57	50.00	-	7.46	13.57	49.00	-	50.01	52.03	151.01	
3.	<i>Pyrus pashia</i>	6.890	-	-	-	27.54	-	-	-	3.240	-	-	-	37.67	-	-	-	
4.	<i>Rhododendron arboreum</i>	-	-	6.77	-	-	-	14.28	-	-	-	11.73	-	-	-	32.78	-	
5.	<i>Quercus leucotrichophora</i>	68.38	76.45	61.47	47.99	39.01	40.50	42.87	50.00	69.22	82.59	72.21	51.00	176.61	199.54	176.55	148.99	
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	300.0	300.0	300.0	300.0	

4.2.1.3 Relative density, Relative frequency, Relative basal area and IVI of tree species at higher (>2100m) altitudinal range and aspects

On the southern aspect, the maximum IVI (191.82) was recorded by *Cedrus deodara*, followed by *Quercus leucotrichophora* (180.76) on northern aspect and minimum IVI (32.7) was recorded by *Pinus roxburghii* on southern aspect at higher altitudinal range (>2100m). On western aspect, oak tree species showed highest IVI (153.73) whereas minimum IVI by *Cedrus deodara* (146.27) presented in Table 13. Importance value index was significantly higher for oak species comparison to any other tree species and hence oak was the species, which was dominating the different stands of Jardhar forest (Garhwal Himalaya) and the homogenous results of IVI of the study were evaluated by Semwal *et al.* (2009).

Table 13: Relative density, Relative frequency, Relative basal area and IVI of tree species at higher (>2100m) altitudinal range and aspects

Parameter		Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
Sr. No.	Tree species	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Cedrus deodara</i>	37.56	68.22	45.39	43.82	50.00	50.00	50.00	33.33	31.68	73.6	50.88	45.84	119.24	191.82	146.27	122.99
2.	<i>Pinus roxburghii</i>	-	6.56	-	28.08	-	16.66	-	33.33	-	9.48	-	26.53	-	32.70	-	87.94
3.	<i>Quercus leucotrichophora</i>	62.44	25.22	54.61	28.10	50.00	33.34	50.00	33.34	68.32	16.92	49.12	27.63	180.76	75.48	153.73	89.07
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.00	300.00	300.00

4.2.2 Phytosociological behavior of shrub speices

4.2.2.1 Relative density, Relative frequency, Relative basal area and IVI of shrub species at lower (<1800m) altitudinal range and aspects

The relative density, relative frequency, relative basal area and importance value index are presented in Table (14). At the lower altitudinal range, the maximum IVI (63.97) was reported for *Rubus ellipticus* on western aspect followed by *Rabdosia rubescens* (63.10) on western aspect whereas minimum IVI (10.02) was found for *Hypercium ablongifolium* on southern aspect followed by *Carissa carandas* (11.82) IVI on southern aspect.

Table 14: Relative density, Relative frequency, Relative basal area and IVI of shrub species at lower (<1800m) altitudinal range and aspects

Parameter		Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
Sr. No.	Shrub species	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Adhatoda vasica</i>	-	6.17	-	9.63	-	5.92	-	8.07	-	5.11	-	9.88	-	17.20	-	27.57
2.	<i>Artemisia vulgaris</i>	-	4.32	-	-	-	4.93	-	-	-	3.98	-	-	-	13.23	-	-
3.	<i>Berberis aristata</i>	10.25	9.62	-	-	6.93	9.87	-	-	7.84	10.80	-	-	25.02	30.28	-	-
4.	<i>Berberis vulgaris</i>	9.34	9.26	-	-	9.22	7.40	-	-	5.88	10.23	-	-	24.44	26.89	-	-
5.	<i>Boenninghausenia albiflora</i>	8.80	-	-	14.07	9.28	-	-	12.10	17.65	-	-	12.96	35.73	-	-	39.13
6.	<i>Carissa carandas</i>	-	4.05	-	-	-	4.93	-	-	-	2.84	-	-	-	11.82	-	-
7.	<i>Cassia floribunda</i>	8.35	-	-	-	6.93	-	-	-	7.84	-	-	-	23.12	-	-	-
8.	<i>Coriaria nepalensis</i>	9.94	-	-	13.77	6.93	-	-	16.14	9.80	-	-	12.96	26.68	-	-	42.87
9.	<i>Daphne cannabina</i>	7.53	11.84	-	14.81	11.79	11.49	-	16.21	7.84	15.34	-	17.28	27.16	38.67	-	48.30
10.	<i>Hypercium ablongifolium</i>	2.82	-	-	-	4.93	-	-	-	2.27	-	-	-	10.02	-	-	-
11.	<i>Lantana camara</i>	-	-	-	7.47	-	-	-	8.07	-	-	-	9.88	-	-	-	25.41
12.	<i>Myrsine africana</i>	10.44	10.28	-	-	6.93	9.86	-	-	7.84	11.93	-	-	25.21	32.08	-	-
13.	<i>Osyris arborea</i>	8.91	-	14.34	-	9.22	-	9.70	-	7.84	-	14.85	-	25.97	-	38.89	-
14.	<i>Prinsepia utilis</i>	-	4.78	15.92	-	-	4.93	12.79	-	-	3.41	15.84	-	-	13.13	44.56	-
15.	<i>Rabdosia rubescens</i>	-	6.86	18.25	16.65	-	6.59	21.09	18.85	-	5.11	23.76	16.05	-	18.57	63.10	51.55
16.	<i>Randia tetrasperma</i>	-	8.82	-	10.28	-	7.40	-	9.76	-	7.95	-	9.88	-	24.18	-	29.92
17.	<i>Rubus ellipticus</i>	10.71	12.24	22.26	-	13.69	11.93	24.89	-	19.59	11.94	16.83	-	44.01	36.09	63.97	-
18.	<i>Rubus niveus</i>	6.65	-	-	-	7.08	-	-	-	3.88	-	-	-	17.65	-	-	-
19.	<i>Sarcococca saligna</i>	9.08	8.94	-	-	12.00	9.82	-	-	4.00	9.09	-	-	25.10	27.84	-	-
20.	<i>Woodfordia floribunda</i>	-	15.07	13.32	-	-	10.54	10.80	-	-	14.85	11.11	-	-	40.47	35.25	-
21.	<i>Woodfordia fruticosa</i>	-	14.16	-	-	-	20.99	-	-	-	13.87	-	-	-	49.01	-	-
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.09	300.00	300.00

On northern aspect, the highest IVI (44.01) was detected for *Rubus ellipticus* and lowest IVI (17.65) for *Rubus niveus*. *Rubus ellipticus* showed dominance behavior and *Hypericum ablongifolium* was least dominant species at lower altitudinal range (1800m).

4.2.2.2 Relative density, Relative frequency, Relative basal area and IVI of shrub species at middle (1800-2100m) altitudinal range and aspects

Berberis aristata was dominant with highest IVI (80.90) among shrub species on northern aspect, followed by *Sarcococca saligna* (72.07) on northern aspect whereas, least IVI (23.07) shown by *Indigofera pulchella* on northern aspect at middle altitudinal range (1800-2100m). On southern aspect, *Berberis aristata* was recorded highest IVI (56.61) and minimum IVI (32.55) by *Boenninghausenia albiflora*. The maximal IVI (56.71) for *Berberis aristata* was recorded, followed by *Rubus ellipticus* (56.16) and minimal IVI (34.30) for *Rabdosia rubescens* on western aspect. At 1800-2100m altitudinal range, *Berberis aristata* was dominant and *Indigofera pulchella* showed least presence (Table 15).

Table 15: Relative density, Relative frequency, Relative basal area and IVI of shrub species at middle (1800-2100m) altitudinal range and aspects

Sr. No.	Parameter Shrub species	Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
		A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Berberis aristata</i>	24.84	18.47	20.87	21.66	32.53	20.28	20.32	15.77	23.53	17.86	15.52	29.73	80.90	56.61	56.71	67.16
2.	<i>Boenninghausenia albiflora</i>	-	11.66	-	-	-	10.18	-	-	-	10.71	-	-	-	32.55	-	-
3.	<i>Coriaria nepalensis</i>	-	-	-	18.44	-	-	-	13.90	-	-	-	21.57	-	-	-	53.91
4.	<i>Daphne cannabina</i>	11.52	-	-	-	15.43	-	-	-	10.81	-	-	-	37.75	-	-	-
5.	<i>Indigofera pulchella</i>	6.14	13.96	-	-	11.53	14.25	-	-	5.41	14.29	-	-	23.07	42.49	-	-
6.	<i>Lantana camara</i>	-	-	-	15.33	-	-	-	11.53	-	-	-	15.69	-	-	-	42.55
7.	<i>Myrsine Africana</i>	-	14.19	15.42	-	-	15.12	14.93	-	-	14.29	13.79	-	-	43.6	44.15	-
8.	<i>Prinsepia utilis</i>	-	11.61	-	-	-	10.91	-	-	-	10.71	-	-	-	33.24	-	-
9.	<i>Rabdosia rubescens</i>	-	-	9.270	-	-	-	11.23	-	-	-	13.79	-	-	-	34.30	-
10.	<i>Randia tetrasperma</i>	-	12.77	-	19.32	-	14.25	-	17.01	-	10.71	-	15.69	-	37.73	-	52.01
11.	<i>Rubus ellipticus</i>	18.30	-	18.44	-	11.26	-	18.75	-	10.81	-	18.97	-	40.37	-	56.16	-
12.	<i>Rubus niveus</i>	11.17	-	16.33	-	11.71	-	16.06	-	13.51	-	13.79	-	36.39	-	46.18	-
13.	<i>Sarcococca saligna</i>	24.78	17.34	19.67	22.07	22.52	15.75	18.71	25.03	24.78	21.43	24.14	23.52	72.07	54.52	62.50	70.63
14.	<i>Woodfordia floribunda</i>	6.43	-	-	-	11.78	-	-	-	5.41	-	-	-	23.64	-	-	-
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.00	300.00

4.2.2.3 Relative density, Relative frequency Relative basal area and IVI of shrub species at higher (>2100m) altitudinal range and aspects

At higher altitudinal range (>2100m), the maximum IVI (91.30) was found for *Sarcococca saligna* on northern aspect, followed by *Berberis aristata* (84.62) whereas, minimum IVI (23.00) for *Rubus niveus* on same aspect. On southern aspect, the highest IVI (70.49) was observed for *Berberis aristata* and lowest IVI (31.45) for *Indigofera pulchella*, followed by *Daphne cannabina* (31.09). The maximum IVI (82.95) was found for

Sarcococca saligna whereas minimum IVI of (40.65) for *Indigofera pulchella* on western aspect. On eastern aspect, the highest importance value index (69.80) was detected for *Berberis aristata* and minimum IVI (58.49) for *Sarcococca saligna* (Table 16). In general, *Sarcococca saligna* revealed dominant shrub species and *Rubus niveus* least dominant species at higher altitudinal range (>2100m).

Table 16: Relative density, Relative frequency, Relative basal area and IVI of shrub species at higher (>2100m) altitudinal range and aspects

Sr. No.	Shrub species	Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
		A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Berberis aristata</i>	29.72	23.35	28.86	28.08	32.68	23.33	26.54	20.51	22.22	23.81	22.22	21.21	84.62	70.49	77.62	69.8
2.	<i>Daphne cannabina</i>	6.21	10.35	-	-	10.91	11.72	-	-	6.06	9.52	-	-	23.18	31.59	-	-
3.	<i>Indigofera pulchella</i>	8.29	10.21	12.77	-	12.23	11.72	13.07	-	15.15	9.52	14.81	-	35.66	31.45	40.65	-
4.	<i>Lantana camara</i>	-	-	-	21.23	-	-	-	17.90	-	-	-	19.44	-	-	-	58.57
5.	<i>Myrsine africana</i>	13.54	20.69	15.29	-	14.72	14.19	17.25	-	15.15	14.29	11.11	-	43.42	49.16	43.66	-
6.	<i>Randia tetrasperma</i>	-	-	-	23.59	-	-	-	19.71	-	-	-	22.22	-	-	-	65.51
7.	<i>Rubus ellipticus</i>	16.57	17.70	16.99	-	14.72	15.71	19.61	-	15.15	14.29	18.52	-	46.45	47.70	55.12	-
8.	<i>Rubus niveus</i>	6.08	-	-	-	10.86	-	-	-	6.06	-	-	-	23.00	-	-	-
9.	<i>Sarcococca saligna</i>	25.46	17.70	26.09	21.43	29.71	23.33	23.53	16.05	36.12	28.57	33.34	21.22	91.30	69.61	82.95	58.49
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.00	300.00	300.00

4.2.3 Phytosociological behavior of herb species

4.2.3.1 Relative density, Relative frequency, Relative basal area and IVI of herb species at lower (<1800m) altitudinal range and aspects

Relative density, relative frequency, relative basal area and importance value index of herb species at lower altitude are presented in Table (17). The highest IVI (86.77) was recorded by *Dioscorea esculenta* on northern aspect, followed by *Bidens pilosa* (85.39) on southern aspect whereas, lowest IVI (32.77) was recorded for *Polystichum discretum* on northern aspect and minimum for *Micromera bilflora* IVI (57.55) on same aspect. On western aspect, the maximal IVI (74.56) was found for *Cyperus rotundas* and minimum IVI (47.27) for *Fragaria indica*. The maximal IVI (84.79) was reported for *Bidens pilosa* and minimal IVI (60.933) for *Thalictrum foliolosum* on eastern aspect. In this altitudinal range, *Dioscorea esculenta* showed superiority and *Polystichum discretum* was least dominant herb species.

Table 17: Relative density, Relative frequency, Relative basal area and IVI of herb species at lower (<1800m) altitudinal range and aspects

Parameter		Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
Sr. No.	Herb species	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Bidens pilosa</i>	-	32.93	28.07	28.68	-	27.27	22.22	28.16	-	25.19	22.22	27.75	-	85.39	72.51	84.79
2.	<i>Cyperus rotundas</i>	23.11	-	24.56	20.33	18.88	-	25.93	25.97	17.81	-	24.07	20.61	59.8	-	74.56	66.91
3.	<i>Dioscorea esculenta</i>	30.49	31.87	-	23.11	27.27	25.20	-	22.11	29.01	23.70	-	18.72	86.77	81.06	-	63.94
4.	<i>Fragaria indica</i>	-	-	15.79	-	-	-	14.81	-	-	-	16.67	-	-	-	47.27	-
5.	<i>Micromera bilflora</i>	-	13.66	15.79	-	-	21.00	18.52	-	-	22.54	17.90	-	-	57.55	52.21	-
6.	<i>Polystichum discretum</i>	9.78	-	-	-	11.58	-	-	-	11.42	-	-	-	32.77	-	-	-
7.	<i>Rubia cardifolia</i>	11.00	-	15.79	-	9.570	-	18.52	-	13.24	-	19.14	-	33.82	-	53.45	-
8.	<i>Thalictrum foliolosum</i>	18.70	-	-	16.25	18.88	-	-	19.49	21.46	-	-	25.19	59.05	-	-	60.93
9.	<i>Viola serpens</i>	14.30	25.79	-	-	18.98	25.64	-	-	17.35	26.01	-	-	50.62	76.60	-	-
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.00	300.00	300.00

4.2.3.2 Relative density, Relative frequency Relative basal area and IVI of herb species at middle (1800-2100m) altitudinal range and aspects

Cyperus rotundas presented the highest IVI (76.29) and *Rubia cardifolia* lowest IVI (23.81) on northern aspect at middle (1800-2100m) altitudinal range. *Cyperus rotundas* showed dominance behavior and *Rubia cardifolia* least dominant herb species. On southern aspect, the maximum IVI (58.25) was found for *Cyperus rotundas* and minimal IVI (27.02) for *Micromera bilflora*, followed by *Artemisia roxburghiana* (35.94). The maximal IVI (74.25) was recorded for *Fragaria indica* and least IVI (43.20) for *Polystichum discretum* on western aspect at 1800-2100m altitudinal range (Table 18).

Table 18: Relative density, Relative frequency, Relative basal area and IVI of herb species at middle (1800-2100m) altitudinal range and aspects

Parameter		Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
Sr. No.	Herb species	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Arisaema sp.</i>	-	16.92	-	-	-	15.24	-	-	-	47.42	-	-	-	47.42	-	-
2.	<i>Artemisia roxburghiana</i>	-	10.00	14.68	-	-	13.65	14.45	-	-	35.94	22.28	-	-	35.94	51.43	-
3.	<i>Cyperus rotundas</i>	24.35	21.43	-	17.00	29.79	20.32	-	16.37	22.15	58.28	-	14.52	76.29	58.25	-	47.89
4.	<i>Fragaria indica</i>	18.62	13.54	27.75	23.29	16.37	15.24	25.30	12.77	12.86	41.07	21.20	19.46	47.84	41.07	74.25	55.52
5.	<i>Micromera bilflora</i>	-	6.27	-	-	-	10.16	-	-	-	27.02	-	-	-	27.02	-	-
6.	<i>Polystichum discretum</i>	6.29	-	13.22	-	10.97	-	12.05	-	10.79	-	17.93	-	28.05	-	43.20	-
7.	<i>Rubia cardifolia</i>	5.67	-	-	10.65	8.18	-	-	19.15	9.96	-	-	11.41	23.81	-	-	41.21
8.	<i>Strobilanthes wallichii/alstata</i>	12.14	-	20.56	-	14.73	-	24.10	-	9.130	-	19.57	-	36.00	-	64.22	-
9.	<i>Thalictrum foliolosum</i>	12.14	13.79	-	-	9.820	10.16	-	-	12.86	37.93	-	-	34.82	37.93	-	-
10.	<i>Viola canescens</i>	13.58	-	23.79	19.79	11.05	-	24.10	15.32	13.69	-	19.02	20.81	38.32	-	66.90	55.91
11.	<i>Viola serpens</i>	14.56	18.05	-	21.92	12.51	15.23	-	22.97	16.19	52.34	-	26.17	43.27	52.37	-	71.07
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.00	300.00	300.00

4.2.3.3 Relative density, Relative frequency, Relative basal area and IVI of herb species at higher (>2100m) altitudinal range and aspects

On northern aspect, the highest IVI (78.24) was detected for *Thalictrum foliolosum*, followed by *Thalictrum foliolosum* (76.84) on western aspect and lowest IVI (20.33) by *Strobilanthus wallichii/alstata* on northern aspect, followed by *Fragaria indica* (25.01) on eastern aspect at higher altitudinal range (>2100m). The maximum IVI (58.09) was recorded for *Polystichum discretum* and minimum IVI (19.05) for *Micromera bilflora* on southern aspect. On western aspect, minimal IVI (30.11) was detected of *Strobilanthus wallichii/alstata*. At higher altitudinal range, *Thalictrum foliolosum* was found dominant herb species and *Strobilanthus wallichii/alstata* was noticed least (Table 19).

Table 19: Relative density, Relative frequency, Relative basal area and IVI of herb species at higher (>2100m) altitudinal range and aspects

Sr. No.	Parameter Herb species	Relative density (%)				Relative frequency (%)				Relative basal area (%)				IVI			
		A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
1.	<i>Arisaema sp</i>	5.580	-	-	-	8.530	-	-	-	6.740	-	-	-	20.85	-	-	-
2.	<i>Artemisia roxburghiana</i>	6.280	-	-	-	8.530	-	-	-	5.70	-	-	-	20.51	-	-	-
3.	<i>Cyperus rotunda</i>	11.14	16.05	-	2.310	12.80	10.31	-	14.04	13.99	17.65	-	26.73	37.93	44.01	-	43.09
4.	<i>Fragaria indica</i>	-	11.24	12.96	9.240	-	13.75	12.43	9.830	-	7.190	11.19	5.940	-	32.17	36.58	25.01
5.	<i>Micromera bilflora</i>	-	4.820	-	-	-	10.31	-	-	-	3.920	-	-	-	19.05	-	-
6.	<i>Polystichum discretum</i>	12.56	17.34	-	18.47	12.80	15.47	-	14.04	16.58	25.49	-	13.86	41.93	58.19	-	46.38
7.	<i>Rubia cardifolia</i>	9.76	1.61	17.54	-	11.37	10.31	14.92	-	9.33	16.34	15.38	-	30.46	28.25	47.84	-
8.	<i>Strobilanthus wallichii/alstata</i>	5.58	-	7.89	-	8.53	-	12.43	-	6.22	-	9.79	-	20.33	-	30.11	-
9.	<i>Thalictrum foliolosum</i>	31.17	21.67	31.57	22.60	25.28	17.18	24.99	16.97	21.79	16.34	20.28	15.03	78.24	55.29	76.84	54.60
10.	<i>Viola canescens</i>	12.55	14.45	2.410	13.87	10.24	12.36	16.58	15.74	12.95	7.190	18.18	10.89	35.74	34.01	37.17	40.48
11.	<i>Viola serpens</i>	13.95	12.82	27.63	24.94	10.23	10.31	18.65	21.07	13.46	5.88	25.18	20.79	37.65	29.03	71.46	66.80
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	300.00	300.00	300.00	300.00

4.2.4 Density (N ha⁻¹) and Basal area (m² ha⁻¹) of tree species at different altitudinal ranges and aspects

Density and basal area of tree species at different altitudinal ranges and aspects are presented in Table (20). Among altitudinal ranges, the maximum density (234.04 N ha⁻¹) observed at lower altitudinal range (<1800m) and minimum density (161.26 N ha⁻¹) was observed at higher altitudinal range (>2100m). The highest basal area (20.14 m² ha⁻¹) was recorded at middle altitudinal range (1800-2100m) and lowest (8.15 m² ha⁻¹) was recorded at

higher altitudinal range (>2100m). Among the different aspects, the maximum density (254.22 N ha⁻¹) was observed on northern aspect and the minimum (154.94 N ha⁻¹) detected on southern aspect. The highest basal area (19.43 m² ha⁻¹) of tree species was recorded on northern aspect and lowest (9.59 m² ha⁻¹) was recorded on southern aspect. Keeping both factors in mind, the maximum density (280.49 N ha⁻¹) was found at middle altitudinal range (1800-2100m) on northern aspect, followed by northern aspect (266.02 N ha⁻¹) at lower altitudinal range (<1800m) and minimum density (119.09 N ha⁻¹) at higher altitudinal range on southern aspect. In the interaction effect, the highest basal area (26.49 m² ha⁻¹) was detected on northern aspect at middle altitudinal range and the lowest basal area (6.82 m² ha⁻¹) was recorded on western aspect at higher altitudinal range (>2100m), followed by southern aspect (6.98 m² ha⁻¹) at same altitudinal range (Table 20).

