

**FLORAL DIVERSITY AND CARBON STOCK ASSESSMENT  
OF HIMALAYAN DRY TEMPERATE AND ALPINE FOREST  
OF HIMACHAL PRADESH**

*Thesis*

by

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(F-2013-29-D)**

submitted to



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This is to certify that the thesis entitled, “**Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh**” submitted in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY (FORESTRY) SILVICULTURE** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) – 173 230 is a record of bonafide research work carried out by **Mr. Rakesh Kumar (F-2013-29-D)** son of Shri Vidya Lal under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

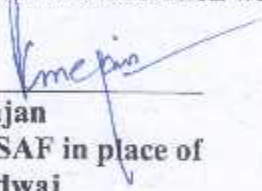
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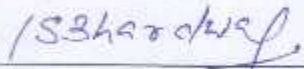
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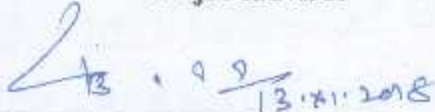
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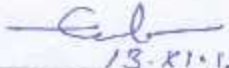
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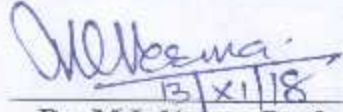
  
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**Place: Nauni, Solan**

**Date:**

**(Rakesh Kumar Negi)**

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## ABBREVIATIONS

AGB	Above Ground Biomass
a.m.s.l.	Above mean sea level
Approx.	Approximately
BA	Basal Area
BD	Bulk Density
BEF	Biomass Expansion Factor
BGB	Below Ground Biomass
C	Carbon
C ha <sup>-1</sup>	Carbon per hectare
CDM	Clean Development Mechanism
cm	Centimeter
CO <sub>2</sub>	Carbon dioxide
°C	Degree Celsius
DBH	Diameter at breast height
<i>et al.</i>	Co- workers
<i>etc</i>	et cetera
FCCC	Framework Convention on Climate Change
Fe	Iron
FSI	Forest Survey of India
g	gram
GHG	Green House Gas
GHGs	Green House Gases
ha	Hectare (10,000 m <sup>2</sup> )
ECD	Ecosystem carbon density
HB	Herb biomass
IPCC	Intergovernmental Panel on Climate Change
i. e.	That is
m	Meter
MAT	Mean Annual Temperature
M ha	Million hectare
Mg ha <sup>-1</sup>	Mega gram per hectare
Mg C ha <sup>-1</sup>	Mega gram carbon per hectare

Mg C ha <sup>-1</sup> yr <sup>-1</sup>	Mega gram Carbon per hectare year
mm	Milimeter
Mn	Manganese
MT	Metric tone
OC	Organic carbon
pH	pouviour of Hydrogen
SOC	Soil Organic Carbon
SCD	Soil Carbon Density
SB	Shrub biomass
SBA	Shrub basal area
SOM	Soil Organic Matter
SR	Species Richness
T	Tonne
TB	Tree biomass
TBA	Tree basal area
TBCA	Total Belowground Carbon allocation
TD	Tree density
t C ha <sup>-1</sup>	Tonne Carbon per hectare
t C ha <sup>-1</sup> yr <sup>-1</sup>	Tonne Carbon per hectare per year
VCD	Vegetation carbon density

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## *Chapter-1*

# INTRODUCTION

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The Himalayas are one of the youngest and richest ecosystems on earth with a variety of species and forest types due to the varying altitude, topographic, and climatic conditions (Mani 1978). This diverse climate and the varied environmental conditions prevailing in Himalayas support diverse habitat and ecosystems with equally diverse life forms. It is recognized as one of the hotspots of biodiversity and harbors nearly 8,000 species of flowering plants, of which 25.3 per cent are endemic (Singh and Hajra 1996). In the past three decades, there has been 23 per cent loss of forest cover in western Himalayas (Anonymous 2005) which are complex and dynamic ecosystems providing different ecosystem services (Khan *et al.* 2012).

Species composition, community structure, and function are the most important ecological attributes of forest ecosystems, which show variations in response to environmental, as well as anthropogenic variables (Gairola *et al.* 2008; Shaheen *et al.* 2012; Bisht and Bhat 2013). A complex of factors *viz.*, vegetation type, slope, aspect, edaphic factors, and altitude (Sharma *et al.* 2009, 2010a; Gairola *et al.* 2011a) determines the community composition, structure, and distribution pattern of diversity in mountain vegetation (Kessler 2001; Schmidt *et al.* 2006). One important factor in mountain ecosystems is elevation (Mcvicar and Korner 2012), which has a strong influence on the structure of the vegetation in most mountains in the world (Zhang *et al.* 2006). Changes in species diversity along elevational gradient have been the subject of numerous studies (Lomolino 2001; Fetene *et al.* 2006), most of them found a hump shaped distribution, showing peak species diversity near the middle of the gradient (Austrheim 2002; Zhang and Ru 2010). The plant community structure and distribution pattern of Himalayan forests are poorly understood (Peer *et al.* 2007). Western Himalaya not only supports huge floristic diversity (Sharma *et al.* 2010b), but also stores large carbon stocks (Sharma *et al.* 2010b; Dar and Sundarapandian 2015a, 2015b).

The Himalayan region is blessed with a wide variety of natural resources including medicinal plants. The total geographical area of the Himalaya in India is 61.5 m ha, out of which 17.8 m ha area is covered by alpine pastures and occupy about 1.52 per cent of the total land area in the country with wide range of variations in terms of its size, climate and

altitudinal ranges which, have created environments that are unique and characteristic to this region only (Negi 2009). These pastures are supposed to be the only true grasslands in India, where the grazing intensity is very high. Alpine pastures in Himachal Pradesh cover around 10,052 sq km *i.e.* 17 per cent of the total geographical area of the state. The present level of grass production in the Himalayan grasslands is even less than 25 per cent of their possible potential. Very little scientific attention has been given to the vegetation of the alpine and dry temperate region of Himachal Pradesh (Verma and Kapoor 2014). Due to lack of proper management practices, a large number of pastures lands have been converted or are in the process of conversion to degraded lands.

North western Himalayan states *viz.*, Himachal Pradesh, Jammu and Kashmir and Uttarkhand occupies about 31 per cent of the total coniferous area, accounting about 49 per cent of the total growing stock in these states. Spruce and silver fir species are usually found associated with deodar, blue pine, chir pine and also with broadleaved species, like oaks, walnut, burash *etc.* Natural regeneration of these species is, however, generally deficient and in many areas conspicuous by their absence. Besides a number of factors considered responsible for the absence of natural regeneration of these species; lack of adequate light on the forest floor in the forest managed under selection system, thick layer of humus accumulation of debris, dense weed growth and continuous grazing (Dhillon 1961: Sufi 1970), poor seed production, infrequent seed years and other biotic factors (Chander *et al.* 2015) are the major factors. More litter fall and low decomposition rates (Singh 1998) have been identified as the hindrances there by affecting the natural regeneration of these species to a considerable extent. Excessive deposits of needles are inimical to the regeneration of all coniferous trees; complete removal of the un-decayed organic matter would enable seedlings to establish in the forests.

Forest soils influence the composition of the forest stand and ground cover, rate of tree growth, vigour of natural reproduction and other silvicultural important factors (Bhatnagar 1968). Physiochemical characteristics of forest soils vary in space and time due to variations in topography, climate, physical weathering processes, vegetation cover and microbial activities (Paudel and Sah 2003). Plant tissues (from above ground litter and below ground root detritus) are the main source of soil organic matter, which influences physico-chemical characteristics of soils such as pH, water holding capacity, texture and nutrient availability (Kumar *et al.* 2004).

Forests are natural store houses of biomass and carbon (C). They sequester and store more carbon (contains over 350,000 Tg C) than any other terrestrial ecosystem and are an important natural 'brake' on climate change. In the last two decade in particular, there has been an increasing interest in the quantification of the biomass of forest ecosystems and its potential with regards to carbon fixation. Knowledge of the biomass carbon densities for different forest types is one of the important components for assessing the contribution of forest lands to the global carbon cycle. A functional relationship between floral diversity and carbon storage and sequestration could have an important implication for the management of carbon sink not only for reforestation and afforestation type projects but also for emission reduction projects that focus on forest conservation and management (Gairola *et al.* 2011). The problem of climate change adds considerable stress to our societies and to the environment that is a fundamental threat to sustainable development. From shifting weather patterns that threaten food production, to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global in scope and unprecedented in scale, in terms of ecological imbalances, biodiversity depletions and other environmental changes.