Total tree density and basal area decreased from lower to higher altitudinal ranges and all aspects viz., northern, southern, western and eastern aspect as shown in Table (20). Tree density was higher on northern aspect than any aspects. The maximum number of seedlings and saplings were found on northern aspect as compared to other aspects and lower altitudinal range than higher. The density of tree species observed in the present study was less as comparable to the density value of 420-1640 individual ha⁻¹ from temperate forests of Kumaon Himalayas as reported by Saxena and Singh (1982). The similar results were obtained by Ghimire *et al.* (2010) *Pinus wallichiana* of AB Jackson in a trans-Himalayan dry valley of north-central Nepal. Kumar *et al.* (2013); Aiba and Kitayama (1999) found that the total density and basal area were decreased with increasing altitudinal gradient. However, reverse trends were also reported from other parts of north western Himalaya (Great Himalayan National Park) where the density of trees increased with increase in altitudinal ranges (Rawat and Singh 2006; Hanief *et al.* 2016). Tree density in this present study is consonant to the density reported by Tripathi *et al.* (1991) for disturbed forest sites in the oak zone around Nainital. Total tree density, sapling and seedling densities were exceptionally maximum in north facing forest than in south facing forests. These results might be attributable to the pronounced aridity of the area perceived by Mong and Vetaas (2006). The tree density values did not vary much as that of this present study and the values evaluated by other workers (Adhikari and Tiwari (1991); Mishra *et al.* (1993); Ilorkar and Khatri (2003) are more or less similar. A homogenous values of basal area of tree species were reported by Thokchom and Yadava (2017).

Table 20: Density (N ha⁻¹) and Basal area (m² ha⁻¹) of tree species at different altitudinal ranges (E) and aspects (A)

Density (N ha ⁻¹)					Mean	Basal area (m ² ha ⁻¹)				Mean
Altitudinal range (m a.s.l)	Aspect					Aspect				
	(Northern) A ₁	(Southern) A ₂	(Western) A ₃	(Eastern) A ₄		(Northern) A ₁	(Southern) A ₂	(Western) A ₃	(Eastern) A ₄	
E ₁	266.02	199.30	228.41	242.45	234.04	20.27	8.40	9.50	16.79	13.74
E ₂	280.49	146.450	162.12	259.41	212.11	26.49	13.39	16.36	24.34	20.14
E ₃	216.16	119.09	130.56	179.22	161.26	11.54	6.98	6.82	7.28	8.15
Mean	254.22	154.94	173.69	227.03		19.43	9.59	10.89	16.14	
CD _{0.05}	Elevation	3.79				Elevation	0.54			
	Aspect	4.38				Aspect	0.63			
	E×A	7.58				E×A	1.09			

E₁ (<1800m), E₂ (1800-2100m) and E₃ (>2100m)

Table 21: Density (N ha⁻¹) and Basal area (m² ha⁻¹) of shrub species at different altitudinal ranges (E) and aspects (A)

Density (N ha ⁻¹)					Mean	Basal area (m ² ha ⁻¹)				Mean
Altitudinal range (m a.s.l)	Aspect					Aspect				
	(Northern) A ₁	(Southern) A ₂	(Western) A ₃	(Eastern) A ₄		(Northern) A ₁	(Southern) A ₂	(Western) A ₃	(Eastern) A ₄	
E1	6,296	16,202	13,484	5,619	10,400	4.36	5.02	4.77	4.71	4.71
E2	4,937	11,394	7,680	3,533	6,886	2.98	4.05	3.14	3.79	3.49
E3	5,509	3,075	4,731	4,871	3,797	1.52	2.45	1.74	2.16	1.97
Mean	4,581	10,224	8,634	4,674		2.95	3.84	3.21	3.55	
CD _{0.05}	Elevation	52.10				Elevation	0.004			
	Aspect	60.16				Aspect	0.005			
	E×A	104.21				E×A	0.008			

E₁ (<1800m a.s.l.), E₂ (1800-2100m a.s.l.) and E₃ (>2100m a.s.l.)

4.2.5 Density (N ha^{-1}) and Basal area ($\text{m}^2 \text{ha}^{-1}$) of shrub species at different altitudinal ranges and aspects

Data presented in Table (21) reveal that different aspects and altitudinal ranges significantly influenced the density (N ha^{-1}) and basal area ($\text{m}^2 \text{ha}^{-1}$) of shrub species. Among different altitudinal ranges, the maximum density of shrub species ($10,400 \text{ N ha}^{-1}$) was recorded at lower altitudinal range ($<1800\text{m}$) and minimum density ($3,797 \text{ N ha}^{-1}$) was recorded at higher altitudinal range ($>2100\text{m}$). The highest basal area ($4.71 \text{ m}^2 \text{ha}^{-1}$) was investigated at lower altitudinal range and lowest ($1.97 \text{ m}^2 \text{ha}^{-1}$) at $>2100\text{m}$ altitudinal range. Among different aspects, the maximum density ($10,224 \text{ N ha}^{-1}$) was observed on southern aspect and lowest ($4,581 \text{ N ha}^{-1}$) was observed on northern aspect. The highest basal area ($3.85 \text{ m}^2 \text{ha}^{-1}$) was observed on southern aspect and lowest ($2.95 \text{ m}^2 \text{ha}^{-1}$) observed on northern aspect. In case of interaction effect, the maximum density ($16,201 \text{ N ha}^{-1}$) was detected at lower altitudinal range ($<1800\text{m}$) on southern aspect, followed by western aspect at same altitudinal range and minimum density ($2,509 \text{ N ha}^{-1}$) was detected at higher altitudinal range ($>2100\text{m}$) on northern aspect. The highest basal area ($5.02 \text{ m}^2 \text{ha}^{-1}$) was found at $<1800\text{m}$ altitudinal range on southern aspect whereas, lowest basal area ($1.52 \text{ m}^2 \text{ha}^{-1}$) was found at higher altitudinal range ($>2100\text{m}$) on northern aspect, followed by ($1.74 \text{ m}^2 \text{ha}^{-1}$) on western aspect at same altitudinal range ($>2100\text{m}$). Parsons (1976) explained the structural and functional analysis of plant communities provided valuable sources of information for understanding relationship between plant form, vegetation structure and environment. Highest density of shrub on southern aspect may be attributed to the lower density and less canopy of trees, which might have resulted in sufficient light to reach on the ground favoring growth of shrub species as reported by Bhandari and Tiwari (1997) and Semwal *et al.* (2007). Human disturbance and seasonal activities also change the structure and composition of the floral community. So this can be attributed to the lower abundance of the shrub species at lower altitudinal ranges. The differences in density and basal area may be attributed to the composition, age structure, succession stage of the forest and degree of disturbance reported by Sundarapandian and Swamy (1997).

4.2.6 Density (N ha^{-1}) and Basal area ($\text{m}^2 \text{ha}^{-1}$) of herb species at different altitudinal ranges and aspects

Density (N ha^{-1}) and basal area ($\text{m}^2 \text{ha}^{-1}$) of herb species at different altitudinal ranges and aspects are described in Table (22). Among the different altitudinal ranges, the maximum density ($91,221 \text{ N ha}^{-1}$) was detected at lower altitudinal range ($<1800\text{m}$) and minimum

Table 22: Density (N ha⁻¹) and Basal area (m² ha⁻¹) of herb species at different altitudinal ranges (E) and aspects (A)

Density (N ha ⁻¹)						Basal area (m ² ha ⁻¹)				
Altitudinal range (m a.s.l)	Aspect				Mean	Aspect				Mean
	(Northern) A ₁	(Southern) A ₂	(Western) A ₃	(Eastern) A ₄		(Northern) A ₁	(Southern) A ₂	(Western) A ₃	(Eastern) A ₄	
E1	76,825	1,23,574	90,556	73,930	91,221	2.35	2.53	2.41	2.51	2.45
E2	72,409	89,011	79,614	59,622	75,164	1.95	2.19	2.01	2.07	2.05
E3	48,515	54,579	63,991	69,074	59,040	1.17	1.87	1.34	1.52	1.47
Mean	65,916	89,055	78,054	67,542		1.86	2.20	1.92	2.03	
CD _{0.05}	Elevation	454.98				Elevation	0.003			
	Aspect	525.37				Aspect	0.004			
	E×A	909.97				E×A	0.006			

E₁ (<1800m a.s.l.), E₂ (1800-2100m a.s.l.) and E₃ (>2100m a.s.l.)

(59,040 N ha⁻¹) was detected at higher altitudinal range (>2100m). The highest basal area (2.45 m² ha⁻¹) was found at <1800m altitudinal range whereas, lowest basal area (1.47 m² ha⁻¹) was found at higher altitudinal range (>2100m). Among the different aspects, the maximal density (89,055 N ha⁻¹) was observed on southern aspect and minimal (65,916 N ha⁻¹) was observed on northern aspect. The highest basal area (2.20 m² ha⁻¹) was recorded on southern aspect and least (1.86 m² ha⁻¹) on northern aspect. In the interaction effect of different altitudinal ranges and aspects, the maximum density (1,23,574 N ha⁻¹) was found at lower altitudinal range on southern aspect whereas, minimum number of herb species (48,515 N ha⁻¹) was found at higher altitudinal range (>2100m) on northern aspect. The highest basal area of herb species (2.53 m² ha⁻¹) was established at <1800m altitudinal range on southern aspect and least basal area (1.17 m² ha⁻¹) was recorded on northern aspect at >2100m altitudinal range.

Gairola *et al.* (2008) reported that tree, herb, shrub, density and basal area decreased with increasing altitudinal ranges. They observed tree density 632 to 243, 843 to 453 and 646 to 557 individual ha⁻¹ and herb density 1,57,267 to 98,667, 2,13,533 to 5,5067 and 1,33,333 to 93,733 from selected three sites with in altitudinal range from 3000 to 3200m and basal area raised from 69.84 to 8.99, 30.33 to 15.29 and 37.16 to 16.75 from each sites. The herb density in present study ranged between 1,23,574 to 48,515 individual ha⁻¹ which is within the range of 1,60,100 to 1,33,935 individual ha⁻¹ reported by Ahmad *et al.* (2016). A similar trend of density and basal area reported by other authors Puri (1960); Gupta and Singh (1962) recorded the greater value of diversity but lower value of basal cover of the mixed forest and they observed that the values decreased with increasing altitudinal ranges.

4.2.7 Similarity index (SI)

Ma (1994) described that similarity and dissimilarity of plant community structure and composition reflect not only the diversity of local habitat, but also the complexity of community to a certain extent. It also reflects the rate of change of species composition with the varying topographic and environmental gradients.

4.2.7.1 Index of Similarity and dissimilarity of tree species at different altitudinal ranges and aspects

The data relevant to number of species in different altitudinal ranges and aspects was used to find similarity and dissimilarity among tree, shrub and herbs species (Table 23, 24

and 25). Among trees, the similarity index ranged from 0.00 to 1.00. The maximum similarity index (0.085) was perceived between western aspect at higher altitudinal range and northern aspect at (>2100m) same altitudinal range, followed by 0.80 similarity between southern aspect at higher (>2100m) altitudinal range and western aspect at same altitudinal range. Minimum similarity index (0.00) was perceived between eastern aspect at lower altitudinal range (<1800m) and northern aspect at higher altitudinal range (>2100m), followed by (0.22) similarity between northern aspect at lower (<1800m) altitudinal range and eastern aspect at same altitudinal. The dissimilarity index ranged from 0.00 to 1.00. The highest dissimilarity index was observed between northern and western aspect at higher altitudinal range (>2100m) and eastern aspect at lower altitudinal range (<1800m). The lowest dissimilarity (0.00) between western aspect at higher altitudinal range and northern aspect at same altitudinal range, followed by (0.15) dissimilarity between eastern aspect at middle altitudinal range (1800-2100m) and southern aspect at same altitudinal range. This similarity index between different altitudinal ranges and aspects may be due to same altitudinal zone and similar type of habitat conditions. Less difference in the value of similarity index expressed that growth forms in the stand responded in similar fashion (Adhikari *et al.* 1992).

Table 23: Index of Similarity and dissimilarity of tree species at different altitudinal ranges and aspects

Similarity		E ₁ (<1800m)				E ₂ (1800-2100m)				E ₃ (>2100m)			
Dissimilarity	Aspect	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
E ₁ (<1800m)	A ₁	-	0.40	0.50	0.22	0.66	0.66	0.66	0.50	0.57	0.75	0.57	0.75
	A ₂	0.60	-	0.66	0.44	0.50	0.66	0.44	0.75	0.28	0.50	0.28	0.50
	A ₃	0.50	0.34	-	0.36	0.36	0.72	0.54	0.54	0.44	0.60	0.44	0.60
	A ₄	0.78	0.56	0.64	-	0.25	0.50	0.25	0.57	0.00	0.28	0.00	0.28
E ₂ (1800-2100m)	A ₁	0.34	0.50	0.64	0.75	-	0.75	0.25	0.57	0.60	0.57	0.66	0.57
	A ₂	0.34	0.34	0.28	0.50	0.24	-	0.75	0.85	0.85	0.85	0.66	0.85
	A ₃	0.34	0.56	0.46	0.75	0.75	0.25	-	0.57	0.66	0.85	0.66	0.85
	A ₄	0.50	0.25	0.46	0.43	0.43	0.15	0.43	-	0.40	0.44	0.40	0.44
E ₃ (>2100m)	A ₁	0.43	0.72	0.56	1.00	0.34	0.15	0.34	0.60	-	0.66	1.00	0.66
	A ₂	0.25	0.50	0.40	0.72	0.43	0.15	0.15	0.56	0.34	-	0.80	0.66
	A ₃	0.43	0.72	0.56	1.00	0.34	0.34	0.34	0.60	0.00	0.20	-	0.80
	A ₄	0.25	0.50	0.40	0.72	0.43	0.15	0.15	0.56	0.34	0.34	0.20	-

A₁ (Northern aspect), A₂ (Southern aspect), A₃ (Western aspect), A₄ (Eastern aspect)

4.2.7.2 Index of Similarity and dissimilarity of Shrub species at different altitudinal ranges and aspects

Among shrubs, the similarity index ranged from 0.00-0.92 (Table 24). The maximum similarity index (0.92) was detected between northern aspect at higher altitudinal range (>2100m) and southern aspect at same altitudinal range, followed by (0.90) similarity between southern aspect at >2100m altitudinal range and western aspect at same range. The minimum similarity or no similarity (0.00) was detected between western aspect at lower altitudinal range (<1800m) and eastern aspect at middle altitudinal range (1800-2100m) and eastern at lower (<1800m) altitudinal range and western aspect at higher altitudinal range. The dissimilarity index ranged from (0.08-1.00). The highest dissimilarity (1.00) was observed between western aspect at lower altitudinal range (<1800m) and eastern aspect at middle altitudinal range (1800-2100m), eastern aspect at lower altitudinal range (<1800m) and western aspect at higher altitudinal range (>2100m) and western aspect at lower altitudinal range and eastern aspect at higher altitudinal range (>2100m). The lowest dissimilarity index (0.08) was observed between southern aspect at >2100m altitudinal range and northern aspect at same altitudinal range, followed by (0.10) dissimilarity between western aspect at higher altitudinal range (>2100m) and southern aspect at same altitudinal range.

Table 24: Index of Similarity and dissimilarity of Shrub species at different altitudinal ranges and aspects

Similarity		E ₁ (<1800m)				E ₂ (1800-2100m)				E ₃ (>2100m)			
Dissimilarity	Aspect	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
Altitudinal range (m a.s.l)													
E ₁ (<1800m)	A ₁	-	0.50	0.23	0.42	0.55	0.44	0.58	0.37	0.66	0.58	0.50	0.26
	A ₂	0.50	-	0.31	0.38	0.40	0.50	0.52	0.33	0.50	0.52	0.44	0.35
	A ₃	0.77	0.69	-	0.28	0.30	0.15	0.33	0.00	0.15	0.16	0.18	0.00
	A ₄	0.58	0.62	0.72	-	0.26	0.26	0.14	0.46	0.13	0.14	0.00	0.33
E ₂ (1800-2100m)	A ₁	0.45	0.60	0.70	0.74	-	0.42	0.46	0.33	0.71	0.76	0.66	0.36
	A ₂	0.56	0.50	0.85	0.74	0.58	-	0.46	0.50	0.57	0.61	0.66	0.54
	A ₃	0.42	0.48	0.67	0.86	0.54	0.54	-	0.36	0.76	0.66	0.72	0.40
	A ₄	0.63	0.67	1.00	0.54	0.67	0.50	0.64	-	0.33	0.36	0.40	0.88
E ₃ (>2100m)	A ₁	0.34	0.50	0.85	0.87	0.29	0.43	0.24	0.67	-	0.92	0.83	0.36
	A ₂	0.42	0.48	0.84	0.86	0.24	0.39	0.34	0.64	0.08	-	0.90	0.40
	A ₃	0.50	0.56	0.82	1.00	0.34	0.34	0.28	0.60	0.17	0.10	-	0.44
	A ₄	0.74	0.65	1.00	0.67	0.64	0.46	0.60	0.12	0.64	0.60	0.56	-

4.2.7.3 Index of Similarity and dissimilarity of herb species at different altitudinal ranges and aspects

Among herbs, similarity index ranged from 0.00 to 0.87 (Table 25). The maximum similarity index (0.87) was detected between southern aspect at middle altitudinal range (1800-2100m) and southern aspect at higher altitudinal range (>2100m), followed by (0.85) similarity between northern aspect at 1800-2100m middle altitudinal range and western and eastern aspect at (>2100m) higher altitudinal range whereas, minimum similarity observed between southern aspect at lower altitudinal range (<1800m) and western aspect at middle altitudinal range (1800-2100m), eastern aspect at <1800m altitudinal range and western aspect at 1800-2100m altitudinal range. The dissimilarity index ranged from 0.13-1.00. The highest dissimilarity was observed between western aspect at (1800-2100m) middle altitudinal range and southern aspect at lower altitudinal range (<1800m) whereas lowest dissimilarity observed between southern aspect at higher altitudinal range (>2100m) and northern aspect at middle altitudinal range (1800-2100m), followed by (0.15) dissimilarity between western and eastern aspect at (>2100m) higher altitudinal range and northern aspect at middle altitudinal range (1800-2100m). Itow and Nakanishi (1980) described that large area contained more varied types than smaller areas, and each of the habitat type supports a specific set of its own, which is more or less different from that of other habitat types. Suyal *et al.* (2010) opined that close proximity results in high similarity index of vegetation.

Table 25: Index of Similarity and dissimilarity of herb species at different altitudinal ranges and aspects

Similarity		E ₁ (<1800m)				E ₂ (1800-2100m)				E ₃ (>2100m)			
Dissimilarity													
Altitudinal range (m a.s.l)	Aspect	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
E ₁ (<1800m)	A ₁	-	0.40	0.36	0.60	0.71	0.46	0.18	0.59	0.66	0.71	0.50	0.66
	A ₂	0.60	-	0.22	0.50	0.33	0.36	0.00	0.22	0.30	0.33	0.20	0.20
	A ₃	0.64	0.78	-	0.44	0.30	0.33	0.20	0.60	0.28	0.46	0.54	0.18
	A ₄	0.40	0.50	0.56	-	0.33	0.36	0.00	0.22	0.30	0.33	0.20	0.40
E ₂ (1800-2100m)	A ₁	0.29	0.67	0.70	0.67	-	0.50	0.61	0.76	0.82	0.87	0.85	0.85
	A ₂	0.54	0.64	0.67	0.64	0.50	-	0.33	0.50	0.62	0.66	0.46	0.66
	A ₃	0.82	1.00	0.80	1.00	0.39	0.67	-	0.40	0.57	0.46	0.36	0.36
	A ₄	0.41	0.78	0.40	0.72	0.24	0.50	0.60	-	0.57	0.76	0.75	0.72
E ₃ (>2100m)	A ₁	0.34	0.70	0.72	0.70	0.18	0.38	0.43	0.43	-	0.70	0.66	0.66
	A ₂	0.29	0.67	0.54	0.67	0.13	0.34	0.54	0.24	0.30	-	0.71	0.85
	A ₃	0.50	0.80	0.46	0.80	0.15	0.54	0.64	0.28	0.34	0.29	-	0.50
	A ₄	0.34	0.80	0.82	0.60	0.15	0.34	0.64	0.28	0.34	0.15	0.50	-

4.3 Vegetation analysis and vegetation indices

The results with regard to various vegetation indices viz., Shannon-wiener, Simpson's dominance and Species richness for various plant categories viz., trees, shrubs and herbs at different altitudinal ranges and aspects are presented in Table (26). In general, vegetation indices, were highest for herbaceous stratum, followed by shrubs stratum. The similar results that, forest species richness was higher in herb layers as compared to other broad leaved forests of Garhwal Himalaya reported by Bhandari and Tiwari (1997) and Bhandari *et al.* (1998). Khali and Bhatt (2014) suggested that high species richness in herbs stratum may be due to relatively less development of canopy in these mature forests, which permit sufficient sunlight to reach the ground and resulted in the luxuriant growth of herb species. Rikhari *et al.* (1989) conclusion that along the altitudinal gradient the upper limit of species richness remains high up to a considerable altitudinal range (2500m) in the Indian Himalayan region.

4.3.1 Species diversity

The tree species diversity ranged from 0.47-1.28 at different altitudinal ranges and aspects (Table 26). The highest tree species diversity of 1.28 was observed at lower altitude (<1800m) on northern aspect and lowest of 0.47 at higher altitude (>2100m) on southern aspect. The maximum shrub species diversity (2.09) was found at lower altitudinal range (<1800m) on southern aspect and minimum (1.40) was found at higher altitudinal range (>2100m) on eastern aspect. The highest herbaceous vegetation species diversity (2.45) was recorded on southern aspect at 1800-2100m and lowest (1.66) was recorded on eastern aspect at higher altitudinal range. Sharma *et al.* (2009) had also explained the pattern of decrease in species diversity with increasing altitudinal ranges and aspects. The recorded index value of present study is similar to the range reported by Gairola *et al.* (2008) for western Himalaya. The similar values of diversity index have also been reported by Monk (1967) and Risser and Rice (1971). They obtained the maximum value (2.3) of diversity index in temperate forests. A higher diversity in the herb layer in the absence of a closed forest canopy has also been reported by Moral (1972); Whittaker and Niering (1975); Zobel *et al.* (1976).

4.3.2 Simpson's dominance

The tree species dominance ranged from 0.21-0.51 and it was highest (0.51) at lower altitudinal range on northern aspect and lowest (0.21) at higher altitudinal range on western aspect.

Table 26: Vegetation indices of tree, shrubs and herbs at different altitudinal ranges and aspects

Parameter		Shannon-weiner index				Simpson's dominance				Species richness			
Plant Categories	Aspects	(Northern)	(Southern)	(Western)	(Eastern)	(Northern)	(Southern)	(Western)	(Eastern)	(Northern)	(Southern)	(Western)	(Eastern)
	Altitudinal range	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
Trees	E ₁	1.28	0.58	0.91	1.25	0.51	0.35	0.49	0.47	1.08	0.64	0.78	0.79
	E ₂	0.88	0.51	0.79	0.82	0.46	0.39	0.42	0.41	0.61	0.41	0.51	0.58
	E ₃	0.78	0.47	0.66	0.69	0.32	0.29	0.21	0.33	0.54	0.35	0.41	0.42
Shrubs	E ₁	1.61	2.09	1.69	1.66	0.84	0.96	0.88	0.71	1.51	2.28	2.04	2.21
	E ₂	1.55	1.96	1.86	1.71	0.64	0.98	0.79	0.74	1.21	1.81	1.72	1.33
	E ₃	1.42	1.49	1.46	1.40	0.57	0.91	0.85	0.68	1.11	1.62	1.27	1.16
Herbs	E ₁	1.84	2.31	2.19	1.76	0.72	0.89	0.89	0.64	1.87	2.59	2.33	2.47
	E ₂	1.72	2.45	2.22	1.81	0.56	0.93	0.83	0.67	1.64	2.19	2.04	1.81
	E ₃	1.72	2.39	1.91	1.66	0.51	0.77	0.74	0.61	1.34	1.91	1.71	1.51

E₁ (<1800m a.s.l.), E₂ (1800-2100m a.s.l.) and E₃ (>2100m a.s.l.)

The maximum shrub species dominance (0.98) was found at 1800-2100m altitudinal range on southern aspect and minimum (0.57) was found at >2100m altitudinal range on northern aspect (Table 26). The highest herbaceous vegetation species dominance (0.93) was recorded on southern aspect at middle altitudinal range (1800-2100m) and lowest (0.51) was recorded on northern aspect at higher altitudinal range (>2100m). Similar changes of species dominance along altitudinal ranges and aspects had also been reported by Sharma *et al.* (2009). The maximum value of simpson's dominance was observed at lower altitudinal range and minimum value was found at higher altitudinal range. Whittaker (1972) alluded that the dominance of one stratum affects the diversity of other stratum. Simpson (1949) and Fisher (1960) suggested that lower values of species dominance in temperate region might be due to the lower rate of evolution and diversification of plant community.

4.3.3 Species richness

The data pertaining to species richness for various plant categories ranged from 0.35-2.59 at different altitudinal ranges and aspects (Table 26). The tree species richness ranged from 0.35-1.08 and it was highest (1.08) at lower altitude (<1800m) on northern aspect whereas, lowest (0.35) was at higher altitude (>2100m) on southern aspect. The maximum shrub species richness (2.28) was found at middle altitudinal range (1800-2100m) on southern aspect and minimum (1.11) was found at higher altitudinal range (>2100m) on northern aspect. The highest herbaceous vegetation richness (2.59) was observed on southern aspect at lower altitudinal range (<1800m) and lowest (1.34) on northern aspect at higher altitudinal range (>2100m). Rahbek (1997) explained the pattern of species richness, which decrease with altitude. Consequently, our study disclosed the maximum species richness at lower altitudinal ranges, compared to higher elevational forest as suggested by Kumar and Ram (2005). In further study, Singh *et al.* (1994) investigated that *Pinus roxburghii* mixed broad-leaved forest had the highest species of plant categories, while higher elevational forest had lowest. Burns (1995) and Austin *et al.* (1996) have shown that total species richness was highest at lower altitudinal range and warmer sites. Pavon *et al.* (2000); Sharma *et al.* (2009) and Sharma and Raina (2013) revealed that the life forms diversity usually decreased with increasing altitudinal ranges and one or two life-forms remains at extreme altitudes. Species richness is one of the main traits of communities because it influences their stability, productivity and susceptibility to invasion (Duffy *et al.* 2007 and Gamfeldt *et al.* 2008).

4.4 Stand characteristics

The mean diameter of different tree species along altitudinal gradients and aspects of Kandaghat Forest Range are summarized in Table (27). The maximum average value of mean diameter (33.25 cm) recorded at middle altitudinal range (1800-2100m) and the minimum average value of mean diameter (25.54 cm) at higher altitudinal range. In case of aspects, the highest mean value of mean diameter (35.32 cm) was detected on eastern aspect, followed by northern aspect (32.29) whereas, the least mean value of mean diameter (23.18 cm) was observed on southern aspect, followed by (27.90 cm) western aspect. The trend was as: eastern > northern > western > southern. In case of the interaction of different altitudinal ranges and aspects, the maximum mean value of diameter (37.09 cm) was found at middle altitudinal range (1800-2100m) on eastern aspect and the minimum mean value (17.42 cm) was found at higher altitudinal range (>2100m) on southern aspect.

Table 27: Mean diameter (cm) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	34.05	23.84	27.46	35.56	30.23
E₂ (1800-2100m)	34.29	28.26	33.37	37.09	33.25
E₃ (>2100m)	28.55	17.42	22.88	33.32	25.54
Aspect Mean	32.29	23.18	27.90	35.32	

CD_{0.05}

Elevation	1.23
Aspect	1.45
E×A	2.52

A perusal of data in Table (28) revealed that the maximum mean average value of height (27.56 m) was recorded at middle altitudinal range (1800-2100m), which was found to be significantly higher than other altitudinal ranges and the minimum mean value (20.71 m) was noticed at higher altitudinal range (>2100m), which was also found to be significantly lower than other altitudinal ranges. Thus the altitudinal ranges recorded the average mean height of tree species in the order: E₂ > E₁ > E₃. In case of aspects, the highest mean value of height (29.14 m) was recorded on northern aspect, followed by eastern aspect (25.88) whereas, the least mean value (19.85 m) was recorded on southern aspect. The trend was observed as: northern > eastern > western > southern. In case of interaction, the maximum average value of mean height (33.61 m) was examined at middle altitudinal range (1800-2100m) on northern aspect and the minimum average value (16.06 m) was examined at upper altitudinal range (>2100m) on southern aspect.

Table 28: Mean height (m) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	28.22	20.12	23.00	26.74	24.52
E₂ (1800-2100m)	33.61	23.39	25.33	27.91	27.56
E₃ (>2100m)	25.61	16.06	18.16	23.00	20.71
Aspect Mean	29.14	19.85	22.17	25.88	

CD_{0.05}

Elevation	1.24
Aspect	1.43
E×A	NS

At different altitudinal ranges, the highest mean value of volume (146.34 m³/ha) was found at middle altitudinal range (1800-2100m) and the least of volume (88.91 m³/ha) was found at higher altitudinal range (>2100). In case of aspects, the maximum average value of volume (127.03 m³/ha) was obtained on northern aspect whereas, the minimum average value of volume (103.85 m³/ha) was obtained on southern aspect, followed by western aspect. The trend was followed as: northern > eastern > western > southern. In case of interaction, the maximum average value of volume (155.90 m³/ha) was observed at middle altitudinal range (1800-2100m) on northern aspect and the minimum average value of volume (81.23 m³/ha) was observed at higher altitudinal range (>2100) on southern aspect. Missanjo *et al.* (2013) examined that there were significant differences in mean height and volume of *Pinus oocarpa* among the altitudinal ranges.

Table 29: Volume (m³/ha) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	130.55	99.42	118.89	123.77	118.162
E₂ (1800-2100m)	155.90	130.91	147.69	150.87	146.34
E₃ (>2100m)	94.63	81.23	87.91	91.89	88.91
Aspect Mean	127.03	103.85	118.16	122.18	

CD_{0.05}

Elevation	0.87
Aspect	1.01
E×A	1.75

4.5 Canopy analysis

Vetaas (2000) stated that reduced canopy cover has a direct effect on seed production, but it may also indirectly affect regeneration through changes in the understorey vegetation

and soil properties. Higher canopy cover by large trees reduces the amount of direct sunlight that reaches the floor, High and large canopy cover may cause litter accumulation, which is not a favorable condition for seed germination and seedling establishment as alluded by Neyisci (1993); Spanos *et al.* (2001) and Bonnet *et al.* (2005). A forest having multilayered canopy with substantial canopy index and depth, and well developed forest floor has a greater protective value compared to a forest with fewer layers and low canopy index explained by Lull (1964). The crown pattern analysis of different altitudinal ranges and aspects .

Crown width

A perusal of the data presented in Table (30) reveals that the maximum average value of crown width (5.04 m) was reported at higher altitudinal range (>2100m), which was found to be significantly higher than other ranges whereas minimum average value of crown width (4.24 m) was reported at lower altitudinal range (<1800m).

In case of aspects, the highest mean value of crown width (5.20 m) was recorded on southern aspect followed by western aspect and least mean value (4.24 m) was reported on northern aspect. The following trend was followed: southern (5.20 m) > western (4.76 m) > eastern (4.64 m) > northern > (4.24 m).

In case of interaction between altitudinal ranges and aspects, the maximum average value of crown width (6.82 m) was examined at middle altitudinal range (1800-2100m) on southern aspect whereas, minimum average value (3.92 m) was examined at lower altitudinal range (<1800m) on northern aspect.

Table 30: Crown width (m) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	3.92	4.13	4.42	4.49	4.24
E₂ (1800-2100m)	4.17	6.82	4.33	4.08	4.85
E₃ (>2100m)	4.63	4.65	5.53	5.35	5.04
Aspect Mean	4.24	5.20	4.76	4.64	

CD_{0.05}

Elevation	0.095
Aspect	0.11
E×A	0.19

Crown height

The data on crown height are summarized in Table (31). Among altitudinal ranges, the maximum average value of crown height (3.67 m) was recorded at lower altitudinal range (<1800m) followed by 3.34 m at higher altitudinal range whereas, minimum average value of crown height of 2.98 m at middle altitudinal range (1800-2100m).

Out of different aspects, the highest mean value of crown height (4.08 m) was obtained on northern aspect, followed by eastern aspect (3.30). The least mean value of crown height (2.85 m) was obtained on southern aspect.

In the interaction between altitudinal ranges and aspects, the maximum mean value (6.46 m) of crown height was noticed at lower (<1800m) altitudinal range on northern aspect whereas, minimum mean value (2.45 m) at lower altitudinal range (<1800m) on eastern aspect, respectively.

Table 31: Crown height (m) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	6.46	2.52	3.25	2.45	3.67
E₂ (1800-2100m)	3.09	3.49	2.67	2.67	2.98
E₃ (>2100m)	2.69	2.55	3.34	4.77	3.34
Aspect Mean	4.08	2.85	3.09	3.30	

CD_{0.05}

Elevation 0.039

Aspect 0.046

E×A 0.079

Crown length

Data in Table (32) depicts that the maximum average value of crown length (11.43 m) was recorded at lower altitudinal range (<1800m), which was significantly higher than value at other altitudinal ranges and the minimum average value (9.20 m) was examined at higher altitudinal range (>2100m), which was found to be significantly lower value at than other altitudinal ranges. Thus the altitudinal ranges recorded the average crown length in the order: E₁ > E₂ > E₃.

In case of different aspects, the highest mean value of crown length (10.80 m) was reported on northern aspect followed by eastern aspect whereas, the least average value of crown length (9.56 m) was reported on western aspect.

In case of the interaction, the maximum average value of crown length (12.26 m) was noticed at lower altitudinal range on eastern aspect whereas, the minimum average crown length (7.85 m) was noticed at higher altitudinal range (>2100m) on western aspect.

Table 32: Crown length (m) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	11.26	11.75	10.45	12.26	11.43
E₂ (1800-2100m)	11.26	9.96	10.39	9.82	10.35
E₃ (>2100m)	9.89	9.38	7.85	9.68	9.20
Aspect Mean	10.80	10.36	9.56	10.59	

CD_{0.05}

Elevation	1.45
Aspect	NS
E×A	NS

Crown basal area

The maximum mean value of crown basal area (4,596 m²/ha) was observed at <1800m altitudinal range whereas, minimum average value of crown basal area (3,482 m²/ha) at middle altitudinal range (1800-2100m) Table (33).

In case of aspects, the highest mean value of crown basal area (4,378 m²/ha) was reported on northern aspect, followed by eastern aspect and the least mean value of crown basal area (3,382 m²/ha) was reported on southern aspect. The trend was followed as: northern > eastern > western > southern.

Table 33: Crown basal area (m²/ha) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	4,451	3,842	4,953	5,140	4,596 (38.41%)
E₂ (1800-2100m)	3,142	2,743	3,923	4,121	3,482 (29.10%)
E₃ (>2100m)	5,542	3,561	3,522	2,917	3,886 (32.48%)
Aspect Mean	4,378 (27.44%)	3,382 (21.20%)	4,133 (25.90%)	4,059 (25.46%)	

CD_{0.05}

Elevation	2.54
Aspect	2.94
E×A	5.09

In case of interaction, the maximum average value crown basal area (5,542 m²/tree) was observed at higher altitudinal range (>2100m) on northern aspect, followed by eastern aspect at same altitudinal range. The minimum mean value of crown basal area (2,743 m²/tree) was examined at middle altitudinal range (1800-2100m) on northern aspect. Biging and Dobbertin 1995; Deal and Tappenier 2002; Nyland 2002 reported that the basal area and crown area have been proved useful elsewhere to estimate diameter growth within competition indices.

Crown surface area

The data in Table (34) reveals that the maximum average value of crown surface area (115.37 m²/tree) was noticed at lower (<1800m) altitudinal range, which was found to be significantly higher than value at other altitudinal ranges whereas, minimum average value of crown surface area (111.82 m²/tree) was noticed at higher altitudinal range (>2100m) significantly lower than other ranges. Thus among altitudinal ranges the mean crown surface area recorded in the order: E₁ > E₂ > E₃. Among different aspects, highest mean value of crown surface area (139.85 m²/tree) was recorded on southern aspect, followed by western aspect whereas, least mean value (92.93 m²/tree) was recorded on northern aspect.

The highest mean value of crown surface area (189.85 m²/tree) was observed at lower altitudinal range (<1800m) on southern aspect and the least mean value of crown surface area (70.35 m²/tree) at <1800m altitudinal range on northern aspect.

Table 34: Crown surface area (m²/tree) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	70.35	189.85	111.69	89.58	115.37
E₂ (1800-2100m)	130.69	142.80	99.79	80.02	113.32
E₃ (>2100m)	77.75	86.90	161.61	121.03	111.82
Aspect Mean	92.93	139.85	124.36	96.87	

CD_{0.05}

Elevation	N/A
Aspect	3.96
E×A	6.80

Crown volume

The results of crown volume (m³/tree) at different altitudinal ranges and aspects are summarized in Table (35). The maximum mean value of crown volume (165.19 m³/tree) was

obtained at lower altitudinal range (<1800m) significantly higher than values at other altitudinal ranges. The minimum average value of crown volume (111.65 m³/tree) was obtained at higher altitudinal range which was also found significantly lower than values at other altitudinal ranges.

In case of aspects, the highest average value of crown volume (175.95 m³/tree) was recorded on southern aspect, followed by western aspect whereas, the least average value (118.62 m³/tree) was recorded on northern aspect followed by eastern aspect.

In case of interaction, the maximum mean value of crown volume (215.01 m³/tree) was detected at lower altitudinal range (<1800m) on southern aspect and the minimum mean value of crown volume (75.14 m³/tree) was detected at higher altitudinal range (>2100m) on northern aspect.

Table 35: Crown volume (m³/tree) of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	171.40	215.01	93.20	181.15	165.19
E₂ (1800-2100m)	109.33	190.91	204.59	110.70	153.88
E₃ (>2100m)	75.14	121.95	150.51	99.01	111.65
Aspect Mean	118.62	175.95	149.43	130.29	

CD_{0.05}

Elevation	2.58
Aspect	2.98
E×A	5.16

Crown per cent

At different altitudinal ranges, the highest average value of crown per cent (80.70) was noticed at lower altitudinal range (<1800m). The least average value of crown per cent (66.67) was noticed at 1800-2100m altitudinal range.

In case of aspects, the maximum mean value of crown per cent (79.56) was obtained on northern aspect followed by eastern aspect whereas, minimum mean value of crown per cent (72.44) was obtained on western aspect followed by southern aspect.

In case of interaction between different altitudinal ranges and aspects, the maximum average value of crown per cent (92.24) was observed at lower altitudinal range (<1800m) on

northern aspect and the minimum average value of crown per cent (55.53) was observed at middle altitudinal range (1800-2100m) on southern aspect (Table 36).

Table 36: Crown per cent of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	92.24	85.49	82.25	62.82	80.70
E₂ (1800-2100m)	71.41	55.53	58.43	81.33	66.67
E₃ (>2100m)	75.05	77.21	76.66	81.60	77.63
Aspect Mean	79.56	72.74	72.44	75.25	

CD_{0.05}

Elevation	1.04
Aspect	1.20
E×A	2.09

Crown spread

The results on crown spread at different altitudinal ranges and aspects are presented in Table (37) reveals that the maximum average value of crown spread (0.41) was found at higher altitudinal range, which was significantly higher than values at other altitudinal ranges. The minimum average value of crown spread (0.37) was found at lower altitudinal range (<1800m) which was also found to be significantly lower than values at other altitudinal ranges.

In case of aspects, highest mean value of crown spread (0.42) was recorded on southern aspect and the least mean value of crown spread (0.36) on northern aspect, followed by eastern aspect.

Table 37: Crown spread of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	0.42	0.31	0.40	0.33	0.37
E₂ (1800-2100m)	0.30	0.51	0.43	0.29	0.38
E₃ (>2100m)	0.35	0.43	0.36	0.50	0.41
Aspect Mean	0.36	0.42	0.40	0.37	

CD_{0.05}

Elevation	0.008
Aspect	0.009
E×A	0.016

The maximum mean value of crown spread (0.51) was recorded at middle altitudinal range (1800-2100m) on southern aspect and minimum (0.29) was recorded at 1800-2100m altitudinal range on eastern aspect.

Crown fullness ratio

The data in Table (38) reveals that the highest mean value of crown fullness ratio (1.22) was noticed at higher altitudinal range (>2100m), which was significantly higher than other altitudinal ranges whereas, the least mean value of crown fullness ratio (1.01) was noticed at lower altitudinal range (<1800m) which was found to be significantly lower than other altitudinal ranges. Thus the altitudinal ranges recorded the mean crown fullness ratio in order: $E_3 > E_2 > E_1$.

The maximum average value of crown fullness ratio (1.24) was obtained on western aspect, followed by northern aspect and the minimum average value (1.00) was obtained on eastern aspect.

In case of interaction, the maximum average value of crown fullness ratio (1.57) was found at middle altitudinal range on northern aspect whereas, the minimum average value of crown fullness ratio (0.75) was found at lower altitudinal range (<1800m) on northern aspect.

Table 38: Crown fullness ratio of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	0.75	0.97	1.32	1.00	1.01
E₂ (1800-2100m)	1.57	0.97	0.89	0.77	1.05
E₃ (>2100m)	1.04	1.12	1.51	1.23	1.22
Aspect Mean	1.12	1.02	1.24	1.00	

CD_{0.05}

Elevation	0.026
Aspect	0.030
E×A	0.053

Crown projection ratio

A perusal of the data presented in Table (39) reveals that among different altitudinal ranges, the maximum average value of crown projection ratio (34.43) was noticed at higher altitudinal range (>2100m) which was significantly higher than other altitudinal ranges and

the minimum average value of crown projection ratio (26.03) was noticed at lower altitudinal range (<1800m).

In case of aspects, highest mean value of crown projection ratio (32.38) was recorded on northern aspect, followed by eastern aspect whereas, least mean value of crown projection ratio (27.94) was recorded on southern aspect.

In case of interaction between different altitudinal ranges and aspects, the maximum mean value of crown projection ratio (44.79) was found at higher altitudinal range on northern aspect whereas minimum average value of crown projection ratio (23.92) was found at lower altitudinal range (<1800m) on eastern aspect.

Table 39: Crown projection ratio of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	27.33	24.84	28.04	23.92	26.03
E₂ (1800-2100m)	25.03	27.93	27.14	30.99	27.77
E₃ (>2100m)	44.79	31.06	31.78	30.09	34.43
Aspect Mean	32.38	27.94	28.99	28.33	

CD_{0.05}

Elevation	0.57
Aspect	0.66
E×A	1.14

Crown quotient to ground cover area

At different altitudinal ranges, the maximum average value of crown quotient to ground cover area (1,262) was recorded at higher altitudinal range (>2100m), which was found significantly higher than other altitudinal ranges and the minimum average value (916) was recorded at lower altitudinal range (<1800m).

In case of aspects, the highest mean value of crown quotient to ground cover area (1,233) was found on northern aspect, followed by eastern aspect whereas, least mean value (935) was found on southern aspect. The trend was followed as: northern > eastern > western > southern.

In case of interaction, the maximum mean value (1,682) of crown quotient to ground cover area was observed at higher altitudinal range (>2100m) on northern aspect and the minimum mean value (686) at lower altitudinal range (<1800m) on southern aspect.