The carbon stock in a forest ecosystem can be broadly categorized as biotic (vegetation carbon) and pedologic (soil carbon) components. In terrestrial ecosystems, forests are the most productive among their biotic components. As trees grow, they sequester carbon in their tissues and as the amount of tree biomass increases, the atmospheric carbon dioxide is mitigated. About 43 per cent - 50 per cent of the dry biomass of trees consists of carbon (Malhi *et al.* 2002; Negi *et al.* 2003). Trees, both in their above and below ground biomass, continue to accumulate carbon until they reach maturity; at that point, about half of the average dry weight of trees will be carbon (Anonymous 2004). On the other hand, trees are long-lived that develop a large biomass, thereby capturing large amounts of carbon over their growth cycle of many decades. Thus, forests can capture and retain large amounts of carbon over long periods. These productive characteristics of forests make them attractive for mitigation of climate change (Nabuurs *et al.* 2007). Accurate estimates of carbon stocks in forests have been gaining global attention as nations seek to comply with agreements under the UN Framework Convention on Climate Change (Brown 2002). Estimates of existing C stock pools, stored in various forest types can be helpful in making decisions about C management.

In India, more than 116 million tons of CO<sub>2</sub> is sequestered per year, which is equivalent to 32 millions of carbon sequestration and contributes to global reduction in atmospheric carbon (Jasmin and Birundha 2011). The carbon stock in forest vegetation varies according to geographical location, plant species and age of the stand (Van Noorwijk *et.al.* 1997).

Soils contain twice as much carbon as in the atmosphere and about 75 per cent of the total terrestrial organic carbon pool (Prentice 2001). Any change in the abundance and composition of soil carbon can substantially affect the global carbon cycle and many other important processes (Batjes 1996). SOC is sensitive to a range of factors including climate, topography, soil and vegetation management, and other anthropogenic conditions (Tan *et. al.* 2004). Although 40 per cent of soil carbon is found beneath forests, carbon pools in forest soils (especially in mountainous areas) are under-sampled and under-studied compared to aboveground carbon pools (Lal 2005). Soils in cold-temperate mountains have high soil organic carbon (SOC) content but with large spatial variability because of the complex terrain and variable climate and vegetative communities it is difficult to estimate.

India has a diverse climate in its geographical landscape and it nurtures sixteen groups of forest types (Champion and Seth 1968) where variety of undergrowth of shrubs and herbs makes these communities diversity rich. Thus, these plant communities vary in their standing carbon stock. Unlike in the developed countries we do not have carbon inventories and database to monitor and enhance carbon sequestration potential of different forests. In India attempts were made to access carbon sequestration at micro level (Ravindranathan *et. al.* 1997). Such kind of micro level studies are essential for sustainable forest management in the country where heavy degradation has been caused by anthropogenic activities and different forest management prescriptions of the past warranted in different periods of time to meet the local and national needs.

Temperate forests cover 767 million hectares worldwide and account for approximately 14 per cent of forest carbon storage (Pan *et al.* 2011). The greatest potential for C storage in temperate forests is usually found within the tree biomass (Son *et al.* 2001; Peichl and Arain 2006), whereas the biomass of understory, deadwood, and litter also contribute considerably (Whittaker and Woodwell 1986). Thus, neglecting the C contained in the biomass and other components may lead to a significant under estimation of the total carbon storage. The role of dry temperate and alpine forests in India is important because of

their potential to accumulate a large amount of carbon in different pools; however, there is a lack of data on different carbon pools in dry temperate and alpine forests of the Himalayas, especially that of Kinnaur district of Himachal Pradesh. Hence, the present study was carried out to know the status of floral diversity and carbon stock in dry temperate and alpine forests area of Kinnaur district in Himachal Pradesh with below mentioned objectives so as to devise better strategies for their management.

**Objectives:**

- i) To study floral diversity of dry temperate and alpine forest ecosystem of Himachal Pradesh;
- ii) To assess regeneration status of dry temperate and alpine forest ecosystem of Himachal Pradesh;
- iii) To assess the carbon stock of dry temperate and alpine forest ecosystem of Himachal Pradesh;
- iv) To determine soil physico-chemical properties of dry temperate and alpine forest ecosystem of Himachal Pradesh.

## *Chapter-2*

# REVIEW OF LITERATURE

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In this chapter, the relevant information related to the present study entitled “**Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh**” has been reviewed have under the following heads:

- 2.1 Floristic composition**
- 2.2 Regeneration status**
- 2.3 Biomass and carbon stock**
- 2.4 Soil carbon stock**
- 2.5 Soil physico-chemical properties**

### **2.1 FLORISTIC COMPOSITION**

A vegetation characteristic varies with season, years, biotic and abiotic components. It is the net result of their interaction, which forms a type of community (Whittaker 1970). According to Odum (1969) species diversity refers to the richness of species as well as balanced species distribution, whereas McIntosh (1967) considered diversity as the number of species in a community including distribution of individuals among the species.

Xingong *et al.* (2003) compared floristic composition and flora in different areas of *Tsuga* communities and reported that the similarity of floristic composition among the communities was low, and the proportion of constant families, genera, and species were: 24.14 per cent, 13 per cent and 3.94 per cent, respectively. However, with the increase in elevation, the proportion of *Tsuga* genus in the floristic composition decreased.

Singh (2004) conducted phytosociological survey in different periodic block of Shimla forest division. In case of shrub, *Berberis aristata* showed dominance in PB-I, PB-II, PB-III and PB-IV, while *Sarcococca saligna* was dominant in PB-III. Among herbaceous vegetation most dominant species was *Eragrostis nutanus* in all PB's. The regeneration studies of deodar revealed that maximum regeneration of recruits, un-established and established was in PB-I with 55.4 per cent established stocking followed by 38 per cent in PB-IV, PB-III were devoid of regeneration of deodar.

Machodo *et al.* (2004) suggested a strong influence of the altitude and geographical proximity on remnant forest of Lavras, Brazil, whereas the pattern of structural dissimilarity suggested a stronger influence of the soil nutritional status and ground water regime in tropical mountain semi deciduous forest.

Nath *et al.* (2005) analysed the species composition, diversity and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India. A total of 200 (94 tree species, 45 shrubs and 61 herbs) plant species belonging to 73 families were recorded in three stands. Tree density and basal area showed a declining trend with the increase in disturbance intensity. *Altingia excelsa*, *Olea dioica*, *Terminalia chebula*, *Mesua ferrea* and *Shorea assamica* in the undisturbed stand and *Albizia procera* alone in the moderately disturbed stand contributed more than 50 per cent of the total tree density in respective stands. Asteraceae, Euphorbiaceae, Lauraceae, Meliaceae and Rubiaceae were the dominant families.

A study on the northeastern upland forest of Pernambuco, Brazil indicated that the humid forests showed higher richness of species and has more floristic similarity with the lowland humid forests (Rodal *et al.* 2005). Adam and Zahiruddin (2005) studied floristic composition and structural comparison of Sarawak forests, Malaysia. The results indicated that Shannon diversity index, species richness and species evenness decreased with increasing altitude and richness is related to type of communities.

Sharma (2006) studied stand parameter and natural regeneration status of silver fir and spruce in Himachal Pradesh. The floristic composition studies revealed that among trees *Abies pindrow* and *Picea Smithiana* dominated most of the site. A maximum dominance of *Abies pindrow* (261.05 IVI) was found at highest elevation in PB-II of Bashla forest range. The dominant shrubs species in study area were *Sarcococca saligna*, *Rosa macrophylla*, *Berberis aristata*, *Lonicera angustifolia*, *Cotoneaster bacillaries*, *Viburnum cotinifolium*, while for the herbs most dominant species were *Fargaria vesca*, *Trifolium pretense* and *Cyperus aristatis*.

Lui and Kang (2006) studied quantitative classification and environmental interception of forest tree species in Hungou, China and reported 40 plants under 7 plant formations. The results also indicated that the spatial distribution of tree species was mainly controlled by altitude, soil fertility and biotype humidity.

Sores *et al.* (2006) reported that geographical proximity and altitude are the main factors responsible for the floristic similarity of many areas of inland Atlantic forest in Araponga MG. Brazil.

The study conducted by Zhu and Li (2006) on species composition and biogeography revealed that the mountain rain forest has similar diversity to the lowland rain forest in southern Yunnan China and further revealed that species richness is not necessarily reduced with the increasing altitude.

Pant and Samant (2006), while studying Mornaula Reserve Forest, one of the biodiversity-rich reserve forests of western Himalaya, reported a total 337 species of economic importance, belonging to 111 families and 260 genera. Of these, there are 75 tree species, 69 shrub species and 193 herbs (including 7 species of pteridophytes).

Shrestha *et al.* (2007) studied distribution and community structure of tree line birch (*Betula utilis*) forest in a trans-Himalayan dry valley of Manang (central Nepal). Along 5 vertical transects, a total of 41 square quadrats (10 m x 10 m) were sampled to determine the importance value index (IVI) of tree species, distribution pattern of seedlings and saplings, and soil attributes. Pure *Betula* forest forming the treeline was mature, with high basal area (2.3 per cent) but mixed *Betula* forest at lower elevations was young. This might have developed after large-scale clear cutting of *Abies spectabilis*. If not severely disturbed, mixed *Betula* forest may be replaced by *Abies spectabilis*.

Semwal *et al.* (2008), while studying structure, composition, diversity, and regeneration status of different forest types in a moist temperate region of Garhwal, India revealed that overall diversity increased in *Pinus*-dominated sites, which were characterized by more-open canopies (canopy cover < 20 per cent) with scattered trees interspersed with young trees, shrub and herb species compared to Quarks forests with a dense crown cover (> 65 per cent). A direct proportional relationship between tree cover and the diversity of substratum vegetation was found. The diversity of shrubs and herbs significantly decreased ( $r^2 = 0.72$  and  $0.83$  for herbs and shrubs, respectively at  $p < 0.05$ ) with increasing tree canopy cover. Tree density was maximum in mixed broadleaf-coniferous forests, while it declined in oak-dominated forests although vegetation cover was highest in mixed oak-forests. In general, *Pinus roxburghii* and *Quercus leucotrichophora* showed fair regeneration in spite of fire and logging. Tree density showed strong correlations with the densities of seedlings and

poles, while sapling density was not significantly correlated that of trees, indicating low sapling density. Observations suggest that conversion of saplings to tree strata is a crucial factor to ensure good regeneration of species in these types of forests.

A study conducted by Ceullo *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 in the study area becomes more compressed towards elevation and the basal area shows different pattern against altitude.

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 (2250-1850 m amsl), medium at mid altitude (2600-2400 m amsl) and lowest at the higher altitude (2800-2700 m amsl). They also recorded significantly negative correlation of density and species richness with altitude and slope.

Kharkwal and Rawat (2010) studied the structure and composition of vegetation in sub tropical forest of Kumaun, Himalaya. They found that *Quercus leucotrichophora* A. Campus, *Quercus floribunda*, *Quercus semecarpifolia* and *Pinus roxburghii* were the dominant tree species in banj-oak, tilonj-oak, kharsu oak and chirpine forests respectively. Among the sampling sites, total density of tree, shrub and herb species was ranged from 10 to 28.6 individuals (ind.100 m<sup>-2</sup>), 1.8 to 21.7 ind. 25 m<sup>-2</sup>, and 28.1 to 103.7 ind. m<sup>-2</sup>, 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 showed contagious distribution pattern in tree, shrub and herb species.

Pala *et al.* (2011) studied species composition and phytosociological status of Chanderbadni sacred forest in Garhwal Himalaya, Uttarakhand India and recorded a total of 80 species representing 75 genera from 40 families, out of these 21, 27 and 32 were trees, shrubs and herbs, respectively. The maximum number of species (12) were found in family Rosaceae followed by Lamiaceae and Asteraceae having seven species each. *Quercus leucotrichophora* with IVI (116.63), *Berberis aristata* with IVI 30.23 and *Andropogon munroi* with IVI of 38.84 were dominant plant species among trees, shrubs and herbs, respectively.

Sobuj and Rahman (2011), while studying the diversity of plant species (trees, shrubs and herbs) in Khadimnagar National Park of Bangladesh. They reported a total of 74 plant species, of which 26 were tree species, 17 were shrubs and 31 were herbs. Among the tree species, *Tectona grandis* showed the highest density (3.03/100 m<sup>2</sup>), frequency (76.67 per cent), relative density (17.7 per cent), relative frequency (11.3 per cent) and relative dominance (37.3 per cent). On the contrary, *Alstonia scholaris* represented the lowest density (0.07/100 m<sup>2</sup>), frequency (6.67 per cent), relative density (0.39 per cent) and relative frequency (0.99 per cent). The lowest relative dominance was found for *Sterculia villosa* (0.14 per cent). However, species with the highest abundance was calculated for *Chukrasia tabularis* (4.58), whereas the lowest was recorded for *Alstonia scholaris*, *Cynometra polyandra*, *Sterculia villosa* (1). Moreover, highest importance value index was measured in *Tectona grandis* (66.3), while it was lowest in *Alstonia scholaris* (1.54). Among shrub species, *Clerodendrum viscosum* represented the highest density (1.03/4 m<sup>2</sup>) and frequency (50 per cent). In contrast, lowest density (0.08/4 m<sup>2</sup>) and frequency (8.33 per cent) were measured in *Antidesma ghaesembila*. Species with the highest abundance was found in *Urena lobata* (2.35), whereas lowest was in *Antidesma ghaesembila* (1). With regard to the herb species, *Thysalonema maxima* showed the highest density (1.03/4 m<sup>2</sup>). On the other hand, lowest density was measured in *Seseli indicum* (0.1/4 m<sup>2</sup>). The calculation depicted that *Eryngium foetidum* had the highest frequency (45 per cent) and the lowest was in *Seseli indicum* (8.33 per cent). But species with the highest abundance was recorded in *Centella asiatica* (2.69). While, the lowest was calculated for *Amaranthus spinosus* (1.07). Species of shrubs and herbs showed random to contagious distribution pattern. Shannon-Wiener diversity index were 2.76, 2.56 and 3.27 for trees, shrubs and herbs, respectively.

Mir *et al.* (2011), while doing ecological analysis of woody species of the Chopal forest division, Himachal Pradesh at five sites under different altitudes and aspects found that the total basal area cover of the forests varied between 0.093 m<sup>2</sup> ha<sup>-1</sup> (*Alnus nepalensis*) at site-IV and 46.682 m<sup>2</sup> ha<sup>-1</sup> at site-V (*Cedrus deodara*). The distribution pattern was found regular, random and contagious. Species diversity index was found maximum 1.597 at site-IV and minimum 0.574 at site-I. Whereas, species richness was found highest (9) at site-V and lowest (2) and site-I and II, respectively.

Joshi (2011), studied vegetation structure, floristic composition and soil nutrient status at three sites of Tropical dry deciduous forest of West Bengal (23°40'54.4"N to 87°40'20.2"E,

23°35'52.3"N to 87°25'42.2"E and 24°04'17.7"N to 87°40'56.4"E). A total 77 of woody individuals ( > 1cm DBH) of six tree species (*Shorea robusta*, *Acacia catechu*, *Bachanania lanzan*, *Holarrhena antidysentric*, *Madhuca indica* and *Pterocarpus marsupium*) belonging to 6 families were enumerated in these sites covering an area of 0.06 ha. Ground vegetation consisted of 3 species of shrubs, 12 species of herbs and 5 species of climbers. The tree density varied from 500 - 1700 stems ha<sup>-1</sup> and basal area ranged from 7.66 – 19.55 m<sup>2</sup> ha<sup>-1</sup>. Shannon-Wiener Index (H) ranged from 0 - 1.28 while Simpson's Index ranged from 0.51 – 1.00. A greater number of tree species fell in 10-15 cm dbh followed by 5-10 cm diameter class.

Dangwal *et al.* (2012) studied plant diversity assessment in relation to disturbances in sub-tropical chir pine forest in district Rajouri of Jammu and Kashmir, India. The high diversity of trees, shrubs and herbs was found in hill base as compared to hill slope and hill top. The decrease in the number of seedling and sapling in hill slope was due to higher anthropological pressure on trees. An increase in the number of shrubs and herbs mainly, *Parthenium hysterophorus* and *Cynodon dactylon* was reported in hill slope because of opening canopy and anthropological interference that provides greater opportunities for the recruitment of these species. *Pinus roxburghii* was the dominant species forming Chir pine type of forest. It was also observed that forest is under risk and will be vanished soon if not maintained properly.

Viraj (2013) examined the floristic diversity along the altitudinal gradient of 3,300 to 5,000 above msl in Phulang valley falling in Lippa-Asrang wildlife sanctuary of district Kinnaur, Himachal Pradesh. The total number of plant species in this area was 127 belonging to 35 families and 93 genera. The dominant families were Asteraceae followed by Fabaceae and Lamiaceae. The number of tree species at 3,300-3,800 m elevation was three with dominance of *Juniperus polycarpus* followed by *Betula utilis*. The number of shrub species was 16 and 5 in the elevation of 3,300-3,800 m and 3,800-4,400 m, respectively. *Lonicera myrtillus* was dominant shrub at 3,300-3,800 m; whereas *Berberis erythroclada* was dominant at 3,800-4,400 m elevation. The number of herb species was 79, 39 and 33 with the dominance of *Thymus linearis*, *Sibbaldia cuneata* and *Potentilla atrosanguinea* at the elevation of 3,300-3,800 m, 3,800-4,400 m and 4,400-5,000 m, respectively. The distribution pattern of most of the species was contiguous at all the altitudes. The index of diversity for herb species was 4.28, 3.56 and 2.99 for 3,300-3,800 m, 3,800-4,400 m and 4,400-5,000 m

elevation ranges, respectively. Out of 62 medicinal plant species, recorded from the area, 16 species fall in the different category of threatened plants.