Table 40: Crown Quotient to ground cover area of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	1,032	686	957	989	916
E₂ (1800-2100m)	986	988	834	1,245	1,013
E₃ (>2100m)	1,682	1,132	1,153	1,082	1,262
Aspect Mean	1,233	935	982	1,105	

CD_{0.05}

Elevation	48.61
Aspect	56.13
E×A	97.22

Crown index

The results of crown index at different altitudinal ranges and aspects are presented in Table (41) reveals that the highest mean value of crown index (1.62) was noticed at lower altitudinal range, which was found significantly higher than values at other altitudinal ranges and the least mean value of crown index (1.32) was noticed at higher altitudinal range (>2100m). Thus the altitudinal ranges recorded the average crown index in order: E₁ > E₂ > E₃.

In case of aspects, the maximum average value of crown index (1.58) was obtained on northern aspect, followed by northern aspect whereas, the minimum average value (1.39) was obtained on southern aspect.

In case of interaction, between different altitudinal ranges and aspects, the highest mean value of crown index (1.83) was observed at lower altitudinal range (<1800m) on eastern aspect and the least mean value of crown index (1.04) was observed at higher altitudinal range (1800-2100m) on western aspect, respectively. Donoso (2005) evaluated the crown index is a useful indicator for predication of growth or regeneration.

Table 41: Crown index of tree species at different altitudinal ranges and aspects

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E₁ (<1800m)	1.67	1.23	1.74	1.83	1.62
E₂ (1800-2100m)	1.56	1.82	1.54	1.22	1.53
E₃ (>2100m)	1.51	1.11	1.04	1.62	1.32
Aspect Mean	1.58	1.39	1.44	1.56	

CD_{0.05}

Elevation	0.014
Aspect	0.016
E×A	0.028

4.6 Solar Radiation (Lux)

A perusal of the data presented in Table (42) reveals that, the maximum average value of the solar radiation (555.30 Lux) was recorded at the higher altitudinal range (>2100m), which was found significantly higher than E₁ and E₂ altitudinal ranges. Minimum average solar radiation (515.15 Lux) was found at lower altitudinal range (<1800m) which was found significantly lower than other altitudinal ranges.

In case of aspects, the maximum mean value of solar radiation (605.58 Lux) was obtained on southern aspect, which was found to be significantly higher than other aspects whereas minimum average value of solar radiation (469.929 Lux) was recorded on northern aspect.

In case of interactions of altitudinal ranges and aspects, the maximum average value of solar radiation (633.14 Lux) recorded at higher altitudinal range (>2100m) on southern aspect whereas, minimum average mean value (446.46 Lux) was noticed at lower altitudinal range on northern aspect.

Table 42: Solar radiation influx (Lux) on forest floor at different altitudinal ranges (E) and aspects (A)

Altitudinal range (m a.s.l)	Aspect				Elevation Mean
	Northern	Southern	Western	Eastern	
E ₁ (<1800m)	446.46	582.90	480.51	550.69	515.14
E ₂ (1800-2100m)	476.48	600.70	490.37	564.72	533.07
E ₃ (>2100m)	486.83	633.14	515.07	586.15	555.30
Mean	469.929	605.586	495.321	567.19	

CD_{0.05}

Elevation 1.96

Aspect 2.26

E×A 3.92

The microenvironment of different aspects of hill slopes is influenced by the intensity and duration of available sunlight (Yadav and Gupta 2006). Under such conditions, solar radiation increases with altitude because of reduced atmospheric turbidity. The pattern of population dynamics of seedlings, saplings and adults of a plants species can expose the recruitment profile, which is used to determine their regeneration status reported by Bekele (1994). Nautiyal *et al.* (2004) stated the alpiners are characterized by low productivity, high intensity of solar radiation and high degree of resource seasonality because of high ultraviolet (UV) radiation, high wind velocity and low temperature. Sharma and Baduni (2000)

suggested that the northern aspect have lower temperature and higher soil and air moisture contents due to less solar exposure as compared southern aspect at the same altitudinal range.

4.7 Regeneration Status

In this present investigation, regeneration studies were carried out on recruits, unestablished and established seedling in all different altitudinal gradients and aspects of Kandaghat Forest Range. Good and Good (1972) suggested three major components viz., ability to initiate new seedlings, ability of seedlings and sapling to survive, and ability of seedlings and saplings to grow which cause the successful regeneration in any site.

Table 43: Regeneration status of different tree species at different elevational ranges on northern and southern aspects

Northern				Southern		
<1800m						
Species	Recruits ha ⁻¹	Un-established ha ⁻¹	Established ha ⁻¹	Recruits ha ⁻¹	Un-established ha ⁻¹	Established ha ⁻¹
<i>Cedrus deodara</i>	833.33	277.77	-	-	-	-
<i>Pistacia integerrima</i>	-	-	-	333.33	694.44	333.33
<i>Pinus roxburghii</i>	-	333.33	416.67	416.67	555.55	555.55
<i>Pyrus pashia</i>	-	208.55	208.33	-	-	-
<i>Quercus leucotrichophora</i>	2500.00	555.55	555.55	2500.00	-	416.67
Total	3333.33	1375.20	1180.55	3250.00	1249.99	1305.55
1800-2100m						
<i>Cedrus deodara</i>	1111.11	555.55	694.44	833.33	333.33	277.78
<i>Pistacia integerrima</i>	-	208.33	-	-	208.33	277.78
<i>Pinus roxburghii</i>	1666.67	-	208.33	972.22	416.67	416.67
<i>Quercus leucotrichophora</i>	1111.11	694.44	416.67	1666.67	555.55	416.67
Total	3888.89	1458.32	1319.44	3472.22	1513.88	1388.90
>2100m						
<i>Cedrus deodara</i>	1666.66	694.44	833.33	1666.67	694.44	944.45
<i>Quercus leucotrichophora</i>	1111.11	416.67	333.33	833.34	555.55	277.77
Total	2777.77	1111.11	1166.66	2500.01	1249.99	1222.22

In northern aspect at lower (<1800m) altitudinal range there were 4 tree species which reported total recruits of 3333.33 N ha⁻¹, unestablished of 1375.20 N ha⁻¹ and established 1180.55 N ha⁻¹ (Table 43). *Quercus leucotrichophora* showed the maximum recruits (2500.00 ha⁻¹), unestablished (555.55 N ha⁻¹) and established (555.55 N ha⁻¹). However, the minimum value for recruits of (833.33 N ha⁻¹) was recorded in case of *Cedrus deodara*, un-established of (208.55 N ha⁻¹) was recorded in case of *Pyrus pashia* and established of (208.33 N ha⁻¹) recorded in case of *Pyrus pashia* at this altitudinal range (<1800m). At the middle altitudinal range (1800-2100m), the highest value for recruits

(1666.67 N ha⁻¹) was noted in case of *Pinus roxburghii*, un-established (694.44 N ha⁻¹) was noted in case of *Quercus leucotrichophora* and established (694.44 N ha⁻¹) noted in case of *Cedrus deodara*. However, the lowest value for recruits (1111.11 N ha⁻¹) was reported in case of *Cedrus deodara*, un-established (208.33 N ha⁻¹) reported in case of *Pistacia integerrima* and established (208.33 N ha⁻¹) reported in case of *Pinus roxburghii*. At the higher altitudinal range (>2100m), *Cedrus deodara* showed maximum recruits (1666.66 N ha⁻¹), un-established (694.44 N ha⁻¹) and established (833.33 N ha⁻¹) and *Quercus leucotrichophora* showed minimum recruits (1111.11 N ha⁻¹), un-established (416.67 N ha⁻¹) and established (333.33 N ha⁻¹).

In southern aspect at lower (<1800m) altitudinal range, the maximum value for recruits (2500.00 N ha⁻¹) was observed in case of *Quercus leucotrichophora*, un-established of (694.44 N ha⁻¹) was observed in case of *Pistacia integerrima* and established of (555.55 N ha⁻¹) *Pinus roxburghii* and the minimum value for recruits of (333.33 N ha⁻¹) was observed in case of *Pistacia integerrima*, un-established of (555.55 N ha⁻¹) observed in case of *Pinus roxburghii* and established (333.33 N ha⁻¹) observed in case of *Pistacia integerrima*. At middle (1800-2100m) altitudinal range, *Quercus leucotrichophora* showed highest recruits (1666.67 N ha⁻¹), un-established (555.55 N ha⁻¹) and established (416.67 N ha⁻¹) and the minimum value for recruits (972.22 N ha⁻¹) recorded in case of *Pinus roxburghii*, un-established (208.33 N ha⁻¹) observed in case of *Pistacia integerrima* and established (277.78 N ha⁻¹) observed in case of *Pistacia integerrima*. At the higher altitudinal range (>2100m), *Cedrus deodara* showed the highest recruits (1666.67 N ha⁻¹), un-established (694.44 N ha⁻¹) and established (944.45 N ha⁻¹) whereas, *Quercus leucotrichophora* showed the minimum recruits (833.34 N ha⁻¹), un-established (555.55 N ha⁻¹) and established (277.77 N ha⁻¹). Tranquillini (1979) and Vetaas (2000) described that tree density, seedling density, sapling density and basal area decreased with elevational gradient on both northern and southern aspects. Rao (1988) alluded the natural regeneration of a tree species however, depends largely on the production and germination of seeds and the establishment of seedlings and saplings.

At western aspect of lower altitudinal range (<1800m), the *Quercus leucotrichophora* showed the maximum recruits (1666.67 N ha⁻¹), un-established (555.55 N ha⁻¹) and established (555.55 N ha⁻¹) and *Cedrus deodara* showed the minimum recruits (416.67 N ha⁻¹), un-established (277.77 N ha⁻¹) and established (208.55 N ha⁻¹). At 1800-2100m altitudinal

range, *Quercus leucotrichophora* showed the highest recruits (1666.67 N ha⁻¹), un-established (555.55 N ha⁻¹) and established (694.44 N ha⁻¹) however, *Cedrus deodara* showed the lowest recruits (694.44 N ha⁻¹), un-established (333.33 N ha⁻¹) and established (277.77 N ha⁻¹). At higher (>2100m) altitudinal range, the maximum value for recruits (1666.67 N ha⁻¹) was recorded in case of *Cedrus deodara* un-established (555.55 N ha⁻¹) was recorded in case of *Cedrus deodara* and established (462.96 N ha⁻¹) was recorded in case of *Quercus leucotrichophora* and *Pinus roxburghii* showed the minimum recruits (416.60 N ha⁻¹), un-established (208.55 N ha⁻¹) and established (277.77 N ha⁻¹).

Table 44: Regeneration status of different tree species at different elevational ranges and western and eastern aspects

Western				Eastern		
<1800m						
Species	Recruits ha ⁻¹	Un-established ha ⁻¹	Established ha ⁻¹	Recruits ha ⁻¹	Un-established ha ⁻¹	Established ha ⁻¹
<i>Cedrus deodara</i>	416.67	277.77	208.55	-	-	-
<i>Pistacia integerrima</i>	-	-	-	555.55	333.33	277.77
<i>Pinus roxburghii</i>	1111.11	416.66	416.64	1111.11	740.74	833.33
<i>Quercus leucotrichophora</i>	1666.67	555.55	555.55	-	-	-
Total	3194.45	1249.98	1180.74	1666.66	1074.07	1111.10
1800-2100m						
<i>Cedrus deodara</i>	694.44	333.33	277.77	-	-	-
<i>Pinus roxburghii</i>	1111.11	416.67	416.67	1111.11	694.44	555.55
<i>Quercus leucotrichophora</i>	1666.67	555.55	694.44	1666.66	555.55	740.74
Total	3472.22	1305.55	1388.88	2777.77	1249.99	1296.29
>2100m						
<i>Cedrus deodara</i>	1666.67	555.55	277.77	416.66	333.33	416.66
<i>Pinus roxburghii</i>	416.60	208.55	277.77	555.55	277.77	208.55
<i>Quercus leucotrichophora</i>	833.33	333.33	462.96	555.55	416.66	277.77
Total	2916.60	1097.43	1018.50	1527.76	1027.76	902.98

At eastern aspect lower (<1800m) altitudinal range, *Pinus roxburghii* showed the maximum recruits (1111.11 N ha⁻¹), un-established (740.74 N ha⁻¹) and established (833.33 N ha⁻¹) whereas, *Pistacia integerrima* showed minimum recruits (555.55 N ha⁻¹), un-established (333.33 N ha⁻¹) and established (277.77 N ha⁻¹). At middle altitudinal range (1800-2100m), the highest value for recruits (1666.66 N ha⁻¹) was observed in case of *Quercus leucotrichophora*, un-established (694.44 N ha⁻¹) was observed in case of *Pinus roxburghii* and established (740.74 N ha⁻¹) was observed in case of *Quercus leucotrichophora* and the minimum recruits (1111.11 N ha⁻¹) observed in case of *Pinus roxburghii*, un-established (555.55 N ha⁻¹) was observed in case of *Quercus leucotrichophora* and established (555.55 N ha⁻¹) was observed in case of *Pinus roxburghii*. At higher altitudinal

range (>2100m), the highest value for recruits (555.55 N ha⁻¹), un-established (416.66 N ha⁻¹) was recorded in case of *Quercus leucotrichophora* and established (416.66 N ha⁻¹) recorded in case of *Cedrus deodara*. The lowest value for recruits (416.66 N ha⁻¹) and un-established (333.33 N ha⁻¹) recorded in case of *Cedrus deodara* and established 208.55 N ha⁻¹ was recorded in case of *Pinus roxburghii*. Scholl and Taylor (2006) reported the population behaviour of tree seedlings in different forests and showed that their recruitment, growth and survival are influenced by a variety of microclimatic and edaphic factors. Growth, survival, seed germination, emergence and establishment of seedlings affect forest regeneration by influencing plant populations in forest (Osunkjaya *et al.* 1992). The similar results of regeneration status have also been obtained by Attri *et al.* (2017) in Rajgarh Forest Range of Himachal Pradesh.

Weighted average height, Establishment index, Stocking index, Establishment Stocking % and Regeneration success (%)

Data in Table (45) reveals that *Quercus leucotrichophora* showed the maximum establishment index (0.74), stocking index (0.27), establishment stocking (20.55%) and regeneration success (27.77%) whereas, *Cedrus deodara* showed the minimum established index (0.19), stocking index (0.02), establishment stocking (0.52%) and regeneration success (2.77%) lower altitudinal range (<1800m) on northern aspect. At middle (1800-2100m) altitudinal range, the highest stocking index (0.33), establishment stocking (18.66%) and regeneration success (33.33%) was observed in case of *Cedrus deodara* whereas, the minimum stocking index (0.02), establishment stocking (0.74%) and regeneration success (2.08%) observed in case of *Pistacia integerrima*. At higher altitudinal range (>2100m), *Cedrus deodara* showed the highest regeneration success (40.27%) whereas, *Quercus leucotrichophora* showed the lowest regeneration success (17.49%).

At southern aspect and lower (<1800m) altitudinal range, the maximum stocking index (0.27), established stocking (19.16%) and regeneration success (27.77%) was observed in report of *Pinus roxburghii* whereas, the minimum stocking index (0.17) was observed in case of *Quercus leucotrichophora*, establishment stocking (8.92%) was observed in case of *Pistacia integerrima* and regeneration success (16.66%) was observed highest in case of *Quercus leucotrichophora*. At the middle altitudinal range (1800-2100m), the *Quercus leucotrichophora* showed the highest stocking index (0.22), establishment stocking (18.66%) and regeneration success (22.22%) whereas, *Pistacia integerrima* showed the lowest stocking index (0.13), establishment stocking (6.46%) and regeneration success (13.19%).

Table 45: Establishment stocking and regeneration success rate of different tree species at different elevational ranges on northern and southern aspects

Northern						Southern				
<1800m										
Species	Weighted average height (cm)	Establishment index	Stocking index	Establishment Stocking (%)	Regeneration success (%)	Weighted average height (cm)	Establishment index	Stocking index	Establishment Stocking (%)	Regeneration success (%)
<i>Cedrus deodara</i>	37.50	0.19	0.02	0.52	2.77	-	-	-	-	-
<i>Pistacia integerrima</i>	-	-	-	-	-	121.00	0.44	0.20	8.92	20.27
<i>Pinus roxburghii</i>		0.66	0.20	13.20	20.00	144.00	0.69	0.27	19.16	27.77
<i>Pyrus pashia</i>	86.70	0.34	0.10	3.54	10.41	-	-	-	-	
<i>Quercus leucotrichophora</i>		0.74	0.27	20.55	27.77	155.00	0.55	0.17	9.16	16.66
Total	124.20	1.93	0.59	37.79	60.95	420.00	1.68	0.64	37.24	64.70
1800-2100m										
<i>Cedrus deodara</i>	95.00	0.56	0.33	18.66	33.33	80.00	0.51	0.14	7.36	14.44
<i>Pistacia integerrima</i>	40.00	0.36	0.02	0.74	2.08	87.00	0.49	0.13	6.46	13.19
<i>Pinus roxburghii</i>	168.00	0.95	0.08	7.91	8.33	83.00	0.74	0.20	15.41	20.83
<i>Quercus leucotrichophora</i>	104.00	0.52	0.23	12.27	23.61	123.00	0.84	0.22	18.66	22.22
Total	407.00	2.39	0.66	39.85	67.36	373	2.58	0.694	47.89	70.68
>2100m										
<i>Cedrus deodara</i>	136.00	0.68	0.4	27.38	40.27	157.00	0.78	0.44	34.88	44.72
<i>Quercus leucotrichophora</i>	103.00	0.51	0.17	8.92	17.49	108.00	0.54	0.16	8.99	16.66
Total	239.00	1.19	0.57	36.3	57.76	265	1.32	0.607	43.87	61.38

At higher altitudinal range (>2100m), the *Cedrus deodara* showed the maximum regeneration success (44.72%) and *Quercus leucotrichophora* showed the lowest regeneration success (16.66%). Forget (1991) examined that many non-pioneer species can established in understorey, forest edges and gaps.

At western aspect lower altitudinal range (<1800m), the *Quercus leucotrichophora* showed maximum establishment stocking (13.05%) and regeneration success (27.77%) whereas, *Cedrus deodara* showed the minimum establishment stocking (5.44%) and regeneration success (11.11%). At middle altitudinal range (1800-2100m), the maximum weighted average height (130 cm) was recorded in case of *Cedrus deodara*, establishment index (0.65) was recorded in case of *Cedrus deodara*, stocking index (0.33) in case of *Quercus leucotrichophora*, establishment stocking (21.33%) recorded for *Quercus leucotrichophora* and regeneration success (33.33%) recorded in case of *Quercus leucotrichophora* and the minimum establishment stocking (7.91%) observed for *Pinus roxburghii* and regeneration success (14.44%) was recorded in case of *Cedrus deodara*. At higher altitudinal range (>2100m), the maximum establishment stocking (15.38%) was observed in case of *Cedrus deodara* and regeneration success (21.85%) was observed for *Quercus leucotrichophora* whereas, the minimum establishment stocking (2.90%) and regeneration success (13.19%) was observed in case of *Pinus roxburghii* (Table 46).

At eastern aspect and lower (<1800m) altitudinal range, *Pinus roxburghii* showed the highest stoking index (0.40), establishment stocking (18.33%) and regeneration success (40.74%) whereas, *Pistacia integerrima* showed the minimum stocking index (0.14), establishment stocking (12.71%) and regeneration success (14.44%). At middle (1800-2100m) altitudinal range, the maximum stocking index (0.35), establishment stocking (19.70%) and regeneration success (35.18%) was recorded in case of *Quercus leucotrichophora* whereas, the minimum stocking index (0.29), establishment stocking (16.62%) and regeneration success (29.16%) was recorded in case of *Pinus roxburghii*. At higher altitudinal range (>2100m), *Cedrus deodara* showed the maximum stocking index (0.19), establishment stocking (11.19%) and regeneration success (19.99%) whereas, *Pinus roxburghii* showed the minimum stocking index (0.13), establishment stocking (1.52%) and regeneration success (13.88%). A poor regeneration potential was a causative factor in disappearance of some species reported by Bentan and Werner (1976); Rao *et al.* (1990); Gupta and Yadav (2005).

Table 46: Establishment stocking and regeneration success rate of tree species at different elevational ranges on western and eastern aspect

Western						Eastern				
<1800m										
Species	Weighted average height (cm)	Establishment index	Stocking index	Establishment Stocking (%)	Regeneration success (%)	Weighted average height (cm)	Establishment index	Stocking index	Establishment Stocking (%)	Regeneration success (%)
<i>Cedrus deodara</i>	99.00	0.49	0.11	5.44	11.11	-	-	-	-	-
<i>Pistacia integerrima</i>	-	-	-	-	-	176.00	0.88	0.14	12.71	14.44
<i>Pinus roxburghii</i>	108.00	0.54	0.20	11.24	20.83	91.00	0.45	0.40	18.33	40.74
<i>Quercus leucotrichophora</i>	95.00	0.47	0.27	13.05	27.77		-	-	-	-
Total	302.00	1.50	0.58	29.73	59.71	267.00	1.33	0.54	31.04	55.18
1800-2100m										
<i>Cedrus deodara</i>	130.00	0.65	0.14	9.38	14.44	-	-	-	-	-
<i>Pinus roxburghii</i>	77.00	0.38	0.20	7.91	20.83	114.00	0.57	0.29	16.62	29.16
<i>Quercus leucotrichophora</i>	129.00	0.64	0.33	21.33	33.33	113.00	0.56	0.35	19.70	35.18
Total	336.00	1.67	0.67	38.62	68.60	227.00	1.13	0.64	36.32	64.34
>2100m										
<i>Cedrus deodara</i>	110.00	0.95	0.16	15.38	16.66	104.00	0.56	0.19	11.19	19.99
<i>Pinus roxburghii</i>	202.00	0.22	0.13	2.90	13.19	27.00	0.11	0.13	1.52	13.88
<i>Quercus leucotrichophora</i>	125.00	0.28	0.21	6.11	21.85	91.00	0.41	0.15	6.26	15.27
Total	437.00	1.45	0.50	24.39	51.70	222.00	1.08	0.47	18.97	49.14

Block and Treter (2001) described that generally plants can grow and survive in a particular range of environmental condition. However variation in these conditions such as temperature, light intensity and precipitation equally play a crucial role in shaping up the forest regeneration pattern along different altitudes. (Duan *et al.* 2009).