Prenil (2014) studied fire effects on phytosociology of vegetation communities in Solan, Himachal Pradesh and reported 29 plant families consisting of trees, shrubs and herbs with 66 genera and 70 species (19 grasses, 2 sedges, 3 legumes, 26 forbs, 17 shrubs and 3 species of trees). The mean density of herbage in *Acacia* forest was 988.40 and 838.40 tillers  $m^{-2}$  and in adjoining grassland was 1089.80 and 992.80 tillers  $m^{-2}$ , in *Quercus* forest it was 424.80 and 370.20 tillers  $m^{-2}$  and in adjoining grasslands 721.40 and 614.60 tillers  $m^{-2}$  was recorded in burnt and unburnt area, respectively. Likewise, Basal area of herbage in *Acacia* forest was 28.92 and 27.35  $cm^2 m^{-2}$  and in adjoining grasslands it was 33.53 and 32.88  $cm^2 m^{-2}$ ; in *Quercus* forest 26.55 and 21.15  $cm^2 m^{-2}$  and in adjoining grasslands 52.24 and 46.03  $cm^2 m^{-2}$  was recorded in burnt and unburnt area, respectively. The shrub density in *Acacia* forest was 667 and 867 tillers  $m^{-2}$  and in adjoining grasslands it was 600 and 500 tillers  $m^{-2}$  in *Quercus* forest 1600 and 2867 tillers  $m^{-2}$  and in adjoining grasslands 1367 and 1534 tillers  $m^{-2}$  was recorded in burnt and unburnt area, respectively. Likewise, Basal area in *Acacia* forest was 0.255 and 0.277  $m^2 ha^{-1}$  and in adjoining grasslands it was 0.151 and 0.397  $cm^2 m^{-2}$ , in *Quercus* forest was 0.437 and 0.573  $cm^2 m^{-2}$  and in adjoining grassland it was 0.32 and 1.088  $cm^2 m^{-2}$  was recorded in burnt and unburnt area, respectively.

Sharma *et al.* (2014) studied floristic diversity and changing pattern of vegetation due to various biotic and abiotic factors in Sangla valley of Himachal Pradesh covering forest and alpine zones of the valley. Study revealed 320 species belonging to 199 genera and 75 families. Asteraceae, Rosaceae, Apiaceae, and Ranunculaceae were dominant. Among genera, *Artemisia* followed by *Polygonum*, *Saussurea*, *Berberis*, and *Thalictrum* were dominant ones. Tree and shrub's density ranged from 205 to 600 and from 105 to 1030 individual per hectare, respectively, whereas herbs ranged from 22.08 to 78.95 ind.  $m^{-2}$ . Nearly 182 species were native to the Himalaya. Maximum altitudinal distribution of few selected climate sensitive species was found to be highest in northeast and north aspects.

Verma and Kapoor (2014) studied the plant diversity along an altitudinal gradient with elevations varying from 3700m to 4700m a.m.s.l in alpine area of Rani Kanda in Rakchham Chitkul wild life sanctuary in district Kinnaur, Himachal Pradesh. Total number of plant species was 102 belonging to 31 families and 66 genera. The dominant families were Asteraceae, Rosaceae, Poygonaceae, Lamiaceae, Scrophulariaceae and Ranunculaceae. The

numbers of shrub species were 5 and 4 at elevation of 3700-4200 m and 4200-4700 m, respectively with the dominance of *Juniperus indica* at both the elevation. The number of herbs species were 81 and 62 at 3700-4200 m and 4200-4700 m with the dominance of *Thymus linearis* at both the elevation, respectively. The distribution pattern of most of species was contiguous. Index of diversity for herb was 3.54 and 3.66 in these elevations respectively. Out of 50 medicinal plant species recorded from the area, 14 species *i.e.* *Betula utilis*, *Meconopsis aculeata*, *Picrorhiza kurrooa*, *Heracleum lanatum*, *Polygonatum multiflorum*, *Polygonatum verticillatum*, *Podophyllum hexandrum*, *Selinum tenuifolium*, *Rheum australe*, *Rheum webbianum*, *Rhodiola heterodonta*, *Rhododendron anthopogon*, *Rhododendron campanulatum*, *Saussurea obvallata* fall in the category of threatened plants.

Dar and Sundarapandian (2016) analysed plant biodiversity patterns in seven temperate forest types [*Populus deltoides* (PD), *Juglans regia*, *Cedrus deodara*, *Pinus wallichiana*, *mixed coniferous*, *Abies pindrow* (AP) and *Betula utilis* (BU)] of Kashmir Himalaya. A total of 177 plant species (158 genera, 66 families) were recorded. Species richness ranged from 24 (PD) to 96 (AP) and most of the species were herbs (82.5 per cent), while shrubs accounted for 9.6 per cent and trees represented 7.9 per cent. Shannon diversity index varied from 0.17 to 1.06 for trees, from 0.36 to 0.94 for shrubs and from 0.35 to 1.41 for herbs. A total of five species were endemic. The total number of stem and basal area of trees were: 35,794 stems (standard mean found to be 330 stems ha<sup>-1</sup>) and 481.1 m<sup>2</sup> (stand mean 40.2 m<sup>2</sup> ha<sup>-1</sup>), respectively. The mean density and basal area ranged from 103 stems ha<sup>-1</sup> (BU) to 1,201 stems ha<sup>-1</sup> (PD), and from 19.4 m<sup>2</sup> ha<sup>-1</sup> (BU) to 51.9 m<sup>2</sup> ha<sup>-1</sup> (AP), respectively. Tree density decreased with increase in diameter class. A positive relationship was obtained between elevation and species richness and between elevation and evenness ( $R^2 = 0.37$  and 0.19, respectively). Tree and shrub communities were homogenous in nature across the seven forest types, while herbs showed heterogeneous distribution pattern.

Khan *et al.* (2016) studied the thirty stands of relatively undisturbed vegetation of pine communities in Indus Kohistan valley quantitatively term. They reported that seven tree species were common in the Indus Kohistan valley. *Cedrus deodara* exhibited the highest mean Importance Value Index (IVI) followed by *Pinus wallichiana*, *Abies pindrow* and *Picea smithiana*. *Pinus gerardiana*, *Quercus baloot* and *Taxus fuana* were the rare species in this area. Six communities and four monospecific stands of *Cedrus deodara* were recognized. *Cedrus-Pinus* community was the most occurring community, which was recorded from 13

different stands. The second most occurring community in the study area was *Abies- Pinus wallichiana* which was recorded from six locations, while *Cedrus-Picea* and *Abies-Picea* communities were observed at two locations each. *Pinus wallichiana - Picea* and *Cedrus-Pinus gerardiana* communities were restricted to one location.

Kumar and Sharma (2016) conducted studies on plant biodiversity of major forest communities in Chail wildlife sanctuary of Himachal Pradesh to assess plant diversity of major forest communities (Chir forest, Oak forest, Deodar + Oak forest, Chir + Oak forest, Deodar forest, Deodar + Chir forest and Mixed forest) of Chail Wildlife Sanctuary. There existed six tree species, 25 shrub species and 67 herb species of 42 families. Oak tree species had higher IVI in all the associated forest. *Rhododendron arboreum*, *Pinus wallichiana* and *Pyrus pashia* had lowest IVI in their community types, hence needs attention. Chir + oak and mixed forest communities were rich in shrub diversity, dominance and richness as compared to other forest communities. Herbaceous diversity, dominance and richness were higher in Chir, mixed and Chir + oak forest communities compared to others, whereas, species richness was maximum in Deodar community.

Verma (2016) studied the plant diversity along an altitudinal gradient with elevations varying from 2200-2600 m a.m.s.l in Dankund beat of Kalatop Khajjiar wild life sanctuary in district Chamba, Himachal Pradesh. Total number of plant species was 102 belonging to 54 families and 95 genera. The dominant families were Asteraceae, Rosaceae, and Fabaceae. The number of tree species at 2200-2400m a.m.s.l and 2400-2600 m a.m.s.l was 12 and 4 with dominance of *Cedrus deodara* and *Picea smithiana*, respectively. The number of shrub species was 27 and 10 with the dominance of *Sorbaria tomentosa* and *Viburnum erubescens* in the elevation of 2200-2400m a.m.s.l and 2400-2600 m a.m.s.l, respectively. The number of herb species was 52 and 53 with the dominance of *Valeriana jatamansii* and *Erigeron multiradiatus*, respectively. The distribution pattern of most of the plant species was contiguous in both the altitudes. Index of diversity for herb species was 3.17 and 3.20 for 2200-2400 m and 2400-2600 m elevation ranges, respectively. Assessment of floristic diversity provides basis for devising suitable strategies for conservation of the plant resources. Accordingly this study was conducted to understand the floristic diversity of dry temperate and alpine region of Kinnaur under different forest types. Out of 140 species 4 families belonging to trees, 11 shrubs, 25 herbs, 11 grasses and 2 ferns were encountered during the study. Among trees species Pinaceae; among shrubs Berberidaceae, Cupressaceae,

Fabaceae and Rosaceae; among herbs Asteraceae, Lamiaceae, Fabaceae, Ranunculaceae and Rosaceae and among grasses Poaceae were the dominant families. Among the total plant species recorded from the area 8 species viz., *Betula utilis*, *Juniperus communis*, *J indica*, *J macropoda*, *Rhododendron campanulatum*, *Picrorhiza kurroa*, *Bergenia stracheyi* and *Ephedra gerardiana* fell in the category of threatened species (Kumar *et al.* 2017).