It has been recorded that regeneration of tree species is affected by fire, grazing, light, canopy density, soil moisture, soil nutrients and anthropogenic pressure. Regeneration of a species is dependent on internal forest process and exogenic disturbance (Table 46).

Regeneration status of different tree species at different altitudinal ranges and aspects

The data in Table (47) reveals that the maximum recruits ($3402.75 \text{ N ha}^{-1}$) recorded at middle altitudinal range (1800-2100m), followed by $2430.53 \text{ N ha}^{-1}$ at higher altitudinal range ($>2100\text{m}$). The highest un-established ($1842.58 \text{ N ha}^{-1}$) was recorded at middle (1800-2100m) altitudinal range whereas minimum of $1495.43 \text{ N ha}^{-1}$ at higher ($>2100\text{m}$) altitudinal range. The maximum established ($1348.37 \text{ N ha}^{-1}$) was recorded at middle altitudinal range (1800-2100m) whereas, minimum of $1077.59 \text{ N ha}^{-1}$ at higher ($>2100\text{m}$) altitudinal range.

Out of four aspects, the highest number of recruits ($3333.33 \text{ N ha}^{-1}$) observed on northern aspect whereas minimum recruits ($1990.73 \text{ N ha}^{-1}$) and highest un-established (1337.95) and established ($1305.55 \text{ N ha}^{-1}$) was observed on southern aspect, followed by northern aspect (122.21 N ha^{-1}). The minimum un-established ($1117.27 \text{ N ha}^{-1}$) and established ($1103.46 \text{ N ha}^{-1}$) was observed on eastern aspect.

In case of interaction of altitudinal ranges and aspects, the maximum recruits ($3888.89 \text{ N ha}^{-1}$) were reported at middle altitudinal range (1800-2100m) on northern aspect whereas, minimum ($1527.76 \text{ N ha}^{-1}$) at higher altitudinal range ($>2100\text{m}$) on eastern aspect. The highest un-established ($1513.88 \text{ N ha}^{-1}$) and established ($1388.90 \text{ N ha}^{-1}$) were detected at middle altitudinal range on southern aspect whereas, minimum un-established ($1027.76 \text{ N ha}^{-1}$) and established (902.98 N ha^{-1}) at higher ($>2100\text{m}$) altitudinal range on eastern aspect. Pande *et al.* (2002) suggested that dominance of established seedlings and saplings under the adult trees affect the future composition of a community.

The data in Table (48) reveals that the maximum establishment index (1.94), stocking index (0.65), establishment stocking (40.00%) and regeneration success (90.32%) was obtained at middle altitudinal range (1800-2100m) whereas, minimum establishment index (1.26), stocking index (0.53), establishment stocking (30.88%) and regeneration success (79.41) obtained at higher altitudinal range ($>2100\text{m}$).

Table 47: Regeneration status of different tree species at different altitudinal ranges and aspects

	Recruits ha ⁻¹			Mean	Un-established ha ⁻¹			Mean	Established ha ⁻¹			Mean
	E ₁	E ₂	E ₃		E ₁	E ₂	E ₃		E ₁	E ₂	E ₃	
A₁	3333.33	3888.89	2777.77	3333.33	1375.2	1458.32	1111.11	1314.87	1180.55	1319.44	1166.66	1222.21
A₂	3250.00	3472.22	2500.01	3074.07	1249.99	1513.88	1249.99	1337.95	1305.55	1388.90	1222.22	1305.55
A₃	3194.45	3472.22	2916.6	3194.42	1249.98	1305.55	1097.43	1217.65	1180.74	1388.88	1018.50	1196.04
A₄	1666.66	2777.77	1527.76	1990.73	1074.07	1249.99	1027.76	1117.27	1111.11	1296.29	902.98	1103.46
Mean	2861.11	3402.77	2430.53		1649.74	1842.58	1495.43		1194.48	1348.37	1077.59	

Table 48: Establishment stocking per cent and regeneration success of different tree species at different altitudinal ranges and aspects

	Establishment index				Stocking index				Establishment Stocking Per cent				Regeneration success			
	E ₁	E ₂	E ₃	Mean	E ₁	E ₂	E ₃	Mean	E ₁	E ₂	E ₃	Mean	E ₁	E ₂	E ₃	Mean
A₁	1.93	2.39	1.19	1.83	0.59	0.66	0.57	0.60	37.79	39.58	36.30	37.89	60.95	67.35	57.76	62.02
A₂	1.68	2.58	1.32	1.86	0.64	0.69	0.60	0.64	37.24	47.89	43.87	43.00	64.7	70.68	61.38	65.58
A₃	1.50	1.67	1.45	1.54	0.58	0.67	0.50	0.58	29.73	38.62	24.39	30.91	59.71	68.60	51.7	60.00
A₄	1.33	1.13	1.08	1.18	0.54	0.64	0.47	0.55	31.04	36.32	18.97	28.77	55.18	64.34	49.41	56.31
Mean	1.61	1.94	1.26		0.58	0.66	0.53		33.95	40.60	30.88		80.18	90.32	73.41	

Out of four aspects, the highest establishment index (1.86), stocking index (0.64), establishment stocking (43%) and regeneration success (65.58%) was observed on southern aspect whereas, lowest establishment index (1.18), stocking index (0.55) establishment stocking (28.77%) and regeneration success (56.31%) was recorded on southern aspect, followed by northern aspect.

In the case of interaction between altitudinal ranges and aspects, the maximum establishment index (2.58), stocking index (0.69), establishment stocking (47.89%) and regeneration success (70.68%) was recorded at middle altitudinal range (1800-2100m) on southern aspect whereas, minimum establishment index (1.08), stocking index (0.47), establishment stocking (18.97%) and regeneration success (49.41%) was recorded at higher altitudinal range (>2100m) on eastern aspect. Malik *et al.* (2016) stated that some of anthropogenic disturbances such as forest fires, overgrazing and lopping affect can be reason of the poor regeneration status of the forest. Shamra and Samant (2013) alluded the regeneration pattern of tree species with in different communities showed different trends.

4.8 Biomass and carbon stock

4.8.1 Aboveground biomass (t ha^{-1})

The biomass and carbon stock at different altitudinal ranges and aspects were recorded in Table (49). At different altitudinal ranges, highest average value of aboveground biomass (82.79 t ha^{-1}) was detected at middle altitudinal range (1800-2100m), followed by lower altitudinal range whereas, the lowest average value of aboveground biomass (46.33 t ha^{-1}) was recorded at higher altitudinal range (>2100m).

Among different aspects, the maximal average value of aboveground biomass (88.19 t ha^{-1}) was reported on northern aspect, followed by eastern aspect (70.30 t ha^{-1}) and minimal average value of aboveground biomass (45.43 t ha^{-1}) was reported on southern aspect, respectively.

In case of interaction of altitudinal ranges and aspects, the highest average value of aboveground biomass (112.20 t ha^{-1}) was recorded at middle altitudinal range (1800-2100m) on northern aspect and lowest (22.55 t ha^{-1}) was found at higher altitudinal range (>2100m) on southern aspect (Table 50). A similar trend reported by Moser *et al.* (2007) and Leuschner *et al.*

(2007) where aboveground biomass decreased with increasing altitudinal range because small trees occurred at higher altitudinal range. Mountousis *et al.* (2006) described that aboveground biomass varied among altitudinal ranges and aspects.

4.8.2 Belowground biomass (t ha^{-1})

At different altitudinal ranges, the maximum average value of belowground biomass (37.85 t ha^{-1}) was reported at middle altitudinal range (1800-2100m) whereas, minimum value of belowground biomass (27.04 t ha^{-1}) was reported at higher altitudinal range ($>2100\text{m}$).

On different aspects, the highest average value of belowground biomass (40.73 t ha^{-1}) was observed on northern aspect and lowest average value (26.62 t ha^{-1}) was observed on southern aspect followed by western aspect (31.22 t ha^{-1}).

Table 49: Biomass (t ha^{-1}) and carbon stock (t C ha^{-1}) at different altitudinal ranges and aspects

Treatment	Parameters							
	AGB (t ha^{-1})	BGB (t ha^{-1})	Total Biomass (t ha^{-1})	Carbon Stock (t C ha^{-1})	Shrub Biomass (t ha^{-1})	Herb Biomass (t ha^{-1})	Vegetation biomass (t ha^{-1})	Vegetation carbon density (t C ha^{-1})
E1 (<1800m)	69.91	34.87	104.78	52.39	2.56	3.19	110.54	55.27
E2 (1800-2100m)	82.79	37.85	120.64	60.32	1.96	3.21	125.82	62.91
E3 (>2100m)	46.33	27.04	73.38	36.69	1.53	2.90	77.82	38.91
CD_{0.05} (E)	9.06	3.96	9.74	4.87	0.09	0.04	9.77	4.88
A1 (Northern)	88.19	40.73	128.92	64.46	1.80	2.58	134.43	67.21
A2 (Southern)	45.43	26.62	72.05	36.02	2.34	3.64	76.43	38.21
A3 (Western)	61.46	31.22	92.68	46.34	2.01	2.68	97.31	48.65
A4 (Eastern)	70.30	34.45	104.75	52.37	1.94	3.50	110.73	55.36
CD_{0.05} (A)	10.46	4.57	11.25	5.62	0.10	0.05	11.28	5.64

In case of interaction of altitudes and aspects, the highest belowground biomass (49.21 t ha^{-1}) was recorded at middle altitudinal range (1800-2100m) on northern aspect followed by lower altitudinal range on northern aspect (40.95 t ha^{-1}). The lowest belowground biomass (17.53 t ha^{-1}) was detected at higher altitudinal range ($>2100\text{m}$) on southern aspect followed by western aspect (28.19 t ha^{-1}) at same altitudinal range. Dar and Sundarapandian (2016) suggested that biomass of different tree species varied with type of forest, species composition, stand area, the

tree size class, pattern of rainfall, edaphic factors and altitude. Mutanga *et al.* (2004) opined that topographic factors such as aspect and altitude with soil properties influence the biomass production.

4.8.3 Total biomass (t ha^{-1})

The maximum average value of total biomass (120.64 t ha^{-1}) was perceived at, middle altitudinal range (1800-2100m) and minimum (73.38 t ha^{-1}) at higher altitudinal range ($>2100\text{m}$).

In case of aspects, the highest average value of total biomass (128.92 t ha^{-1}) was noticed on northern aspect, followed by eastern aspect (104.75 t ha^{-1}) whereas, the lowest average value of total biomass (72.05 t ha^{-1}) was noticed on southern aspect.

The maximal mean value of total biomass (161.42 t ha^{-1}) was recorded at middle (1800-2100m) altitudinal range on northern aspect, followed by the same on eastern aspect (136.26 t ha^{-1}) and minimal mean value of total biomass (40.08 t ha^{-1}) was examined at higher altitudinal range ($>2100\text{m}$) on southern aspect, followed by western aspect (77.13 t ha^{-1}) at same altitudinal range. The maximum tree biomass (128.92 t ha^{-1}) was observed on the northern aspect at middle altitudinal range (1800-2100m). These finding are similar with other studies showing maximum biomass in shaded aspects as reported by Gong *et al.* (2008); Ucles *et al.* (2015); Tewari and Karky 2007. Many authors (Rana *et al.* 1988; Rawat and Singh 1988) have studied the plant biomass and net productivity of forests located between 300 and 2200m in Central Himalayan region. Chhabra *et al.* (2002) had found 251.8 t/ha of biomass in Jammu and Kashmir, which was highest of all the states in India. Similarly, Gairola *et al.* (2011) examined the total biomass of 80.8%, aboveground biomass 19.20 % from Garhwal Himalaya, India. The homogenous results of above and belowground biomass reported by Chhabra *et al.* (2002). Barford *et al.* (2001) and Yang *et al.* (2005) alluded coniferous forest had a higher biomass stock as compared to broad-leaved forest, which indicates the forest type and girth class have profound positive impact on the total biomass. Biomass decreased with increasing altitudinal range was also reported by Kharkwal *et al.* (2010) in Kumaun Himalaya, India. Sharma (2009) stated that lower biomass production at lower altitude was due to the presence of low wood density species at lower altitude. However, at higher altitudinal range, the deodar and ban were dominating species which have comparatively higher wood density. Therefore it can be concluded that as move from

lower to higher altitude the proportion of the tree species having higher wood density increased and hence biomass.

4.8.4 Carbon stock (t C ha^{-1})

At different altitudinal ranges, the highest average value of carbon stock ($60.32 \text{ t C ha}^{-1}$) was recorded at middle altitudinal range (1800-2100m) whereas, the lowest of carbon stock ($36.69 \text{ t C ha}^{-1}$) was found at higher altitudinal range.

On the different aspects, the maximal average value of carbon stock ($64.46 \text{ t C ha}^{-1}$) was observed on northern aspect and minimal ($36.02 \text{ t C ha}^{-1}$) on southern aspect followed by western aspect ($46.34 \text{ t C ha}^{-1}$).

In case of interaction of altitudinal ranges and aspects, the maximum mean value of carbon stock ($80.71 \text{ t C ha}^{-1}$) was noticed at middle altitudinal range (1800-2100m) on northern aspect, followed by eastern aspect ($68.13 \text{ t C ha}^{-1}$) at same altitudinal range (1800-2100m). The minimum mean value of carbon stock ($20.04 \text{ t C ha}^{-1}$) was noticed at higher altitudinal range ($>2100\text{m}$) on southern aspect, followed by western aspect ($38.56 \text{ t C ha}^{-1}$) at higher altitudinal range ($>2100\text{m}$). Callaham *et al.* (2004) suggested the higher altitude with lower temperature can be the reason for slower decomposition rates. These lower decomposition rates, however, offer one single advantage in the short period more carbon would be stored in the forest floor. Kumar *et al.* (2013) determined total carbon stock of *Pinus roxburghii* forest was highest at lower altitudinal range and lowest at higher altitudinal range from Garhwal Himalaya. Variation among forest carbon stocks depends on plant species composition, geographic location, stand age and management practices (Sherstha and Singh 2008; Chaturvedi *et al.* 2011; Chaturvedi and Raghubanshi 2015 and Sharma *et al.* 2016). In many parts of the world that live tree biomass and carbon stocks decline with increasing altitudinal range has been reported by Leuschner *et al.* (2007); Moser *et al.* (2007) and Zhu *et al.* (2010).

4.8.5 Shrub biomass (t ha^{-1})

The highest average value of shrub biomass (2.56 t ha^{-1}) was examined at lower altitudinal range ($<1800\text{m}$) and lowest (2.90 t ha^{-1}) at higher altitudinal range ($>2100\text{m}$).

On the different aspects, the maximum average value of shrub biomass (2.34 t ha^{-1}) was reported on southern aspect, followed by (2.01 t ha^{-1}) western aspect and minimum average value of shrub biomass (1.80 t ha^{-1}) on northern aspect.

Table 50: Interaction effects of biomass (t ha^{-1}) and carbon stock (t C ha^{-1}) at different altitudinal ranges and aspects

Elevations	Aspects	Parameters							
		AGB (t ha^{-1})	BGB (t ha^{-1})	Total Biomass (t ha^{-1})	Carbon Stock (t C ha^{-1})	Shrub Biomass (t ha^{-1})	Herb Biomass (t ha^{-1})	Vegetation Biomass (t ha^{-1})	Vegetation carbon density (t C ha^{-1})
E ₁	A ₁ (Northern)	91.87	40.95	132.82	66.41	2.39	2.81	138.51	69.25
	A ₂ (Southern)	58.18	32.07	90.26	45.13	2.84	3.93	95.46	47.73
	A ₃ (Western)	62.21	32.97	95.18	47.59	2.52	2.85	100.54	50.27
	A ₄ (Eastern)	67.38	33.49	100.87	50.43	2.50	3.17	107.65	53.82
E ₂	A ₁ (Northern)	112.20	49.21	161.42	80.71	1.71	2.60	166.95	83.47
	A ₂ (Southern)	55.56	30.25	85.81	42.90	2.20	3.99	90.13	45.06
	A ₃ (Western)	66.58	32.50	99.08	49.54	2.02	2.77	103.77	51.88
	A ₄ (Eastern)	96.82	39.44	136.26	68.13	1.90	3.48	142.46	71.23
E ₃	A ₁ (Northern)	60.49	32.04	92.53	46.26	1.29	2.34	97.84	48.92
	A ₂ (Southern)	22.55	17.53	40.08	20.04	1.98	3.01	43.71	21.85
	A ₃ (Western)	55.59	28.19	77.13	38.56	1.46	2.43	82.09	41.04
	A ₄ (Eastern)	46.70	30.42	83.79	41.89	1.41	3.84	87.63	43.81
CD _{0.05} (A)		18.12	NS	19.49	9.47	NS	0.09	19.55	9.77

The maximal mean value of shrub biomass (2.84 t ha^{-1}) was perceived at lower altitudinal range ($<1800\text{m}$) on southern aspect and minimal (1.29 t ha^{-1}) at higher altitudinal range ($>2100\text{m}$) on northern aspect followed by eastern aspect (1.41 t ha^{-1}) at higher altitudinal range. Radosevich and Osteryoung (1987); Puettmann and Berger (2006) described that the biomass production and partitioning, crown structure and leaf area of trees can be altered by plant composition. The differences in productivity of aspect may also be due to differences in soil conditions, phenology of dominant species reported by Gupta and Singh (1981).

4.8.6 Herb biomass (t ha^{-1})

At different altitudinal ranges, the maximum mean value of herb biomass (3.21 t ha^{-1}) was detected at middle altitudinal range ($1800\text{-}2100\text{m}$) and minimum (2.90 t ha^{-1}) at higher altitudinal range ($>2100\text{m}$).

Among aspects, the maximal average value of herb biomass (3.64 t ha^{-1}) was noticed on southern aspect, followed by eastern aspect (3.50 t ha^{-1}) whereas, minimal average value of herb biomass (2.58 t ha^{-1}) was noticed on northern aspect followed by western aspect (2.68 t ha^{-1}).

In case of interaction of altitudinal ranges and aspects, the highest average value of herb biomass (3.99 t ha^{-1}) was found at middle altitudinal range (1800-2100m) on southern aspect followed by (3.93 t ha^{-1}) lower altitudinal range (<1800m) on southern aspect and lowest average value of herb biomass (2.34 t ha^{-1}) was found at higher altitudinal range (>2100m) on northern aspect.

4.8.7 Vegetation biomass (t ha^{-1})

At different altitudinal ranges, the highest vegetation biomass (125.82 t ha^{-1}) was detected at middle altitudinal range (<1800m) whereas, the lowest (77.82 t ha^{-1}) at higher altitudinal range.

Among different aspects, the maximum vegetation biomass (134.43 t ha^{-1}) was observed on northern aspect followed by eastern aspect (110.73 t ha^{-1}). The minimum vegetation biomass (76.43 t ha^{-1}) was observed on southern aspect, followed by western aspect (97.31 t ha^{-1}).

In case of the interaction, the maximum vegetation biomass (166.95 t ha^{-1}) was noticed at middle altitudinal range (1800-2100m) on northern aspect followed by eastern aspect (142.43 t ha^{-1}) at same altitudinal range and the minimum vegetation biomass (43.71 t ha^{-1}) was noticed at higher altitudinal range on southern aspect.

4.8.8 Vegetation carbon density (t C ha^{-1})

At different altitudinal ranges, the highest mean value of vegetation carbon density ($62.91 \text{ t C ha}^{-1}$) was recorded at 1800-2100m altitudinal range whereas, lowest mean value of vegetation carbon density ($38.91 \text{ t C ha}^{-1}$) at higher altitudinal range, followed by ($55.27 \text{ t C ha}^{-1}$) lower altitudinal range.

Out of four aspects, the maximum average value of vegetation carbon density ($67.21 \text{ t C ha}^{-1}$) was reported on northern aspect, followed by eastern aspect ($55.36 \text{ t C ha}^{-1}$) whereas, the minimum average value of vegetation carbon density ($38.21 \text{ t C ha}^{-1}$) was reported on southern aspect.

In the case of interaction between different altitudinal ranges and aspects, the highest vegetation carbon density ($83.47 \text{ t C ha}^{-1}$) was examined at middle altitudinal range (1800-

2100m) on northern aspect, followed by eastern aspect at same altitudinal range (71.23 t C ha⁻¹) and the lowest vegetation carbon density (21.85 t C ha⁻¹) was found at higher altitudinal range (>2100m) on southern aspect. The carbon density values are also lower than the world average value of 160.0 t ha⁻¹ as given by Houghton (1995).

4.9 Soil Analysis

Among environmental factors, parameters such as slope, aspect, elevation and many others have effects on soil physical and chemical parameters (Enright *et al.* 2005). Topography directly through changes and adjustments on environmental factors, and indirectly through its effect on soil formation has a major impact on plant communities. The knowledge of topography characteristics is necessary to manage these lands. Topography through effects on soil moisture and microclimate has a significant impact on the characteristics of the ecosystem and controls vegetation patterns (Clark, 1990). Altitude is one of the affecting factors on changes in soil properties (Sharma *et al.* 2009). The spatial variation in soil properties is influenced by both biotic and abiotic factors such as topography induced microclimate differences, altitude, parent material and vegetation community reported by Johnson *et al.* (2000). Mendoza (2002) described the aspect also induces local variations in microclimate, which along with chemical and physical composition are the main regulators of decomposition rates of soil organic matter. Luna (2005) alluded the best vegetation grows on cool northern aspects with deep moist shale soil however, its growth gets stunted on shallow and dry soils on the warmer southern aspects, mostly because of insufficient soil moisture.

The results of some soil physico-chemical characteristics on different aspect (Northern, Southern, Western, Eastern) along three altitudinal gradients viz., <1800, 1800-2100m and >2100m asl are presented under following main headings:

4.9.1 pH

The data pertaining to soil pH is presented in Table (51 and 52). The maximum average pH value (6.05) was recorded at lowest (<1800m) altitudinal range which was, followed by the middle (1800-2100m) altitudinal range (5.81) whereas, minimum average value of pH (5.69) was found at the higher altitudinal range (>2100m).

For different aspects, the maximum average value of pH (5.93) was recorded at southern aspect which was, followed by northern aspect (5.84) whereas, the minimum average value of pH (5.71) was found at the eastern aspect followed by western aspect (5.80).