A study conducted by Masoodi *et al.* (2017) in *Abies pindrow* forests of Uttarakhand of western Himalayas with the aim to analyze the diversity of plant species in the altitudinal range of 2200-3300 m above mean sea level (msl). The analysis of species revealed that the generic spectrum belonged to 73 families, comprising of 204 genera with 315 species of trees, shrubs and herbs which highlights the rich species diversity of higher plants in the *Abies pindrow* forests of the Western Himalaya in India. Maximum number of species belonged to family Asteraceae (29 species), followed by Poaceae (23 species), Rosaceae (21 species), Lamiaceae (17 species), Orchidaceae (15 species), Ranunculaceae (13 species), Apiaceae (12 species), Caprifoliaceae (11 species) and Polygonaceae (10 species), whereas other families had less than 10 species. Most of the forests in the present study were pure *Abies pindrow* forests. Tree species primarily belonged to family Pinaceae, shrubs to Rosaceae, Berberidaceae and Caprifoliaceae whereas; herbaceous flora primarily belonged to Asteraceae, Lamiaceae, Orchidaceae, Ranunculaceae, Polypodiaceae, Aspleniaceae, Poaceae and Cyperaceae. A total of 198 species were present out of which 5 were trees, 50 shrubs and 143 were herbaceous species. The herbaceous species comprised of 103 herbs, 4 climbers, 21 ferns, 11 grasses and 4 sedges.

Sharma and Samant (2017) examined the floral biodiversity in Parvati valley of Kullu District, Himachal Pradesh. A total of 19 species of the orchids representing 13 genera were recorded between 1100-3600 m amsl. Of these, 13 species were natives, 6 species near endemic and 5 species non-natives. These species represented in grassland, shady moist, forests, alpine meadows, moist rocks and boundary habitats.

Saikia *et al.* (2017) surveyed vegetation along an elevation gradient ranging from 870 to 4161 m in 354 belt transects (500 m × 10 m in size) in Arunachal Pradesh and analyzed using various ecological indices. A total of 482 plants were recorded in the present study, of which 153 are non-woody herbs and grasses belonging to 55 families and 329 are woody trees and shrubs belonging to 74 families. The 482 identified species belong to 117 families and 251 genera, of which 94.10 per cent are phanerogams (Angiosperms: 421 species (spp.)

and Gymnosperms: 10 spp.) and 5.90 per cent cryptogams (Pteridophytes: 27 spp.). The family Fabaceae contributed the greatest species diversity with a total of 27 plant species (Papilionaceae: 10 spp., Mimosaceae: 9 spp. and Caesalpinaceae: 8 spp.) followed by Poaceae (21 spp.), Ericaceae (20 spp.), Asteraceae (18 spp.), Lauraceae (17 spp.), Euphorbiaceae (16 spp.), Urticaceae (15 spp.) and 49 monotypic families. The most dominant trees were of *Castanopsis indica* (24 individuals per ha), followed by *Quercus semicarpifolia* (12 individuals per ha) and *Pinus roxburghii* (12 individuals per ha) and some bamboos (*Dendrocalamus strictus*: 69 individuals per ha; *Bambusa pallida*: 16 individuals per ha). The studied forest stands were rich in various bamboos; a total of 14 different bamboos were recorded in the present study including *Dendrocalamus strictus*, *Bambusa tulda*, *B. pallida* etc. Common IUCN red-listed species were *Aquilaria malaccensis*, *Begonia tessaricarpa*, *Gledetsia assamica*, *Gymnocladus assamicus*, *Livistona jenkinsiana*, *Rhododendron meddenii*, *Rhododendron thomsonii*.

Attri *et al.* (2017) studied floristic composition and natural regeneration status of chir pine forests in Sirmaur district of Himachal Pradesh. Chir pine displayed maximum density (690 individuals ha<sup>-1</sup>), abundance (6.9), basal area of 44.65 m<sup>2</sup> ha<sup>-1</sup> and IVI of 269.95. There were 7 species of shrubs recorded with a total density of 2,160 individuals per hectare, abundance of 20.00, basal area of 1,314.51 cm<sup>2</sup> ha<sup>-1</sup> and total IVI of 300. Where, maximum density (1040 ind. ha<sup>-1</sup>), abundance (8.7), basal area (575.48 cm<sup>2</sup> ha<sup>-1</sup>) and IVI (104.69) were observed for *Cassia floribunda* and per cent frequency (60) for *Berberis aristata*. Herbaceous vegetation comprised of 11 species of herbs, out of which 7 species are grasses species, one species each of sedge and fern were recorded from the study area. Among herbs, *Salvia glutinosa* showed maximum density (29,000 ind. ha<sup>-1</sup>) and IVI (24.18), while per cent frequency was maximum for *Lespedeza gerardiana* (60). In grasses, *Dicanthium annulatum* showed maximum density (98,000.00 individuals ha<sup>-1</sup>), basal area (125290 cm<sup>2</sup> ha<sup>-1</sup>) and IVI (86.87) and maximum abundance (24.00) was observed for *Heteropogon contortus*, while minimum density (14,000.00 cm<sup>2</sup> ha<sup>-1</sup>) was recorded for *Chrysopogon montanus* and minimum IVI (9.17) for *Setaria glauca*.

## 2.2 REGENERATION STATUS

Gupta (1996) while studying the regeneration in fir and spruce forest in Shimla district of Himachal Pradesh found that regeneration of fir (687.5 ha<sup>-1</sup>) on an average was more than spruce (312.5 ha<sup>-1</sup>) in a Narkanda, whereas it was higher at Chhachpur for fir

(833.33 ha<sup>-1</sup>) and Spruce (1875.00 ha<sup>-1</sup>). The regeneration with the increase in elevation decreased from 1250 ha<sup>-1</sup> to 208.33 ha<sup>-1</sup> for fir and from 625 ha<sup>-1</sup> to 156.25 ha<sup>-1</sup> for spruce at Narkanda. The regeneration with increase in elevation at Chhachpur on the other hand noticed increase in regeneration of fir from 625 ha<sup>-1</sup> to 1041.67 ha<sup>-1</sup> and decrease in regeneration of spruce from 2083.33 ha<sup>-1</sup> to 1666.67 ha<sup>-1</sup>.

Glaz and Zajaczkowski (2002), while studying natural regeneration of fir, spruce and beech observed that natural regeneration is most common in stands reaching the felling age *i.e.* for spruce at 81-100 years, fir 91-149 years and beech more than 80 years. Further, it was observed that non-significant correlation between young natural regeneration and the value of the main stand characteristics such as site, age, type of vegetation cover, degree of shelter and basal area existed.

Grassi *et al.* (2004) studied distribution, growth and natural regeneration of Norway spruce (*Picea alba*) and Silver fir (*Abies alba*). In both species, most natural regeneration was clumped and located at the margin of the gaps but fir saplings were more represented in understory and less in gaps as compared to spruce. The majority of saplings (established) were already present as the gap formation was predominant. Thus, sapling established before gap formation can play an important role in gap refilling.

Sharma and Raj (2004) assessed the natural regeneration status of *Juniperous macropoda* in Ladakh. They reported preponderance of mature and over mature trees and biotic pressure in the form of overgrazing, lopping of twigs, leaves and cones for burning as incense were identified as major factors responsible for poor natural regeneration status.

Singh (2004) studied natural regeneration of *Cedrus deodara* in different periodic blocks in Koti forest and found maximum established regeneration of 1388.8 ha<sup>-1</sup>, maximum established stocking percent (55.54) in PB I, followed by PB IV, whereas PB II was devoid of regeneration, with maximum value on northern aspect at about 2100 m a.s.l. Poor natural regeneration was attributed to the grazing which affected the distribution pattern by inhibiting regeneration and establishment.

Balwant *et al.* (2007) studied phenology, relative density and average height, regeneration, conservation and management status of *Cedrus deodara*, *Pinus roxburghii* and *Quercus leucotrichophora* in western Himalaya. Study revealed that *Cedrus deodara* had

maximum density and good regeneration, while the growth and establishment of *Pinus roxburghii* and *Quercus leucotrichophora* was affected by intense biotic pressure, such as lopping of ban during lean period for fodder.

Lanker (2007) studied the natural regeneration status of *Taxus wallichiana* in Kotgarh, Theog and Chopal Forest Divisions. He reported the total absence of established regeneration in the study area. A similar study conducted by Sharma (2006) also reported poor status of fir and spruce natural regeneration in all selected sites of Jubbal forest range, where a maximum 33.11 per cent established stocking in the middle elevation, while minimum value was recorded for higher elevation.

Gupta (2007) studied the natural regeneration status of silver fir and spruce in Kullu, Rajgarh and Kotgarh Forest Divisions of Himachal Pradesh and reported overall regeneration success of 91.68 per cent in Kullu, followed by 74.69 per cent in Kotgarh and 72.47 per cent in Rajgarh forests, respectively in descending order.

Semwal *et al.* (2008) studied structure, composition, diversity and regeneration status of different forest types in a moist temperate region of Garhwal, India. They revealed that overall diversity increased in chir pine dominated sites, which were characterized by more open canopies with scattered trees interspersed with young trees, shrub and herb species compared to oak forests with a dense crown cover. A direct proportional relationship between tree cover and the diversity of sub-stratum vegetation was found to increase with increasing tree canopy cover. Tree density showed strong correlations with the densities of seedlings and poles. The observations suggest that conversion of saplings to tree strata is a crucial factor to ensure good regeneration of species

According to Bahar *et al.* (2008), the growth performance of seedlings was better in seed production areas compared to natural stands of chir pine in Uttarakhand as density as well as thick layer of litter affects the growth and development of seedlings. Weeds also check the growth of seedlings through root competition though grasses are not harmful.