In case of interaction of elevation ranges and aspects, the maximum average value of pH (6.11) was recorded at lower altitude (<1800m) on the southern aspect. The minimum average value of pH (5.60) was recorded at higher altitude on northern aspect followed by same altitude gradient (5.69) on eastern aspect.

The pH value of soil decreased with the increasing altitudinal ranges and the highest value of pH was found at southern aspect, followed by western and minimum value was found at the eastern aspect.

The soil pH is known to influence the availability of plant nutrient and has been shown as a good indicator of forest soil fertility (Waring and Major 1964). In the present study soil pH ranged between 5.73 and 6.28. The acidic nature of soil is also reported by several other workers for oak dominated forests of Himalaya (Bhandari *et al.* 2000; Dhanai *et al.* 2000 and Kumar *et al.* 2004). Leskiw (1998) reported that forest soils should be slightly acidic for nutrient supply to be balanced. The acidic nature of the forest soil is generally attributed to release of greater number of H⁺ ions the decomposing resinous residues stated by Hodges (1996) from conifer forest vegetation. De Hann (1997) reported the reduction in pH can be attributed to accumulation and subsequent slow decomposition of organic matter, which releases acids. The value of recorded pH in present study were lower than the value of pH presented by Qasba *et al.* (2017) for Sankaracharya Reserved Forest. Equivalently, value of pH in range of 5.5 to 6.5 was recorded by Bisht and Lodhiyal during 2005 in coniferous forest of Central Himalaya.

4.9.2 Bulk density (g cm⁻³)

The results on bulk density are summarized in Table (51 and 52). The values exhibited significant differences between the altitudinal gradients and aspects. The maximum bulk density (0.81 g cm⁻³) was recorded at higher altitude (>2100m), followed by the middle altitude (1800-2100m) with bulk density 0.74 g cm⁻³. The minimum mean value of the bulk density (0.69 g cm⁻³) was recorded at lower altitude (<1800m).

Out of four aspects, the maximum average value of the bulk density (0.86 g cm^{-3}) recorded on southern aspect followed by western aspect (0.73 g cm^{-3}). The minimum average value of the bulk density (0.68 g cm^{-3}) was reported for the northern aspect followed by eastern aspect (0.70 g cm^{-3}).

In case of intercation of elevation ranges and aspects the maximum average value of bulk density (1.02 g cm^{-3}) was recorded at higher altitude ($>2100\text{m}$) on southern aspect followed by western aspect at same altitudinal range. The minimum average value of bulk density (0.64 g cm^{-3}) was recorded at lower altitude ($<1800\text{m}$) on the northern aspect followed by western aspect. The maximum average value of the soil bulk density was recorded at higher altitudinal range on the southern aspect and the minimum average value of the bulk density was recorded at lower altitudinal range on the northern aspect. Sone (1975); Coote and Ramsay (1983) reported the reduction of bulk density of soil due to increase in soil organic carbon. These values of bulk density were slightly higher than the range of $0.95\text{-}1.20 \text{ g cm}^{-3}$ observed by Bisht and Lodhiyal (2005).

Table 51: Physico-chemical properties of forest soils of western Himalaya at different altitudinal ranges and aspects

Treatment	Parameters					
	pH	Bulk density (g cm^{-3})	Organic carbon (g kg^{-1})	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
E ₁ ($<1800\text{m}$)	6.05	0.69	21.35	521.08	19.43	307.17
E ₂ ($1800\text{-}2000\text{m}$)	5.81	0.74	24.71	580.10	23.28	331.10
E ₃ ($>2100\text{m}$)	5.69	0.81	16.55	364.16	16.26	246.68
CD _{0.05}	0.028	0.014	0.56	16.13	0.17	5.87
Aspects						
A ₁ (Northern)	5.84	0.68	23.30	513.77	24.85	284.88
A ₂ (Southern)	5.93	0.86	17.94	461.88	13.91	287.73
A ₃ (Western)	5.80	0.73	19.87	482.66	18.05	297.67
A ₄ (Eastern)	5.71	0.70	22.38	495.47	21.82	310.16
CD _{0.05}	0.033	0.016	0.64	18.63	0.20	6.77

4.9.3 Soil organic carbon (g kg^{-1})

The results on soil organic carbon are summarized in Table (51, 52). On the different altitudinal gradients, the maximum organic carbon (24.71 g kg^{-1}) was recorded at middle altitude

(1800-2100m) followed by the lower altitude (<1800m) with organic carbon of 21.35 g kg⁻¹ and the minimum mean value of organic carbon (16.55 g kg⁻¹) was found at higher altitude (>2100m).

The maximum value of soil organic carbon (23.30 g kg⁻¹) was recorded on the northern aspect, followed by the eastern aspect (22.38 g kg⁻¹). The minimum value of the soil organic carbon (17.94 g kg⁻¹) recorded on the southern aspect followed by the western aspect (19.87 g kg⁻¹).

Corresponding to both elevation ranges and aspects, the maximum average value of soil organic carbon (29.46 g kg⁻¹) was recorded at middle altitude gradient (1800-2100m) on northern aspect, followed by eastern aspect 26.04 g kg⁻¹. The minimum average value of soil organic carbon (15.46 g kg⁻¹) was recorded at higher altitude (>2100m) on southern aspect followed by same altitude on the western aspect 15.52 g kg⁻¹.

The maximum soil organic carbon was recorded at middle altitude (1800-2100m) on the northern aspect whereas, the minimum was recorded at higher altitude (>2100m) on the southern aspect, respectively. Highest values of soil organic carbon were observed in the northern aspect as compared to other aspects. Significantly increased organic carbon contents in soils under northern aspect may be ascribed to more leaf litter deposition (Zegeye 1999 and Kater *et al.* 1992). Soil organic carbon plays an important role in determining the size of the microbial biomass and the level of soil enzyme activity. Higher contents of soil organic carbon can support more biological activity because the energy and available nutrient status in soils are enhanced as reported by Nourbakhsh (2007). The present study showed that soil organic carbon decreased with increasing altitudinal range because of low input of soil organic matter however, bulk density showed reverse trend with soil organic carbon. Altitude is often employed to study the effects of climate variables on soil organic matter dynamics as reported by Lemenih and Itanna (2004). Physical soil properties, such as soil structure, particle size, and composition, have profound impact on soil carbon. Soil particle size has an influence on the rate of decomposition of soil organic carbon (Jobbagy and Jackson 2000). The release of nutrients from litter decomposition is a fundamental process in the internal bio-chemical cycle of an ecosystem, and

decomposers recycle a large amount of carbon that is bound in the plant or tree to the atmosphere (Sevgi and Tecimen 2008).

4.9.4 Available Nitrogen (kg ha^{-1})

Data in Table (51) depicts that the maximum average value of nitrogen ($583.10 \text{ kg ha}^{-1}$) was recorded at middle altitude (1800-2100m) followed by lower altitudinal gradient ($<1800\text{m}$) with available nitrogen of $521.02 \text{ kg ha}^{-1}$. The minimum average value of available nitrogen ($364.16 \text{ kg ha}^{-1}$) was recorded at higher altitude ($>2100\text{m}$).

The maximum mean value of the nitrogen amongst aspects was found at the northern aspect ($513.77 \text{ kg ha}^{-1}$) followed by the eastern aspect ($495.47 \text{ kg ha}^{-1}$) whereas, the minimum mean value of the available nitrogen ($461.66 \text{ kg ha}^{-1}$) was found on the southern aspect followed by the western aspect ($482.66 \text{ kg ha}^{-1}$).

The maximum average value of available nitrogen ($608.00 \text{ kg ha}^{-1}$) was recorded at middle altitude (1800-2100m) on northern aspect followed by eastern aspect ($587.33 \text{ kg ha}^{-1}$) at middle altitudinal gradient. The minimum average value of available nitrogen ($335.00 \text{ kg ha}^{-1}$) was recorded at higher altitudinal gradient ($>2100\text{m}$) on southern aspect followed by western aspect ($354.00 \text{ kg ha}^{-1}$) at higher altitudinal gradient.

The maximum mean value of the available nitrogen at altitude and aspects was found at middle altitudinal ranges (1800-2100m asl) on the northern aspect whereas, the minimum mean value was found at higher altitudinal gradients ($>2100\text{m asl}$) on the southern aspect respectively. The forest surface soils are higher in N levels as compared to sub-surface soils stated by Mandal *et al.* (1990).

4.9.5 Available Phosphorus (g kg^{-1})

The results on the soil phosphorus are presented in Table (51) show that the maximum average available phosphorus (23.28 kg ha^{-1}) was recorded at the middle altitude (1800-2100m) followed by the lower altitude ($<1800\text{m}$) 19.43 kg ha^{-1} . The minimum average value of the phosphorus (16.26 kg ha^{-1}) was recorded at the higher altitude ($>2100\text{m}$).

On the selected aspects, the maximum mean value of the available phosphorus (24.85 kg ha⁻¹) was found on the northern aspect followed by the eastern aspect (21.82 kg ha⁻¹). The minimum mean value of the phosphorus (13.91 kg ha⁻¹) was found on the southern aspect followed by the western aspect (18.05 kg ha⁻¹).

Corresponding different altitudinal gradients and aspects, the maximum average value of available phosphorus (28.83 kg ha⁻¹) was recorded at middle altitude (1800-2100m) on northern aspect followed by at middle altitudinal gradient on eastern aspect 25.63 kg ha⁻¹. The minimum average value of available phosphorus (10.70 kg ha⁻¹) recorded at higher altitudinal gradient on the southern aspect which followed by western aspect (14.86 kg ha⁻¹) at higher altitude (>2100m).

The maximum mean value of the available phosphorus found at the middle altitude (1800-2100m asl) on the northern aspect whereas, the minimum mean value of the available phosphorus was found at higher altitude (>2100m) on southern aspect (Table 52). Smal and Olszewska (2008) alluded the total and available phosphorus content in the humus horizon in forest soils decreases with stand age, with higher values in young stands. Dwivedi *et al.* (2005) recorded that the available phosphorus ranged from 2.35 to 25.66 kg ha⁻¹ in some surface of Jammu and Kashmir. The values of bulk density were similar to the our results ranged from 9.3 to 18.20 kg ha⁻¹ reported by Kumar *et al.* 2004 in pine forest.

4.9.6 Available Potassium (g kg⁻¹)

The maximum average value of the available potassium (331.10 kg ha⁻¹) recorded at middle altitude (1800-2100m) which followed by lower altitude (<1800m) with potassium content of 307.17 kg ha⁻¹. The minimum average value of available potassium (246.68 kg ha⁻¹) was recorded at higher altitude (>2100m).

Out of four aspects, the maximum mean value of the available potassium (310.16 kg ha⁻¹) was found on the eastern aspect followed by the western aspect (297.67 kg ha⁻¹). The minimum mean value of the available phosphorus (284.88 kg ha⁻¹) was found on the northern aspect followed by the southern aspect (287.73 kg ha⁻¹).

Consedering the different elevational ranges and aspects, the maximum average value of available potassium (347.29 kg ha⁻¹) was recorded at middle altiude (1800-2100m) on eastern aspect followed by middle altitudinal gradient on western aspect (333.12 kg ha⁻¹). The minimum average value of available potassium (225.13 kg ha⁻¹) recoded at >2100m on northern aspect followed by southern aspect (243.64 kg ha⁻¹) at higher altitudianl gradient (>2100m).

The maximum mean value of the available potassium was found at middle altitude (1800-2100m) on eastern aspect whereas, the minimum value found at higher altitude (>2100m) on northern aspect (Table 52). Basumatary and Bordoloi (1992) investigated the decrease of potassium caused by leaching and drainge, which results in destruction of vegetation. The values of potassium ranged from 135 to 320 kg ha⁻¹ observed by Rao *et al.* (2008) in surface soils of Ramachandrapuram, Mandal, soils.

Table 52: Interaction effect of elevations (E) and aspects (A) on physico-chemical properties of soil of western Himalayan Forest

Interaction	Parameters					
	pH	Bulk density (g cm ⁻³)	Organic carbon (g kg ⁻¹)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
E ₁ A ₁	6.04	0.64	24.97	538.66	24.96	312.13
E ₁ A ₂	6.11	0.74	17.95	502.66	14.13	291.43
E ₁ A ₃	6.05	0.69	19.60	516.66	17.53	306.53
E ₁ A ₄	6.02	0.68	22.89	526.33	21.10	318.59
E ₂ A ₁	5.80	0.69	29.46	608.00	28.83	317.38
E ₂ A ₂	5.94	0.83	20.36	548.00	16.90	328.14
E ₂ A ₃	5.77	0.72	22.96	577.33	21.76	333.12
E ₂ A ₄	5.73	0.70	26.04	587.33	25.63	347.29
E ₃ A ₁	5.72	0.71	18.20	394.66	20.76	225.13
E ₃ A ₂	5.76	1.02	15.46	335.00	10.70	243.64
E ₃ A ₃	5.69	0.79	15.52	354.00	14.86	253.36
E ₃ A ₄	5.60	0.74	17.04	373.00	18.73	264.60
CD _{0.05}	0.057	0.028	1.12	NS	0.34	11.74

Phosphorus and potassium has not shown any particular trend with altitude (Kumar *et al.* 2010). The results of soil phyciso-chemical properties indicated that the middle altitude was better than other studied altitudinal gradients may be due to the better decomposition and presence of leaf liiter etc. The different classes of elevation had a significant impact on the

percentage of stones and pebbles in the soil and at higher elevations, this is due to leaching of salts from higher elevations to lower elevations (Qanbari and Jamali 2015). Dimiri *et al.* (2006) opined the total soil potassium varied on different altitudinal ranges and the higher content of available potassium was found in surface soil in the form of exchangeable potassium.

The forests also have a marked influence on the growth and development of soils. The lower moisture content and water holding capacity of the soils on southern aspects as compared to the other aspects indicate relatively drier conditions on the southern aspects. This is because north-east aspects are generally moister and cooler as compared to the south-west aspects, which also affects various other soil properties (Sharma *et al.* 2010).

Forest stands growing on northern aspects are more productive and have better soil properties as compared to southern aspects. Therefore, it is recommended that plantation of these forest types can be undertaken on the northern aspects for better results in the Himalayan temperate forests (Sharma *et al.* 2010).

4.10. Correlation studies

Correlation studies for different parameters at different altitudinal ranges and aspects

Mean Diameter

Significantly positive correlation was observed with total density, total basal area, total biomass, carbon stock vegetation carbon density and soil parameters (SOC and NPK). Non-significantly positive correlation was found with recruits, un-established, established, establishment index, stocking index, establishment stocking per cent and regeneration success, herb biomass, and non-significantly negative correlation with mean height, crown width, crown spread, shrub biomass and pH.

Mean Height

Non-Significantly positive correlation was observed with recruits, un-established, established, establishment index, stocking index, establishment stocking per cent, regeneration success, shrub biomass, herb biomass, pH and available nitrogen. Non-significantly but negative correlation was established with mean diameter, total density, total basal area, crown width,

crown spread, total biomass, carbon stock, vegetation carbon density, Soil organic carbon, available phosphorus and available potassium.

Total Density

Significantly positive correlation was obtained with mean diameter, total basal area, recruits, establishment index, total biomass, carbon stock, vegetation carbon density, Soil organic carbon, available nitrogen and phosphorus and significantly but negative correlation with crown width. Non-significantly positive correlation was established with shrub biomass, established, un-established, stocking index, establishment stocking per cent, regeneration success, pH and available potassium but non-significantly negative with mean height, crown spread, crown spread and herb biomass.

Total basal area

Total basal area was found to be in a significantly positive correlation with mean diameter, total density, recruits, un-established, establishment index, regeneration success, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen, available phosphorus and potassium. Non-significantly positive correlation was observed with established, stocking index, establishment stocking per cent, shrub biomass and pH whereas, non-significantly negative with mean height, crown width, crown spread and herb biomass.

Crown Width

Crown width was found to be in a significantly positive correlation only with crown spread but negative significant correlation with total density. Crown width displayed non-significantly positive correlation with herb biomass and negative non-significant with mean height, Mean diameter, total basal area, recruits, un-established, established, established index, stocking index, established stocking per cent, regeneration success, shrub biomass, total biomass, carbon stock, vegetation carbon density, and soil properties. Osunkoya *et al.* (2007) found a strong but negative correlation between crown diameter and tree height.

Crown spread

Crown spread displayed significantly positive correlation only with crown width, but significantly negative correlation with recruits, established, establishment index, stocking index,

regeneration success. Non-significant positive correlation was found with only herb biomass but non-significantly negative correlation with mean diameter, mean height, total density, total basal area, un-established, establishment stocking per cent, shrub biomass, total biomass, carbon stock, vegetation carbon density, and soil properties.

Recruits

Recruits displayed significant positive correlation with total density, total basal area, un-established, established, establishment index, stocking index, establishment stocking per cent, regeneration success, total biomass, carbon stock, vegetation carbon density, soil organic carbon, and significant but negative correlation with crown spread. Non-significant positive correlation was obtained with md, mean height, shrub biomass, pH, available phosphorus and potassium and non-significant but negative correlation with crown width and herb biomass.

Un-established

Significantly positive correlation was obtained with total basal area, recruits, established, establishment index, stocking index, establishment stocking per cent, regeneration success, total biomass, carbon stock, vegetation carbon density, soil organic carbon and available nitrogen. Non-significantly positive correlation was found with mean diameter, mean height, total density, shrub biomass, herb biomass, pH, available phosphorus and potassium whereas, non-significantly negative correlation with crown width and crown spread.

Established

Significantly positive correlation was observed with recruits, un-established, establishment index, stocking index, establishment stocking per cent, regeneration success, available nitrogen and available potassium and significantly but negative correlation with crown spread. Non-significantly positive correlation was found with mean height, mean diameter, total density, total basal area, shrub biomass, total biomass, carbon stock, vegetation carbon density pH, soil organic carbon, available phosphorus and non-significant negative correlation with crown width and herb biomass.

Established Index

Significantly positive correlation was found with total density, total basal area, recruits, un-established, established, stocking index, and establishment stocking per cent, regeneration

success, total biomass, carbon stock, vegetation carbon density, soil organic carbon and significantly negative correlation with crown spread. Non-significantly positive correlation was obtained with mean diameter, mean height, shrub biomass, herb biomass, pH, available nitrogen, available phosphorus, available potassium and non-significantly negative correlation with crown width.

Stocking Index

Stocking index was found to bear significantly positive correlation with recruits, un-established, established, establishment index, establishment stocking per cent, regeneration success, available nitrogen and available potassium and significantly negative correlation with crown spread. Non-significantly positive correlation was seen with mean height, mean diameter, total density, total basal area, crown spread, shrub biomass, herb biomass, total biomass, carbon stock, vegetation carbon density pH, soil organic carbon and available phosphorus and non-significantly but negative correlation with crown width.

Established Stocking Per cent

Established stocking per cent was obtained significantly positive correlation with recruits, un-established, established, establishment index, stocking index, regeneration success, available nitrogen, and available potassium whereas, non-significantly positive correlation with mean diameter, mean height, total density, total basal area, shrub biomass, herb biomass, total biomass, carbon stock, vegetation carbon density, pH, soil organic carbon, and available phosphorus and non-significant negative correlation with crown width.

Regeneration Success

Regeneration success only displayed significantly positive correlation with total basal area, recruits, un-established, established, establishment index, stocking index, establishment stocking, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen and available potassium and significant but negative correlation with crown spread. Non-significantly but positive correlation was observed with mean height, mean diameter, total density, shrub biomass, herb biomass, pH and available phosphorus and non-significant negative correlation with crown width.

Table 53: Correlation matrix showing correlation between different parameters at different altitudinal ranges and aspects

	MD	MH	TD	TBA	CW	CS	Rc	Un	Es	EI	SI	ESP	RS	SB	HB	TB	CAS	VCD	pH	SOC	N	P	k
MH	-0.3	1																					
TD	.716**	-0.011	1																				
TBA	.758**	-0.25	.755**	1																			
CW	-0.27	-0.225	-.633*	-0.418	1																		
CS	-0.162	-0.324	-0.562	-0.429	.635*	1																	
Rc	0.38	0.442	.617*	.581*	-0.538	-.735**	1																
Un	0.278	0.443	0.491	.628*	-0.345	-0.554	.818**	1															
Es	0.169	0.245	0.357	0.566	-0.245	-.684*	.741**	.802**	1														
EI	0.254	0.52	.610*	.598*	-0.558	-.615*	.736**	.883**	.598*	1													
SI	0.193	0.299	0.377	0.561	-0.243	-.674*	.751**	.852**	.991**	.649*	1												
ESP	0.082	0.177	0.345	0.536	-0.032	-0.396	.590*	.790**	.869**	.600*	.871**	1											
RS	0.238	0.306	0.411	.604*	-0.263	-.669*	.764**	.880**	.983**	.686*	.997**	.867**	1										
SB	-0.035	0.528	0.201	0.048	-0.266	-0.098	0.441	0.381	0.392	0.362	0.394	0.476	0.383	1									
HB	0.055	0.448	-0.144	-0.147	0.347	0.309	-0.133	0.029	-0.016	0.018	0.022	0.06	0.046	0.393	1								
TB	.782**	-0.086	.873**	.901**	-0.454	-0.482	.668*	.687*	0.51	.650*	0.543	0.501	.588*	0.04	-0.155	1							
CAS	.782**	-0.086	.873**	.901**	-0.454	-0.482	.668*	.688*	0.51	.651*	0.543	0.501	.588*	0.04	-0.155	1.00**	1						
VCD	.784**	-0.083	.879**	.901**	-0.46	-0.494	.678*	.688*	0.518	.651*	0.549	0.503	.594*	0.048	-0.158	1.00**	1.000**	1					
pH	-0.022	0.479	0.328	0.076	-0.227	-0.145	0.516	0.428	0.366	0.416	0.374	0.536	0.36	.929**	0.219	0.142	0.142	0.151	1				
SOC	.780**	-0.2	.789**	.980**	-0.44	-0.39	.602*	.654*	0.554	.632*	0.561	0.56	.604*	0.15	-0.119	.925**	.925**	.925**	0.181	1			
N	.670*	0.052	.633*	.809**	-0.302	-0.283	.699*	.671*	.615*	0.575	.616*	.647*	.649*	0.465	0.135	.778**	.778**	.780**	0.452	.873**	1		
P	.881**	-0.325	.823**	.912**	-0.423	-0.357	0.507	0.476	0.311	0.48	0.328	0.274	0.376	-0.148	-0.252	.941**	.941**	.940**	-0.055	.915**	.697*	1	
K	.646*	-0.025	0.45	.696*	-0.153	-0.112	0.519	0.534	.595*	0.347	.592*	.591*	.617*	0.51	0.317	.615*	.615*	.617*	0.397	.754**	.922**	0.546	1

MH- mean ht, MD- mean dia, TD- total density, TBA- total basal area, CW- cr. width, CS- cr. spread, Rc- recruits, Un-E- un-established, Es- established, EI- established index, SI- stocking index, ESP- established stocking per cent, RS- regeneration success, SB- shrub biomass, HB- herb biomass, TB- total biomass, CAS- carbon stock, VCD- vegetation carbon density SOC- soil organic carbon, N- available nitrogen, P- available phosphorus, K- available potassium

Shrub Biomass

Significantly positive correlation was established with only pH. Non-significant but positive correlation with mean height, total density, total basal area, recruits, un-established, established, establishment index, stocking index, regeneration success, herb biomass, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen and available potassium whereas, non-significant negative correlation with mean diameter, crown width and crown spread available phosphorus.