Dhaulkhandi *et al.* (2008) studied the regeneration potential of natural forest site in Gangotri, Uttarakhand and reported that seven tree species from the site and maximum number of seedlings were observed of *Pinus wallichiana* (1080 individuals ha<sup>-1</sup>) followed by *Picea smithiana* (1040 individuals ha<sup>-1</sup>). As far as regeneration status was concerned, 71.4 per

cent species showed good regeneration, 14.3 per cent poor regeneration and 15.3 per cent species were not regenerating.

Sharma *et al.* (2010) studied the natural regeneration of *Pinus gerardiana* in dry temperate forest of Kinnaur and reported preponderance of mature and over mature trees and biotic pressure in the form of collection of seeds and overgrazing were the major factors responsible for poor natural regeneration.

Kumar *et al.* (2011) conducted a study in *Pinus roxburghii* and *Anogeissus latifolia* forests to understand the distribution pattern, regeneration status and effect of forest on micro climatic conditions. They reported that in *Pinus roxburghii* forests only *Acacia catechu* was co-dominant species. Whereas, in *Anogeissus latifolia* forest the associated species were *Acacia catechu*, *Lannea coromandelica* and *Emblica officinalis*. The high density of tree species in *Anogeissus latifolia* forest resulted in reduced density of regenerating species. The species diversity was also higher in *Anogesissus latifolia* forest. In both forest types, climatic conditions favoured natural regeneration of different species.

Dangwal and Singh (2012) compared the vegetation of chir pine forest and also studied the regeneration status of chir pine in relation to the disturbance in Nowshera, Jammu & Kashmir, India. The whole area was divided into five sites and showed that diversity index was invariably higher for trees followed by herbs and shrubs. Out of the 58 species reported from the forest, 23 were trees, 13 shrubs and 22 herbs. Recruitment of shrubs and herbs on some sites showed the open canopy in highly disturbed site and investigated data also shows heavy deforestation and over-grazing.

Pant and Samant (2012) examined regeneration status in Khokhan Wildlife Sanctuary located in the Kullu district of northwestern Himalaya. They reported seventeen forest tree communities in which *Cedrus deodara* community was the most widely distributed followed by *Quercus leucotrichophora*, *Abies pindrow* and *Quercus semecarpifolia* communities, respectively. *Cedrus deodara* community had highest density of trees (1468 individual ha<sup>-1</sup>), seedlings (1290 ind. ha<sup>-1</sup>) and saplings (1172 ind. ha<sup>-1</sup>), while *Picea smithiana* community recorded the highest total basal area (186.2 m<sup>2</sup> ha<sup>-1</sup>) and out of 17 forest tree communities, eight showed highest regeneration of the dominant species, six showed highest regeneration of the co-dominant species indicating the possibility of at least partial replacement of the dominant species by the co-dominant species in the near future. Three communities showed

poor or no regeneration of the dominant species indicating a total replacement of the dominants in future.

Bisht *et al.* (2013) conducted studies on population status and regeneration of *Quercus semecarpifolia* and *Quercus floribunda* in a subalpine forest of western Himalaya. Saplings of *Q. semecarpifolia* belonging to the 51-100 cm size class and those of *Q. floribunda* belonging to the 101-150 cm size class were well represented in studied subalpine forests. Comparable seedling emergence and establishment of both species, either in the habitat dominated by same or different species seems to be an adaptational strategy of these species in subalpine forests. Seedling to tree ratio for *Q. semecarpifolia* was higher in the stand dominated by *Q. floribunda*, while comparable pattern was observed for *Q. floribunda* in the stand dominated by *Q. semecarpifolia*. Establishment of higher percent of seedlings of one species in the habitats dominated by another species of *Quercus* appears to indicate an oligarchic nature of oaks in subalpine forests.

Sharma and Ahmed (2014) studied natural regeneration status of *Pinus roxburghii* in Ponda watershed of Rajouri Forest Range, Jammu & Kashmir, India and reported that regeneration status of chir pine was fairly good with the densities of seedling, sapling and adults of 6050, 258 and 211.25 ind. ha<sup>-1</sup>, respectively.

Kumar *et al.* (2016) studied regeneration complexities of *Pinus gerardiana* in dry temperate forests of Indian Himalaya. *Pinus gerardiana* regeneration success is lower than that of required for sustainable forest management, but varies widely among sites in the temperate forest Himalayas. Results suggest that in different forests, regeneration success is influenced by collection of seed (nut) by tribal people, grazing and browsing, soil, sand and nutrient content. Regeneration varied with sites and it was observed that site with more *P. gerardiana* regeneration have less biotic interference, soil, sand and litter depth, but more soil nutrient availability. This research elucidates associations between successful *P. gerardiana* regeneration and site factors such as soil nutrient availability.

Attri *et al.* (2017) studied natural regeneration status in different periodic blocks of chir pine stands and found that maximum recruits (6333.33 ha<sup>-1</sup>), un-established (1444.44 ha<sup>-1</sup>) and established (1083 ha<sup>-1</sup>) were found in periodic block -I. There was not much difference in weighted average height and establishment index of chir pine in all the periodic blocks.

Maximum stocking index (0.58) percent regeneration (57.78) and established stocking percent (32.29) were found in PB -I as compared to others.

Kumar *et al.* (2017) studied Regeneration status of dominant forest communities of Chail wildlife sanctuary (H.P.) and found that per cent regeneration ranged from 30-67.50 in Chail wildlife sanctuary. Regeneration was satisfactory in chir (65 per cent) and deodar forest community (67.50 per cent), but deodar + chir (30 per cent), chir + oak (32.50 per cent), mixed (40 per cent), oak (42.50) forest communities had poor regeneration. Chir pine showed poor establishment of regeneration in association with deodar. Oak showed poor response to established regeneration in mixed forest community. Oak regeneration was also unable to establish in association with chir. *Rhododendron arboretum* and *Pyrus pashia* seems to be under threat as regeneration of these species is almost absent.

Parveen *et al.* (2017) examined the pattern of tree regeneration of two montane forests across the anthropogenic disturbance gradients in Garhwal Himalaya, Uttarakhand, India. Vegetation data was collected from 60 sample plots using a stratified random sampling technique. Circumference was used to differentiate three layers of a species into adults (Circumference > 31.5 cm), saplings (Circumference 10.5–31.4 cm) and seedlings (Circumference < 10.5 cm). A total of 25 tree species belonging to 22 genera and 18 families were recorded in the present study. Species richness at the study sites varied from 7 to 15 species. The proportion of trees (0.90 per cent), saplings (6.80 per cent) and seedlings (92.30 per cent) in both the forests indicated a good regeneration status in general.

### **2.3 BIOMASS AND CARBON STOCK**

International concern about the effects on climate of increased atmospheric concentrations of greenhouse gases such as carbon dioxide has focused policy attention on the dynamics of carbon in terrestrial vegetation and soils. Forests absorb carbon dioxide (CO<sub>2</sub>) from the atmosphere during photosynthesis and release it during respiration and the decay of dead plant material. Approximately 120 billion tons of carbon (Gt C) is absorbed annually through photosynthesis and comparable amount is released through respiration and decomposition (Karthi 2001). Carbon sequestration is the provision of long term storage of carbon in the terrestrial biosphere, belowground or the ocean so that the buildup of CO<sub>2</sub> concentration in the atmosphere will reduce or slow down in order to improve environmental

conditions and check the process of environmental degradation especially through forestry, horticulture and agriculture.

Many natural and artificial processes can act as atmospheric sponges that absorb carbon dioxide. Ocean, forests, most plants and algae collect carbon through the photosynthesis process. This capturing of atmospheric carbon by a healthy ecosystem is called a “Carbon Sink”. While all living plant matter absorbs CO<sub>2</sub> as part of photosynthesis, trees process significantly more than smaller plants due to their large size and extensive root structure. In essence, trees, as kings of plants world, have much more “woody biomass” to store CO<sub>2</sub> than smaller plants, and as a result are considered nature’s most efficient “Carbon Sinks”. The rate of carbon absorption and hence the magnitude of the carbon sink, is greatest in the earliest stages of regeneration and declines as forests mature. The amount of carbon stored in forests can change over time because of natural variation in climatic factors, such as temperature and rainfall; the natural developmental or successional dynamics of vegetation; or disturbances such as fires, storms, or pest and disease outbreaks. Carbon sequestration is the process of removing additional carbon from the atmosphere and depositing it in other reservoir principally through changes in land use. In practical terms carbon sequestration occurs mostly through the expansion of the forests or by conserving them (Houghton 1995). Therefore, terrestrial carbon sequestration is the net removal of CO<sub>2</sub> from the atmosphere and storing it in terrestrial ecosystems (Sedjo and Marland 2003). So, forest expansions and sustainable forests, as mitigation measures, have a significant contribution to the environmental benefit but any shrinkage of forests, as emission, has a long term influence and impact (Levy *et al.*, 2004).

Carbon sequestration by plants is the extraction of the atmospheric carbon dioxide and its storage in terrestrial ecosystems for a very long period of time, in terms of live biomass, so that it is not immediately re-emitted back to atmosphere (Lal 2004). Once they die the biomass becomes a part of the food chain and enters the soil as soil carbon. If the biomass is incinerated, the carbon is re-emitted into the atmosphere as carbon dioxide and is free to move in the carbon cycle.

Forests play an important role in global carbon cycling, since they are large pools of carbon as well as potential carbon sinks and sources to the atmosphere. Accurate estimation of forest biomass is required for green house gas inventories and terrestrial carbon accounting. The need for reporting carbon stocks and stock changes for the Kyoto protocol

have placed additional demands for accurate surveying methods that are verifiable, specific in time and space, and that cover large areas at acceptable cost. The aim of Kyoto protocol was to reduce the green house gas emission by 5.2 per cent below the 1990 levels by 2012 (IPCC 2003; Krankina *et al.*, 2005). The first phase of the protocol has started in 2007 and the second phase has also already started in the year 2008.

Negi and Chauhan (2002) while working on biomass and productivity of sal forest (*Shorea robusta*) concluded that sal accounted for carbon storage between 18.50-98.10 per cent of the total crop at 11 representative sites.

Goodale *et al.* (2002) studied forest sector carbon budgets of Canada, U.S.A., Russia, China and Europe and reached at a general agreement that terrestrial systems in the northern hemisphere provided a significant sink for atmospheric CO<sub>2</sub>, Northern forests and woodlands provided a total sink of 0.6-0.7 Pg yr<sup>-1</sup> of C per year during early 1990's, consisting of 0.21 Pg yr<sup>-1</sup> in living biomass, 0.08 Pg yr<sup>-1</sup> in forest products, 0.15 Pg yr<sup>-1</sup> in dead wood and 0.13 Pg yr<sup>-1</sup> in the forest floor and soil organic matter.

Lal and Singh (2000) reported that new plantations have significantly high productivity value compared to natural forests and fully developed plantations. The biomass of 25 years old plantations is estimated to be twice than that of 8 year plantations but the primary productivity values are the same. These plants absorb CO<sub>2</sub> more efficiently from the atmosphere. Estimates of annual carbon uptake increment suggest that Indian forests and plantations have removed at least 0.125 G t CO<sub>2</sub> from the atmosphere in the year 1995. Banfield *et al.* (2002) reported that in the boreal forest ecosystem of West Alberta, Canada, the average above ground carbon stock ranged from 43 to 50 Mg ha<sup>-1</sup>.

Raizada *et al.* (2003) estimated the rate of carbon flux in selected plantation forests in India and revealed that planted forests of short rotation tree species with regular leaf shedding patterns have more capacity for carbon sequestering in litter which decomposes more rapidly than species with annual or bimodal leaf shedding patterns. Fast growing conifers may produce slow decomposing litter leading to accumulation on forest floor, hence, risk for fire damage and decline in ground flora diversity and productivity. Mixed plantation forests of exotic and native species could be more efficient in sequestering carbon than monocultures, and fast growing hardy species, like *Eucalyptus spp* would be ideal choice for wastelands

afforestation/reforestation, and softwood species for agri-silvicultural practices in soil of fertile plain areas.

Kraenzel *et al.* (2003) estimated the carbon storage potential of 20 years old Panamanian teak (*Tectona grandis*) plantations. A regression relating diameter at breast height (dbh) to total tree carbon storage was constructed and used to estimate plantation-level tree carbon storage, which averaged 120 t ha<sup>-1</sup>. The carbon storage in Panamanian harvest age teak plantations was estimated to be 351 t ha<sup>-1</sup>.

There are three principles forest biomes: boreal, temperate and tropical. The boreal or taiga forest occupies a circumpolar belt. Temperate forests cover mid-latitudes between 25 and 50° north and south of the Equator, and comprise both evergreen and deciduous species. Tropical forests occur about 25° north and south of the Equator, and comprise both evergreen and deciduous species. Predominant types of tropical forests include lowland rainforest, montane forests and mangrove forests (Lal 2005).

Mural and Bhat (2005) studied biomass estimation equations for tropical deciduous and evergreen forests. In their study, linear and non linear equations were developed to estimate biomass of tropical forests along with estimates of goodness of fit and percentage of errors. Basal area and height of trees were found to give high goodness of fit and low percentage of errors for deciduous forests. Generally, the coefficient of determination (R<sup>2</sup>) was low for evergreen forests, probably due to presence of trees of different height in canopies that may have different growth rates. The coefficient of determination was high and estimate of error was low for deciduous forests. Thus the biomass estimate equations for deciduous forests are precise and useful for field applications.

Gera *et al.* (2006) studied carbon sequestration potential and cost effectiveness of tree growing operations on farm lands of Rupnagar district of Punjab (India). Project based-comprehensive mitigation analysis process was used to estimate the sequestration potential between 2005-2030 under three models namely; poplar block planting, poplar bund planting and *Eucalyptus* bund planting. The poplar block plantation gave maximum sequestration potential of 115 t ha<sup>-1</sup> which was higher by 79.69 per cent and 105.34 per cent with respect to *Poplar* bund plantation and *Eucalyptus* bund planting, respectively.

Sanneh (2007) estimated the status of carbon stock under different land use systems in wet temperate north-western Himalayas at different altitudinal gradients *viz.*, 1500 m-1800 m a.s.l., 1800 m-2100 m a.s.l. and 2100 m-2400 m a.s.l. Result of his finding indicated that maximum above ground biomass (308.96 t ha<sup>-1</sup>), below ground biomass (62.09 t ha<sup>-1</sup>) and total biomass (371.06 t ha<sup>-1</sup>) was in the forest land use system. It was followed by silvi-pasture, agri-silvipasture, agri-horticulture, agriculture and grassland systems, respectively. The rate of biomass production (t ha<sup>-1</sup>) increased with increasing altitudinal ranges. The rate of total biomass production at 1500 m-1800 m, 1800 m-2100 m, 2100 m-2400 m a.s.l. was 106.31 t ha<sup>-1</sup>, 113.19 t ha<sup>-1</sup>, and 141.41 t ha<sup>-1</sup>, respectively.

Manhas *et al.* (2006) estimated the stem biomass, growing stock (GS) and carbon stock of Indian forests for the year 1984 and 1994. They reported that forest area, wood biomass, GS, and carbon stock were 63.86 M ha, 4327.99 M m<sup>3</sup>, 2398.19 Mt and 1085.06 Mt, respectively in 1984 and with the reduction in forest area (63.34 M ha) in 1994, wood biomass (2395.12 Mt) and carbon stock (1083.69 Mt) also reduced subsequently. The conifers of temperate region, stocked maximum carbon in their woods, 28.88 to 65.21 t ha<sup>-1</sup>, followed by Mangrove forests, 28.24 t ha<sup>-1</sup>, *Dipterocarp* forests, 28.00 t ha<sup>-1</sup>, and *Shorea robusta* forests, 24.07 t ha<sup>-1</sup>. They also reported that land use changes and fuel wood requirements are the main cause of negative change and total of 24.75 Mt carbon was lost during 1984-1994 and 21.35 Mt carbon during 1991-94 at a rate of 2.48 Mt yr<sup>-1</sup> and 5.35 Mt yr<sup>-1</sup> carbon, respectively.

Fang *et al.* (2007) studied the biomass production and carbon sequestration potential of 10 years poplar plantations with different management patterns *i.e.* four planting density (1111, 833, 625 and 500 stems ha<sup>-1</sup>) and three poplar clones (NL-80351, I-69 and I-72). Based on the model of total biomass production developed, total plantation biomass production was significantly different in the plantations. The ranking of the plantation biomass production by planting density was 1111>833 >625>500 stems ha<sup>-1</sup>, and by components was stem > root > branch > leaf for all plantations. At 10 years, the highest total biomass in the plantation of 1111 stems ha<sup>-1</sup> reached about 146 t ha<sup>-1</sup>, which was 5.3 per cent, 11.6 per cent and 24.2 per cent, higher than the plantations of 833, 625 and 500 stems ha<sup>-1</sup>, respectively. The annual increment of biomass production over 10 years differed significantly among initial planting density and stand ages (p<0.01), but no significant difference was observed from age 7 to 10. Mean carbon concentration among all biomass components

ranged from 42-50 per cent, with the highest carbon concentrations in stems and the lowest in leaves.

Jina *et al.* (2008) studied the rate of carbon sequestration of degraded and non-degraded oak and pine forest of central Himalaya. They reported that in degraded and non-degraded sites of ban oak, the rate of carbon sequestration potential (CSP) was 1.47 and 6.23 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. Whereas, in the chir pine forest the rate of CSP was 1.07 and 6.66 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively.