Herb Biomass

Non-significantly positive correlation was obtained with mean height, mean diameter, crown width, un-established, establishment index, stocking index, establishment stocking per cent, regeneration success, carbon stock, shrub biomass, pH, available nitrogen, available potassium and non-significantly negative correlation total density, total basal area, recruits, established, total biomass, carbon stock, vegetation carbon density, soil organic carbon and available phosphorus.

Total Biomass

Significantly positive correlation of total biomass was observed with mean diameter, total density, total basal area, recruits, un-established, establishment index, regeneration success, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen, available phosphorus and available potassium. Non-significantly but positive correlation was found with shrub biomass, established, stocking index, establishment stocking per cent, and pH and non-significantly but negative correlation with mean height, crown width, crown spread.

Carbon Stock

Carbon stock was displayed significantly positive with mean diameter, total density, total basal area, recruits, un-established, establishment index, regeneration success, total biomass, vegetation carbon density, soil organic carbon, available nitrogen, available phosphorus and available potassium. Non-significantly but positive correlation of carbon stock was found with established, stocking index, establishment stocking per cent, and pH whereas, non-significant but negative correlation with mean height, crown width, crown spread, and herb biomass. Forest biomass and carbon stock were also observed to be

positively correlated with increasing altitude reported by Alves *et al.* 2010; Gariola *et al.* 2011; Sharma *et al.* 2016.

Vegetation carbon density

Significantly positive correlation of vegetation carbon density was obtained with mean diameter, total density, total basal area, recruits, un-established, establishment index, regeneration success, total biomass, carbon stock, soil organic carbon, available nitrogen, available phosphorus and available potassium. Non-significantly positive correlation was observed with established, stocking index, establishment stocking per cent, shrub biomass and pH and non-significant but negative correlation with mean height, crown width, crown spread, and herb biomass.

pH

Significantly positive correlation was established only with shrub biomass. pH showed the non-significantly but positive correlation with mean height, total density, total basal area, recruits, un-established, established, establishment index, stocking index, establishment stocking per cent, regeneration success, herb biomass, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen and available potassium. Non-significantly negative correlation of pH was seen with mean height, mean diameter, crown width, crown spread, and available phosphorus.

Soil Organic Carbon

Soil organic carbon was displayed significantly positive with mean diameter, total density, total basal area, recruits, un-established, establishment index, total biomass, carbon stock, vegetation carbon density, available nitrogen, available phosphorus and available potassium. Non-significantly positive correlation of soil organic carbon was found with established, stocking index, establishment stocking per cent and shrub biomass whereas, non-significant negative correlation with mean height, crown width, crown spread, and herb biomass. Gupta and Sharma (2008) showed that soil organic carbon and available phosphorus were positively correlated because all these attributes were intimately linked with soil humus. Gupta and Sharma (2008) also argued that the available potassium is not much influenced by soil organic matter because it is not the direct supplier of potassium, in our results, available potassium showed a significant positive correlation with organic carbon. Kaushal (1992) found significant positive correlation of organic carbon with increase in altitude.

Available Nitrogen

Significantly positive correlation was observed with mean diameter, total density, total basal area, recruits, un-established, established, stocking index, establishment stocking per cent, regeneration success, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available phosphorus and available potassium. Non-significantly but positive correlation was found with mean height, shrub biomass, herb biomass, pH whereas non-significantly negative correlation with crown width and crown spread. Available nitrogen showed the positive correlation with potassium reported by Basumatary and Bordoloi (1992).

Available Phosphorus

Significantly positive correlation of available phosphorus was obtained with mean diameter, total density, total basal area, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen. Non-significantly positive correlation was found with recruits, un-established, established, establishment index, stocking index, establishment stocking per cent, regeneration success and available potassium whereas non-significantly negative correlation only seen with mean height, crown width, crown spread, shrub biomass, herb biomass and pH.

Available Potassium

Significantly positive correlation was observed with mean diameter, total basal area, established, stocking index, establishment stocking per cent, regeneration success, total biomass, carbon stock, vegetation carbon density, soil organic carbon, available nitrogen. Non-significantly positive correlation of available phosphorus was found with total density, recruits, un-established, establishment index, pH and available phosphorus whereas, non-significantly negative correlation with mean height, crown width and crown spread.

Chapter-5

SUMMARY AND CONCLUSION

The present study entitled “**Variation in vegetation along altitude and aspects in western Himalaya**” is summarized below:

Presented study was conducted at three different altitudinal ranges along four aspects of Kandaghat Forest Range of Solan division. All of these sites are located in the Solan district of Himachal Pradesh. The Study area lies between longitudes $76^{\circ}56'$ and $77^{\circ}12'$ East and latitudes $30^{\circ}46'$ and $31^{\circ}10'$ North. The geographical area of division is 721.30 sq. km. The study was carried out to achieve the objectives:-

- i. To study the phytosociological behaviour of vegetation and regeneration status of tree species at different altitudinal ranges and aspects.
- ii. To study the biomass production and carbon stock of vegetation at different altitudinal ranges and aspects.
- iii. To study the soil properties at different altitudinal ranges and aspects.

To achieve the first objective, three sample plots for trees size of $31.62 \times 31.62 \text{ m}^2$, $5 \times 5 \text{ m}^2$ for shrubs and $1 \times 1 \text{ m}^2$ for herbaceous vegetation were laid out randomly in each forest site along altitudinal ranges and aspects, the results of which are summarized as below:

Floristic composition and phytosociology

The tree species ranged from 2 to 6, shrub species from 4 to 13 and herbaceous vegetation ranged from 4 to 9 species. In this present study, the maximum tree species (6) was recorded at lower altitudinal range on western aspect, followed by same altitudinal range on northern aspect, maximum shrub species (13) were found at lower altitudinal range ($<1800\text{m}$) on southern aspect and herb species (9) were recorded at higher altitudinal range ($>2100\text{m}$) on northern aspect. The mean density of tree at different altitudinal ranges and aspect ranged between 119.09 to 280.49 N ha^{-1} (Table 20). The highest mean tree density (280.49 N ha^{-1}) was reported at middle altitudinal range (1800-2100m) on northern aspect and lowest mean tree density (119.09 N ha^{-1}) found at higher altitudinal range ($>2100\text{m}$) on southern aspect. A decreasing pattern was observed on density with increasing altitudinal ranges and all aspects. The average density of shrubs ranged from 2,509 to $16,201 \text{ N ha}^{-1}$ at

different altitudinal ranges and aspects. The maximum average density of shrub ($16,201 \text{ N ha}^{-1}$) was examined at $<1800\text{m}$ altitudinal range on southern aspect and minimum average density ($2,509 \text{ N ha}^{-1}$) was examined at $>2100\text{m}$ altitudinal range on northern aspect. A decreasing pattern was observed on density with increasing altitudinal range on all aspects. In the case of herbaceous vegetation, mean density ranged from $48,515$ to $1,23,573 \text{ N ha}^{-1}$ at different altitudinal range and aspects. The highest mean density of herbs ($1,23,573 \text{ N ha}^{-1}$) was recorded at lower altitudinal range ($<1800\text{m}$) on southern aspect and lowest mean density ($48,515 \text{ N ha}^{-1}$) was recorded at higher altitudinal range ($>2100\text{m}$) on northern aspect. In herbaceous vegetation, no specific trend was obtained in density of herbs along the altitudinal ranges and all four aspects.

The mean basal area of trees ranged from 6.82 to $26.49 \text{ m}^2 \text{ ha}^{-1}$ (Table 20). The maximum average basal area ($26.49 \text{ m}^2 \text{ ha}^{-1}$) of tree was detected at middle altitudinal range ($1800\text{-}2100\text{m}$) on northern aspect and minimum average value of basal area ($6.82 \text{ m}^2 \text{ ha}^{-1}$) of tree was detected at higher altitudinal range ($>2100\text{m}$) on western aspect, followed by southern aspect. A decreasing pattern was observed along increasing altitudinal range on all aspects. The average basal area of shrubs ranged from 1.52 to $4.71 \text{ m}^2 \text{ ha}^{-1}$ (Table 21). The highest mean basal area of shrub ($4.71 \text{ m}^2 \text{ ha}^{-1}$) was obtained at $<1800\text{m}$ altitudinal range on southern aspect whereas lowest basal area ($1.52 \text{ m}^2 \text{ ha}^{-1}$) of shrub was obtained at higher altitudinal range ($>2100\text{m}$) on northern aspect. A decreasing pattern of basal area was observed with increasing altitudinal ranges on all aspects. The mean basal area of herbs ranged between 1.17 to $2.53 \text{ m}^2 \text{ ha}^{-1}$ (Table 22). The maximum average value of basal area ($2.53 \text{ m}^2 \text{ ha}^{-1}$) of herbs was found at $<1800\text{m}$ altitudinal range on southern aspect and minimum average value of basal area ($1.17 \text{ m}^2 \text{ ha}^{-1}$) of herbs was found at higher altitudinal range ($>2100\text{m}$) on northern aspect respectively.

The average value of mean diameter ranged from 17.42 to 37.09 cm (Table 27). The maximum value of mean diameter (37.09 cm) was recorded at $1800\text{-}2100\text{m}$ altitudinal range on eastern and the minimum mean value of diameter (17.42 cm) found at higher altitudinal range ($>2100\text{m}$) on southern aspect. The value of mean height ranged between 16.06 to 33.61 m (Table 28). The maximum average value of mean height (33.61 m) was examined at $1800\text{-}2100\text{m}$ altitudinal range on northern aspect and the minimum average value (16.06 m) examined at $>2100\text{m}$ altitudinal range on southern aspect. Thus the altitudinal ranges recorded the average mean height in the order: $E_2 > E_1 > E_3$. The mean volume of trees at

different altitudinal ranges and aspects ranged from 81.23 to 155.90 m³/ha (Table 29). The maximum average value volume was observed at middle altitudinal range (1800-2100m) on northern aspect and the minimum average value of volume was observed at higher altitudinal range on southern aspect.

Vegetation indices

The Shannon wiener index of trees (Table 26) ranged from 0.47 to 1.28 at different altitudinal ranges and aspect. The highest tree species diversity (1.28) was observed at lower altitudinal range (<1800m) on northern aspect and lowest (0.47) at >2100m on southern aspect. A decreasing pattern was observed with increasing altitudinal range on all aspects. The Shannon wiener index of shrubs ranged from 1.40 to 2.09. The maximum shrub species diversity (2.09) was found at lower altitudinal range (<1800m) on southern aspect and minimum (1.40) was found at higher altitudinal range (>2100m) on eastern aspect. A decreasing pattern was found along altitudinal ranges on all aspects. The Shannon wiener index of herbs ranged from 1.66 to 2.45. The highest herbaceous vegetation species diversity (2.45) was recorded on southern aspect at 1800-2100m and lowest (1.66) was recorded on eastern aspect at higher altitudinal range. A decreasing pattern was observed along the different altitudinal ranges and all aspects.

The simpson's diversity index of trees (Table 26) ranged between 0.21 to 0.51. Maximum simpson's diversity (0.51) was obtained at lower altitudinal range (<1800m) on northern aspect and lowest (0.21) was obtained at higher altitudinal range (>2100m) on western aspect. A decreasing pattern was found at different altitudinal ranges on northern, southern and western aspect while specific trend was found on eastern aspect. The Simpson's diversity of shrubs ranged from 0.57 to 0.98. Maximum shrub species diversity (0.98) was found at 1800-2100m on southern aspect and minimum (0.57) was found at >2100m altitudinal range on northern aspect. No specific trend observed along altitudinal ranges and aspects. The simpson's diversity of herbs ranged from 0.51 to 0.93. The highest herbaceous vegetation species diversity (0.93) was recorded on southern aspect at middle altitudinal range (1800-2100m) and lowest (0.51) was recorded on northern aspect at higher altitudinal range (>2100m).

The species richness of tree species ranged from 0.35-1.08 (Table 26) at different altitudinal ranges and aspects. The maximum species richness (1.08) was found at lower

altitudinal range (<1800m) on northern aspect and minimum richness (0.35) was found at higher altitudinal range on southern aspect. A decreasing pattern was observed with increasing altitudinal ranges on all aspects. The species richness of shrubs ranged from 1.11 to 2.28. Maximum richness (2.28) of shrubs species was recorded at middle altitudinal range (1800-2100m) on southern aspect and minimum (1.11) was recorded at higher altitudinal range (>2100m) on northern aspect. A decreasing pattern was observed along the altitudinal ranges on all aspects. The species richness of herbs ranged from 1.34 to 2.59. The highest richness (2.59) of herbs was examined at <1800m altitudinal range on southern aspect and lowest species richness (1.34) was examined at >2100m altitudinal range on northern aspect.

Canopy analysis

The mean crown width at different altitudinal ranges and aspects ranged from 3.92 to 6.82 m as shown in Table (30). The maximum mean crown width (6.82 m) was reported at middle altitudinal range (1800-2100m) on southern aspect and minimum crown width (3.92 m) was reported at <1800m altitudinal range on northern aspect. In the case of aspects, the following trend was followed: southern > western > eastern > northern.

The crown height ranged from 2.45 to 6.46 m (Table 31). The highest crown height (6.46 m) was observed at lower altitudinal range (<1800m) on western aspect and lowest crown height (2.45 m) was observed at lower altitudinal range on eastern aspect.

Solar radiation

Maximum mean solar radiation (555.30 Lux) was reported at higher altitudinal range, which was found to be significantly higher than other altitudinal ranges. Minimum mean solar radiation (515.14 Lux) was reported at lower altitudinal range (<1800m), which was found to be significantly lower than other altitudinal ranges. Thus the altitudinal ranges recorded the mean solar radiation in the order: $E_3 > E_2 > E_1$. And in the case of different aspects, the highest average solar radiation (605.58 Lux) was detected on southern aspect and lowest (469.92 Lux) was detected on northern aspect, which was found to be significantly lower than other aspects. In the interaction between different altitudinal ranges and aspects, the maximum solar radiation (633.14 Lux) was detected at >2100m altitudinal range on southern aspect and minimum (446.46 Lux) was found at lower altitudinal range on northern aspect.

Regeneration status

The objective of regeneration survey was to assess was adequate regeneration at different altitudinal ranges and all aspects. The adequacy of regeneration is judged on the basis of number of established plants in unit area.

The maximum number of recruits ($3888.89 \text{ N ha}^{-1}$) was depicted at middle altitudinal range (1800-2100m) on northern aspect whereas the minimum number of recruits ($1527.76 \text{ N ha}^{-1}$) was depicted at higher altitudinal range (>2100m) on eastern aspect. The highest un-established was observed maximum ($1513.88 \text{ N ha}^{-1}$) at 1800-2100m altitudinal range on southern aspect and minimum ($1027.76 \text{ N ha}^{-1}$) was observed at >2100m on eastern aspect followed by $1074.07 \text{ N ha}^{-1}$ at lower altitudinal range on same aspect. The highest established regeneration ($1388.90 \text{ N ha}^{-1}$) was recorded at middle altitudinal range (1800-2100m) on southern aspect and the lowest established regeneration (902.98 N ha^{-1}) at higher altitudinal range (>2100m) on eastern aspect. The maximum regeneration success (70.68%) was noticed at middle altitudinal range (1800-2100m) on southern aspect and minimum regeneration success (49.14%) at higher altitudinal range (>2100m) on eastern aspect followed by the same altitudinal range on western aspect (51.70%).

Biomass and carbon stock

Biomass and carbon stock were determined under different altitudinal ranges showed in Table (49 and 50). At different altitudinal ranges the maximum mean aboveground biomass (82.73 t ha^{-1}) was observed at middle altitudinal range (1800-2100m) whereas, minimum mean aboveground biomass (46.33 t ha^{-1}) was observed at higher altitudinal range (>2100m) which was found to be significantly higher than other altitudinal ranges. In the case of aspects, following trend was followed: northern > eastern > western > southern. In the interaction between different altitudinal ranges and aspects, the highest average aboveground biomass (112.20 t ha^{-1}) was detected at middle altitudinal range (1800-2100m) on northern aspect and lowest average aboveground biomass (22.55 t ha^{-1}) was detected at higher altitudinal range (>2100m) on southern aspect respectively.

The highest mean belowground biomass (37.85 t ha^{-1}) was found at middle altitudinal range which was found to be significantly higher than lower and higher altitudinal ranges. The lowest mean belowground biomass (27.04 t ha^{-1}) was found at higher altitudinal range (>2100m). Thus the altitudinal ranges recorded the mean belowground biomass in the order:

$E_2 > E_1 > E_3$. In the case of aspects, the mean belowground biomass (40.73 t ha^{-1}) was noticed on northern aspect followed by eastern aspect whereas, minimum belowground biomass (26.62 t ha^{-1}) was noticed on southern aspect followed by western aspect. The highest belowground biomass (49.21 t ha^{-1}) was recorded at middle altitudinal range (1800-2100m) on northern aspect whereas, lowest belowground biomass (17.53 t ha^{-1}) was recorded at higher altitudinal range ($>2100\text{m}$) on southern aspect.

At different altitudinal ranges, the highest average total biomass (120.64 t ha^{-1}) was found at middle altitudinal range and the lowest average total biomass (73.38 t ha^{-1}) was determined at higher altitudinal range. Thus the altitudinal ranges recorded the average total biomass in the order: $E_2 > E_1 > E_3$. On the different aspects, the maximum total biomass (128.92 t ha^{-1}) was reported on northern aspect followed by eastern aspect and minimum total biomass (72.05 t ha^{-1}) was reported on southern aspect followed by western aspect. In the case of interaction, the maximum average total biomass (161.42 t ha^{-1}) was obtained at middle (1800-2100m) altitudinal range on northern aspect whereas, minimum average total biomass (40.08 t ha^{-1}) was obtained at higher altitudinal range ($>2100\text{m}$) on southern aspect.

The maximum average shrub biomass (2.56 t ha^{-1}) was recorded at lower altitudinal range ($<1800\text{m}$) and lowest (1.53 t ha^{-1}) was recorded at higher altitudinal range ($>2100\text{m}$). In case of aspects, the highest mean shrub biomass (2.34 t ha^{-1}) was found on southern aspect and minimum mean (1.80 t ha^{-1}) found on northern aspect. The following trend was followed: southern $>$ western $>$ eastern $>$ northern. The highest mean shrub biomass (2.20 t ha^{-1}) observed was at lower altitudinal range ($<1800\text{m}$) on southern aspect whereas, the lowest mean shrub biomass (1.29 t ha^{-1}) was found at higher ($>2100\text{m}$) altitudinal range on northern aspect.

At different altitudinal ranges, the maximum average herb biomass (3.21 t ha^{-1}) was examined at middle altitudinal range which was found to be significantly higher than other altitudinal ranges and the minimum average herb biomass (2.90 t ha^{-1}) was examined at higher altitudinal range. Among different aspects, the maximum mean herb biomass (3.64 t ha^{-1}) was recorded on southern aspect and minimum (2.58 t ha^{-1}) recorded on northern aspect. The following trend was followed was southern $>$ western $>$ eastern $>$ northern. The maximum mean herb biomass (3.99 t ha^{-1}) was noticed at lower ($<1800\text{m}$) altitudinal range on southern aspect and the minimum mean herb biomass (2.34 t ha^{-1}) was noticed at higher altitudinal range on northern aspect.

The highest average carbon stock ($64.32 \text{ t C ha}^{-1}$) was obtained at middle altitudinal range (1800-2100m) which was found to be significantly higher than other altitudinal ranges and the lowest average carbon stock ($36.69 \text{ t C ha}^{-1}$) was obtained at higher altitudinal range (>2100m) which was significantly lower than other altitudinal ranges. Thus the altitudinal ranges recorded the mean carbon stock in the order: $E_2 > E_1 > E_3$. In case of aspects, the maximum mean carbon stock ($64.46 \text{ t C ha}^{-1}$) was obtained on northern aspect and minimum mean carbon stock ($36.02 \text{ t C ha}^{-1}$) was obtained on southern aspect. The following trend was followed: northern > eastern > western > southern. In the case of interaction, the highest mean carbon stock ($88.71 \text{ t C ha}^{-1}$) was detected at middle altitudinal range on northern aspect and lowest mean carbon stock ($20.04 \text{ t C ha}^{-1}$) was detected at higher (>2100m) altitudinal range on southern aspect.

The maximum mean value of vegetation biomass (125.82 t ha^{-1}) and vegetation carbon density ($62.91 \text{ t C ha}^{-1}$) was observed at middle altitudinal range (1800-2100m), which was found to be significantly higher than other altitudinal ranges whereas, the lowest mean value of vegetation biomass (76.43 t ha^{-1}) and vegetation carbon density ($38.21 \text{ t C ha}^{-1}$) found at higher (>2100m) altitudinal range. Thus the altitudinal ranges recorded the mean vegetation biomass and vegetation carbon density in the order: $E_2 > E_1 > E_3$. In case of aspects, the maximum mean value of vegetation biomass (134.43 t ha^{-1}) and vegetation carbon density ($67.21 \text{ t C ha}^{-1}$) was obtained on northern aspect and minimum mean vegetation biomass (76.43 t ha^{-1}) and vegetation carbon density ($38.21 \text{ t C ha}^{-1}$) on southern aspect. The following trend was followed: northern > eastern > western > southern.

Soil physico-chemical properties

The highest mean value of pH (6.05) was depicted at lower altitudinal range (<1800m) which was significantly at par with other altitudinal ranges and the lowest mean value of pH (5.69) was depicted at higher altitudinal range (>2100m). In the case of aspects, the maximum average value of pH (5.93) was noticed on southern aspect followed by northern aspect and the minimum average value of pH (5.71) was noticed on eastern aspect.

At different altitudinal ranges, the maximum average value of bulk density (0.81 g cm^{-3}) was found at higher (>2100m) altitudinal range which was significantly higher than other altitudinal range whereas, minimum average value of bulk density (0.69 g cm^{-3}) was found at lower (<1800m) altitudinal range. In the case of aspect, the highest mean bulk density (0.86 g cm^{-3}) was found on northern aspect and the lowest mean bulk density (0.69 g cm^{-3}) was found on southern aspect. The following trend was followed: northern > eastern > western > southern.

cm⁻³) was recorded on southern aspect and minimum (0.68 g cm⁻³) recorded on northern aspect. An increasing pattern was found with increasing altitudinal range on all four aspects.

The maximum mean organic carbon (24.71 g kg⁻¹) was reported at middle altitudinal range (1800-2100m) and the minimum mean organic carbon (16.55 g kg⁻¹) was reported at higher altitudinal range (>2100m). In the case of aspects, the highest average organic carbon (23.30 g kg⁻¹) was recorded on northern aspect followed by eastern aspect and the lowest organic carbon (17.94 g kg⁻¹) observed on southern aspect. The following trend was followed: northern > eastern > western > southern.

The maximum available nitrogen and phosphorus were obtained at middle altitudinal range (1800-2100m), which were significantly at par with other altitudinal ranges and minimum available nitrogen and phosphorus were obtained at higher altitudinal range (>2100m), which was found to be significantly lower than other altitudinal ranges. Thus the altitudinal range recorded the mean available nitrogen and phosphorus in the order: E₂ > E₁ > E₃. In case of aspects, the highest available nitrogen (513.77 kg ha⁻¹) and phosphorus (24.85 kg ha⁻¹) were observed on northern aspect followed by eastern aspect and the lowest available N and P were observed on southern aspect. The following trend was followed: northern > eastern > western > southern.

The maximum available potassium (331.10 kg ha⁻¹) was found at middle altitudinal range (1800-2100m) which was significantly at par with other altitudinal ranges and minimum (246.68 kg ha⁻¹) was recorded at higher altitudinal range (>2100m). In case of aspects, the highest available potassium (310.16 kg ha⁻¹) was found on eastern aspect whereas minimum (284.88 kg ha⁻¹) observed on northern aspect followed by southern aspect.

Correlation studies

In the correlation studies of various parameters at different altitudinal ranges along aspects, it was explained that the tree biomass had a highly significant positive correlation with the total density, total basal area, carbon stock, vegetation carbon density, soil organic carbon and available phosphorus. Crown spread showed a significant negative correlation with recruits, established, establishment index, stocking index, and regeneration success.

Conclusion

- ✓ In the present study, a total of 48 plant species were recorded of which 13 were tree species, 22 shrub species and 13 herb species belonging to 33 families. Maximum tree floristic diversity was found at lower (<1800m) altitudinal range on western aspect, shrub diversity also at same altitudinal range on southern aspect and herb diversity was found at higher (>2100m) altitudinal range on northern aspect.
- ✓ The maximum tree density (254.22 N ha⁻¹) was observed on northern aspect, followed by eastern aspect (227.03 N ha⁻¹), maximum shrub diversity (10,224 N ha⁻¹) was observed on southern aspect, followed by western aspect (8,634 N ha⁻¹) as compared to other aspects and herbaceous density was found maximum on southern aspect (89,055 N ha⁻¹). In case of elevation, it was showed decreasing trend with increasing altitudinal ranges on all aspects.
- ✓ The highest basal area (19.43 m² ha⁻¹) of tree species were noticed on northern aspect, the maximum basal area of shrubs (3.84 m² ha⁻¹) and herbs (2.20 m² ha⁻¹) was noticed on southern aspect, followed by western aspect. Basal area of plant categories showed the decreasing pattern with increasing altitudinal ranges on all aspects.
- ✓ Species diversity of trees ranged from 0.47 to 1.28, whereas, shrubs species diversity ranged from 1.40 to 2.09 while, herbs species diversity ranged from 1.66 to 2.45. Species dominance of trees ranged from 0.21 to 0.51, whereas, shrubs species dominance ranged from 0.57 to 0.98, while herbaceous vegetation ranged from 0.51 to 0.93. Species richness of trees ranged from 0.35 to 1.08, whereas, shrub species richness ranged from 1.11 to 2.28, while, herbaceous vegetation richness ranged from 1.34 to 2.59. In plant categories, the highest vegetation indices were noticed of herbaceous layer followed by shrubs layer.
- ✓ Maximum recruits were found at 1800-2100m altitudinal range on northern aspect and minimum found at >2100m altitudinal range on eastern aspect. Highest regeneration success (70.68%) was reported at middle altitudinal range on southern aspect.
- ✓ Highest solar radiation (633.14 Lux) was recorded at higher altitudinal range (>2100m) on southern aspect and lowest solar radiation (446.46 Lux) was recorded at lower altitudinal range (<1800m) on northern aspect. In case of solar radiation an increasing pattern was observed with increasing altitudinal ranges on all aspects.

- ✓ Maximum total biomass and carbon stock were depicted at middle altitudinal range on northern aspect and minimum total biomass and carbon stock were depicted at >2100m altitudinal range on southern aspect. Total biomass and carbon stock were showed the decreasing pattern with increasing altitudinal range on all four aspects. Maximum shrub biomass was obtained at lower altitudinal range on southern aspect and minimum was obtained at higher altitudinal range on northern aspect. Highest herb biomass was examined at 1800-2100m altitudinal range on southern aspect and lowest was examined at >2100m altitudinal range on northern aspect.
- ✓ The study showed the highest biomass on northern aspect as compared to other aspects. This difference might be due to the difference in litter fall amount and its decomposition rate. In addition, the absence of high decomposition rate of litter on southern aspect may contribute for the presence of less biomass and carbon stock on southern aspect.
- ✓ The highest vegetation carbon density ($83.47 \text{ t C ha}^{-1}$) was recorded at middle altitudinal range (1800-2100m) on northern aspect and the lowest vegetation carbon density ($21.85 \text{ t C ha}^{-1}$) at higher altitudinal range on southern aspect.
- ✓ In case of soil properties, the maximum available nitrogen and phosphorus were observed at middle altitudinal range on northern aspect whereas minimum available nitrogen and phosphorus obtained at higher altitudinal range on southern aspect. The highest available potassium was recorded at middle altitudinal range on eastern aspect and minimum at higher altitudinal range on northern aspect.

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APPENDIX-1

Analysis of variance table for density of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1,537.450			
Factor A	2	33,462.347	16,731.173	843.740	0.00000
Factor B	3	57,311.375	19,103.792	963.390	0.00000
Interaction A X B	6	9,028.100	1,504.683	75.880	0.00000
Error	22	436.255	19.830		
Total	35	101,775.526			

APPENDIX-2

Analysis of variance table for basal area of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	33.276			
Factor A	2	863.649	431.824	1,043.738	0.00000
Factor B	3	568.684	189.561	458.178	0.00000
Interaction A X B	6	126.367	21.061	50.906	0.00000
Error	22	9.102	0.414		
Total	35	1,601.077			

APPENDIX-3

Analysis of variance table for density of shrubs

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	178,248.360			
Factor A	2	261,974,060.571	130,987,030.286	35,031.108	0.00000
Factor B	3	218,784,034.843	72,928,011.614	19,503.832	0.00000
Interaction A X B	6	150,426,249.749	25,071,041.625	6,704.987	0.00000
Error	22	82,261.590	3,739.163		
Total	35	631,444,855.113			

APPENDIX-4

Analysis of variance table for basal area of shrubs

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.012			
Factor A	2	45.325	22.663	1,001,560.570	0.00000
Factor B	3	4.022	1.341	59,255.967	0.00000
Interaction A X B	6	0.542	0.090	3,990.994	0.00000
Error	22	0.000	0.000		
Total	35	49.902			

APPENDIX-5

Analysis of variance table for density of herbs

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	7,309,248.699			
Factor A	2	6,213,856,901.164	3,106,928,450.582	10,897.652	0.00000
Factor B	3	3,104,180,482.207	1,034,726,827.402	3,629.338	0.00000
Interaction A X B	6	3,705,555,379.265	617,592,563.211	2,166.226	0.00000
Error	22	6,272,215.853	285,100.721		
Total	35	13,037,174,227.189			

APPENDIX-6

Analysis of variance table for basal area of herbs

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.010			
Factor A	2	5.793	2.896	206,322.797	0.00000
Factor B	3	0.699	0.233	16,590.740	0.00000
Interaction A X B	6	0.283	0.047	3,355.575	0.00000
Error	22	0.000	0.000		
Total	35	6.784			

APPENDIX-7

Analysis of variance table for volume of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	176.499			
Factor A	2	19,789.619	9,894.810	9,339.867	0.00000
Factor B	3	2,690.161	896.720	846.428	0.00000
Interaction A X B	6	280.262	46.710	44.091	0.00000
Error	22	23.307	1.059		
Total	35	22,959.849			

APPENDIX-8

Analysis of variance table or mean diameter of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	141.549			
Factor A	2	362.202	181.101	82.591	0.00000
Factor B	3	757.217	252.406	115.110	0.00000
Interaction A X B	6	66.935	11.156	5.088	0.00207
Error	22	48.240	2.193		
Total	35	1,376.143			

APPENDIX-9

Analysis of variance table for mean height of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	146.005			
Factor A	2	283.082	141.541	66.207	0.00000
Factor B	3	452.601	150.867	70.569	0.00000
Interaction A X B	6	17.487	2.915	1.363	0.27272
Error	22	47.033	2.138		
Total	35	946.208			

APPENDIX-10

Analysis of variance table for crown width of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.004			
Factor A	2	4.198	2.099	169.427	0.00000
Factor B	3	4.234	1.411	113.920	0.00000
Interaction A X B	6	13.964	2.327	187.844	0.00000
Error	22	0.273	0.012		
Total	35	22.674			

APPENDIX-11

Analysis of variance table for crown height of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.072			
Factor A	2	2.871	1.436	669.826	0.00000
Factor B	3	7.600	2.533	1,181.903	0.00000
Interaction A X B	6	35.323	5.887	2,746.636	0.00000
Error	22	0.047	0.002		
Total	35	45.914			

APPENDIX-12

Analysis of variance table for crown length of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	41.921			
Factor A	2	29.830	14.915	5.142	0.01472
Factor B	3	7.895	2.632	0.907	0.45351
Interaction A X B	6	8.966	1.494	0.515	0.79048
Error	22	63.817	2.901		
Total	35	152.429			

APPENDIX-13

Analysis of variance table for crown basal area of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	633.493			
Factor A	2	7,634,890.662	3,817,445.331	427,022.352	0.00000
Factor B	3	4,910,271.583	1,636,757.194	183,088.910	0.00000
Interaction A X B	6	13,674,686.242	2,279,114.374	254,943.475	0.00000
Error	22	196.673	8.940		
Total	35	26,220,678.653			

APPENDIX-14

Analysis of variance table for crown surface area of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	803.052			
Factor A	2	75.984	37.992	2.345	0.11937
Factor B	3	13,605.289	4,535.096	279.895	0.00000
Interaction A X B	6	31,578.834	5,263.139	324.828	0.00000
Error	22	356.463	16.203		
Total	35	46,419.622			

APPENDIX-15

Analysis of variance table for crown volume of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	531.133			
Factor A	2	19,109.801	9,554.901	1,041.748	0.00000
Factor B	3	16,936.818	5,645.606	615.527	0.00000
Interaction A X B	6	39,638.596	6,606.433	720.283	0.00000
Error	22	201.784	9.172		
Total	35	76,418.133			

APPENDIX-16

Analysis of variance table for crown per cent of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	317.354			
Factor A	2	1,304.235	652.118	431.952	0.00000
Factor B	3	292.672	97.557	64.620	0.00000
Interaction A X B	6	2,500.965	416.827	276.100	0.00000
Error	22	33.213	1.510		
Total	35	4,448.440			

APPENDIX-17

Analysis of variance table for crown spread of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.025			
Factor A	2	0.011	0.006	61.810	0.00000
Factor B	3	0.018	0.006	63.617	0.00000
Interaction A X B	6	0.153	0.025	275.591	0.00000
Error	22	0.002	0.000		
Total	35	0.208			

APPENDIX-18

Analysis of variance table for crown fullness ratio of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.082			
Factor A	2	0.311	0.155	161.930	0.00000
Factor B	3	0.325	0.108	112.719	0.00000
Interaction A X B	6	1.700	0.283	294.998	0.00000
Error	22	0.021	0.001		
Total	35	2.438			

APPENDIX-19

Analysis of variance table for crown projection ratio of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	199.453			
Factor A	2	471.479	235.739	523.287	0.00000
Factor B	3	111.085	37.028	82.195	0.00000
Interaction A X B	6	412.523	68.754	152.618	0.00000
Error	22	9.911	0.450		
Total	35	1,204.451			

APPENDIX-20

Analysis of variance table for crown quotient ratio of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	117,339.096			
Factor A	2	765,665.264	382,832.632	117.625	0.00000
Factor B	3	483,769.121	161,256.374	49.546	0.00000
Interaction A X B	6	711,136.864	118,522.811	36.416	0.00000
Error	22	71,603.218	3,254.692		
Total	35	2,149,513.563			

APPENDIX-21

Analysis of variance table for crown index of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.028			
Factor A	2	0.557	0.278	1,064.987	0.00000
Factor B	3	0.227	0.076	289.237	0.00000
Interaction A X B	6	1.684	0.281	1,073.732	0.00000
Error	22	0.006	0.000		
Total	35	2.502			

APPENDIX-22

Analysis of variance table for solar radiation

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1,638.258			
Factor A	2	9,710.289	4,855.145	916.719	0.00000
Factor B	3	106,436.639	35,478.880	6,698.904	0.00000
Interaction A X B	6	634.798	105.800	19.976	0.00000
Error	22	116.517	5.296		
Total	35	118,536.502			

APPENDIX-23

Analysis of variance table for aboveground biomass of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	2,696.38			
Factor A	2	8,203.65	4,101.82	36.27	0.00000
Factor B	3	8,586.43	2,862.14	25.31	0.00000
Interaction A X B	6	2,225.31	370.88	3.28	0.01852
Error	22	2,487.39	113.06		
Total	35	24,199.18			

APPENDIX-24

Analysis of variance table for belowground biomass of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1,271.22			
Factor A	2	747.34	373.67	17.29	0.00003
Factor B	3	949.90	316.63	14.65	0.00002
Interaction A X B	6	239.63	39.93	1.84	0.13569
Error	22	475.29	21.60		
Total	35	3,683.39			

APPENDIX-25

Analysis of variance table for total biomass of tress

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	7,460.14			
Factor A	2	13,884.90	6,942.45	53.03	0.00000
Factor B	3	15,239.16	5,079.72	38.80	0.00000
Interaction A X B	6	3,623.02	603.83	4.61	0.00355
Error	22	2,879.92	130.90		
Total	35	43,087.15			

APPENDIX-26

Analysis of variance table for carbon stock of trees

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1,865.035			
Factor A	2	3,471.225	1,735.613	53.034	0.00000
Factor B	3	3,809.790	1,269.930	38.804	0.00000
Interaction A X B	6	905.755	150.959	4.613	0.00355
Error	22	719.982	32.726		
Total	35	10,771.788			

APPENDIX-27

Analysis of variance table for biomass of shrubs

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.240			
Factor A	2	6.405	3.202	261.458	0.00000
Factor B	3	1.433	0.478	38.997	0.00000
Interaction A X B	6	0.129	0.021	1.755	0.15529
Error	22	0.269	0.012		
Total	35	8.476			

APPENDIX-28

Analysis of variance table for biomass of herbs

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.142			
Factor A	2	0.709	0.355	127.273	0.00000
Factor B	3	8.077	2.692	966.486	0.00000
Interaction A X B	6	2.441	0.407	146.046	0.00000
Error	22	0.061	0.003		
Total	35	11.430			

APPENDIX-29

Analysis of variance table for vegetation biomass

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	7,607.190			
Factor A	2	14,435.647	7,217.824	54.831	0.00000
Factor B	3	15,966.958	5,322.319	40.432	0.00000
Interaction A X B	6	3,609.534	601.589	4.570	0.00373
Error	22	2,896.012	131.637		
Total	35	44,515.341			

APPENDIX-30

Analysis of variance table for vegetation carbon density

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1,901.797			
Factor A	2	3,608.912	1,804.456	54.831	0.00000
Factor B	3	3,991.740	1,330.580	40.432	0.00000
Interaction A X B	6	902.383	150.397	4.570	0.00373
Error	22	724.003	32.909		
Total	35	11,128.835			

APPENDIX-31

Analysis of variance table for soil pH

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.092			
Factor A	2	0.830	0.415	373.891	0.00000
Factor B	3	0.099	0.033	29.658	0.00000
Interaction A X B	6	0.027	0.004	4.026	0.00716
Error	22	0.024	0.001		
Total	35	1.073			

APPENDIX-32

Analysis of variance table for soil organic carbon

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	2.877			
Factor A	2	354.050	177.025	3,011.685	0.00000
Factor B	3	192.316	64.105	1,090.608	0.00000
Interaction A X B	6	48.220	8.037	136.725	0.00000
Error	22	1.293	0.059		
Total	35	598.755			

APPENDIX-33

Analysis of variance table for bulk density of soil

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.037			
Factor A	2	0.101	0.050	185.018	0.00000
Factor B	3	0.176	0.059	215.454	0.00000
Interaction A X B	6	0.053	0.009	32.747	0.00000
Error	22	0.006	0.000		
Total	35	0.373			

APPENDIX-34

Analysis of variance table for nitrogen of soil

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	52,912.342			
Factor A	2	298,939.422	149,469.711	416.832	0.00000
Factor B	3	12,867.590	4,289.197	11.961	0.00007
Interaction A X B	6	700.961	116.827	0.326	0.91626
Error	22	7,888.868	358.585		
Total	35	373,309.182			

APPENDIX-35

Analysis of variance table for phosphorus of soil

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	8.621			
Factor A	2	296.338	148.169	3,546.403	0.00000
Factor B	3	605.639	201.880	4,831.964	0.00000
Interaction A X B	6	5.611	0.935	22.385	0.00000
Error	22	0.919	0.042		
Total	35	917.128			

APPENDIX-36

Analysis of variance table for potassium of soil

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	12,386.151			
Factor A	2	42,117.956	21,058.978	415.698	0.00000
Factor B	3	2,429.647	809.882	15.987	0.00001
Interaction A X B	6	2,204.117	367.353	7.251	0.00023
Error	22	1,114.505	50.659		
Total	35	60,252.375			

**DR Y S PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY
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Title of the Thesis	:	“Variation in Vegetation along altitude and aspects in western Himalaya”
Name of the Student	:	Sonam Rajput
Admission Number	:	F-16-21-D
Major Adviser	:	Dr. C. L. Thakur, Principal Scientist
Major Field	:	Forestry
Minor Field(S)	:	Silviculture
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ABSTRACT

The present study was conducted in Kandaghat forest of Solan Forest Division (H.P.) along an altitudinal gradient (<1800 to >2100m) in western Himalaya. The study area was divided in to three altitudinal ranges viz., lower altitude (<1800m), middle altitude (1800-2100m) and higher altitude (>2100m) and four aspects. The aim of the study was to describe and examine the effect of variation in the structure and composition of the vegetation along altitudinal ranges and aspects. A total plant species were recorded of which 13 tree species, 22 shrub species and 13 herb species belonging to 33 families. The highest tree density (280.49 N ha⁻¹) was observed at middle altitudinal range on northern aspect and the lowest (119.09 N ha⁻¹) at higher altitudinal range (>2100m) on southern aspect. Shrub and herb density did not show any particular trend. The maximum shrub (16,202 N ha⁻¹) and herb density (1,23,574 N ha⁻¹) were found at lower altitudinal range (<1800m) on southern aspect. The highest vegetation indices was noticed in herbaceous layer followed by shrub layer due to relatively less development of canopy which permit sufficient sunlight to reach the ground for luxuriant growth. The maximum crown width (6.82 m) and crown spread (0.51) were obtained at middle altitudinal range (1800-2100m) on southern aspect and the minimum on northern aspect. Solar radiation increases with increasing altitudinal ranges on all aspects. The highest regeneration success (70.68%) was obtained at middle altitudinal range on southern aspect whereas, the lowest regeneration success (49.14%) at higher altitudinal range on eastern aspect. The tree biomass (161.42 t ha⁻¹), carbon stock (80.71 t C ha⁻¹) and vegetation carbon density (83.47 t C ha⁻¹) were recorded highest on northern aspect at middle altitudinal range while shrub biomass (2.56 t ha⁻¹) at lower altitudinal range and herb biomass (3.21 t ha⁻¹) at middle altitudinal range. The soil nutrients viz., pH, bulk density, soil organic carbon, available nitrogen, phosphorus and potassium were found in the range of 5.60 to 6.11, 0.64 to 1.02 g cm⁻³, 15.46 to 29.46 g kg⁻¹, 335.00 to 608.00 kg ha⁻¹, 10.70 to 28.83 kg ha⁻¹ and 225.13 to 347.29 kg ha⁻¹. The highest soil nutrients (soil organic carbon, nitrogen and phosphorus) were recorded at middle altitudinal range on northern aspect.

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Dr. C. L. Thakur (Principal Scientist)

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