Kishwan *et al.* (2009) reported that during 1995-2005, carbon stocks stored in Indian forests have increased from 6244.78 to 6621.55 million tons (Mt), registering an annual increment of 37.68 Mt C = 138.15 Mt CO<sub>2</sub> eq. This annual removal of CO<sub>2</sub> by forests is enough to neutralize 9.31 per cent of India's total annual emissions of 2000. Estimates showed that the continued removal of CO<sub>2</sub> by forests would still be able to offset 6.35 per cent and 4.87 per cent of the projected annual emissions in 2010 and 2020. Afforestation and reforestation of 6 million hectares of degraded forest land under National Mission with participation of Joint Forest Management Committees (JFMC's) would be able to add another 18 Mt C = 66 Mt CO<sub>2</sub> eq. by 2020. Even if half of the biomass increment (6 Mt) is removed annually on a substantial basis from 2025 onwards, the emission removal capability of forestry sector would still be able to offset every year 5.02 per cent of the 2020 level emissions.

Jana *et al.* (2009) studied the carbon sequestration rate and aboveground biomass carbon potential of four young species *i.e.* *Shorea robusta*, *Albizia lebbek*, *Tectona grandis* and *Artocarpus integrifolia*. The carbon sequestration rate (mean) from the ambient air during winter season as obtained by *Shorea robusta*, *Albizia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 11.13, 14.86 and 2.57g ha<sup>-1</sup> in overcast skies and 4.22 g ha<sup>-1</sup>, respectively. The annual carbon sequestration rate from ambient air were estimated at 8.97 t C ha<sup>-1</sup> by *Shorea robusta*, 11.97 t C ha<sup>-1</sup> by *Albizia lebbek*, 2.07 t C ha<sup>-1</sup> by *Tectona grandis* and 3.33 t C ha<sup>-1</sup> by *Artocarpus integrifolia*. The percentage of carbon content (except root) in the aboveground biomass of *Shorea robusta*, *Albizia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 47.45 per cent, 47.12 per cent, 45.45 per cent, and 43.33 per cent, respectively. The total aboveground biomass carbon stock per hectare as estimated for *Shorea robusta*, *Albizia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 5.22, 6.26, 7.97 and 7.28 t C ha<sup>-1</sup>, respectively in these forest stands.

Nizami *et al.* (2009) estimated carbon stocks in sub-tropical pine (*P.roxburghii*) forests at two sites, Ghoragali and Lehterar, of Pakistan as  $126\pm 2.94$  and  $99\pm 1.58$  t ha<sup>-1</sup>, respectively.

Sharma (2009) studied the distribution of biomass in different land uses, *viz.*, chir pine, ban oak, deodar, other broadleaved, culturable and un-culturable land uses, distributed in five forest ranges *i.e.* Dharampur, Parwanoo, Solan, Kandaghat and Subathu along altitudinal gradient from 900 to 2100 m of Solan Forest Division, Himachal Pradesh. The results revealed that out of 1.07 Mt of total biomass in the division, the chir pine land use contributes 36.63 per cent, ban oak 32.78 per cent, other broadleaves 28.94 per cent, deodar 1.15 per cent and culturable land 0.48 per cent. Along altitudinal gradient, it was 44.89 per cent in 1500-1800 m, 42.38 per cent in 1200-1500 m, 10.35 per cent in 1800-2100 m and 2.36 per cent in 900-1200 m elevation. The Dharampur Forest Range accounted for 31.60 per cent, Parwanoo 27.38 per cent, Solan 25.77 per cent, Kandaghat 11.22 per cent and Subathu 4.01 per cent of the total biomass.

Sharma *et al.* (2010) studied the carbon stocks of some major forest types of Garhwal Himalaya and found that values of above ground biomass density varied between 27.28 and 98.85 Mg ha<sup>-1</sup>. Among the conifer dominated forest types, value of total C density varied between 73.30 and 245 C Mg ha<sup>-1</sup>, whereas among the broad leaved dominated forests it ranged between 59.20 and 159.38 C Mg ha<sup>-1</sup>.

Juan *et al.* (2010) studied biomass and carbon stocks of *Pinus patula* and *Tectona grandis* stands in tropical forest plantations of different development stages in combination with inventory assessments. The information was obtained from individual trees in different development stages in 54 patula pine plots and 42 teak plots. The total carbon obtained was 99.6 Mg ha<sup>-1</sup> in patula pine and 85.7 Mg ha<sup>-1</sup> in teak forests. Carbon storage in trees was similar between patula pine and teak plantations; Carbon storage in trees represents 37 per cent and 60 per cent of the total carbon content in patula pine and teak plantations, respectively.

Zhu *et al.* (2010) estimated C stocks in vegetation, detritus, and soils of 22 forest plots along an altitudinal gradient from 700-2,000 m to quantify altitudinal changes in carbon storage of major forest ecosystems in Mt Changbai, Northeast China. Total ecosystem

average C density was 237 t C ha<sup>-1</sup> (ranging from 112 to 338 t C ha<sup>-1</sup>) across all the forest stands, of which 153 t C ha<sup>-1</sup> (52–245 t C ha<sup>-1</sup>) was stored in vegetation biomass, 14 t C ha<sup>-1</sup> (2.2–48 t C ha<sup>-1</sup>) in forest detritus (including standing dead trees, fallen trees, and floor material), rest in soil organic matter (1m depth). Among all the forest types, the lowest total vegetation C density occurred in *Betula ermanii* forest, whereas the highest detritus C density was observed in *Picea* and *Abies* forests. The C density of the three ecosystem components showed distinct altitudinal patterns: with increasing altitude, vegetation C density decreased significantly and detritus C density first increased and then decreased.

Metzker *et al.* (2011) conducted a study in five permanent monitoring plots (1 ha each) in the Rio Doce State Park (RDSP), the most continuous Atlantic Forest remaining in Minas Gerais, Brazil and considered one of the world's hotspots. The above ground biomass ranged from 201 Mg ha<sup>-1</sup> in the primary forest to 92 Mg ha<sup>-1</sup> in the secondary forest. The recruitment rate (1.8) was higher than the mortality rate (1.1); however, the average diameter of dead trees was higher than that of the recruited trees. Notwithstanding this result, the internal diametric increment (in growth) in RDSP was compensated by the biomass loss of dead trees, producing positive growth in the annual biomass and increasing their carbon stocks by 1.0 Mg C ha<sup>-1</sup>yr<sup>-1</sup>.

Sharma *et al.* (2011) studied carbon stock of seven major forest types of temperate zone of Garhwal Himalaya to understand the effect of slope aspects on carbon (C) density and make recommendations for forest management based on priorities for C conservation/sequestration, tree density and biomass 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*. They reported that total carbon density ranged between 77.3 C Mg ha<sup>-1</sup> on SE aspect (*Quercus leucotrichophora* forest) and 291.6 C Mg ha<sup>-1</sup> on NE aspect (moist *Cedrus deodara* forest).

Gairola *et al.* (2011) assessed live tree biomass and C stocks in moist temperate Mandal-Chopta forest of Chamoli District, Garhwal Himalaya, Uttarakhand, India. They reported that total live tree biomass density (TBD) varied from 215.5 to 468.2 Mg ha<sup>-1</sup> and tree carbon density (TCD) varied from 107.8 to 234.1 Mg C ha<sup>-1</sup>. The average values of TBD and TCD for the study area were 356.8 ±83.0 Mg ha<sup>-1</sup> and 178.4 ± 41.5 Mg C ha<sup>-1</sup> respectively. Comparative assessment of the data suggests that these values are similar to the

earlier recorded values of C and biomass density for other forests of Garhwal Himalaya and Uttarakhand, but are higher than those reported from most of the other parts of the country.

Rao *et al.* (2012) estimated standing biomass and carbon stocks in linear, scattered and block structures of trees outside forests through non-destructive method in Kadapa district of Andhra Pradesh. A total of 39.1 ha area was sampled in the district for this purpose. The study recorded a total of 20 species from linear plots, 37 species from scattered plots and 22 species in block plots with mean stem density of 251, 120 and 80.5 individuals ha<sup>-1</sup> and mean basal area is 21.19, 11.30 and 7.90 m<sup>2</sup> ha<sup>-1</sup> respectively. The growing stock density is 16.95, 60.64 and 3.58 m<sup>3</sup> for linear, scattered and block structures, respectively and standing biomass density values are 124.97±256.02 Mg ha<sup>-1</sup>, 36.91±35.03 Mg ha<sup>-1</sup> and 29.57±14.66 Mg ha<sup>-1</sup> for the same. The carbon stocks values in linear structure is 59.36±121.61 Mg ha<sup>-1</sup>; scattered structure, 17.53±16.64 Mg ha<sup>-1</sup> and block structure, 14.04±6.96 Mg ha<sup>-1</sup>. The girth class distribution has shown that linear and scattered structures >150 cm GBH class contributes higher values of growing stock, standing biomass and carbon stocks.

Kumar *et al.* (2013) assessed the carbon stock variation of *Pinus roxburghii* forest along different altitudes *i.e.* 1100, 1300 and 1500 m msl of Garhwal Himalaya, India. They reported that tree density of this forest ranged between 590 tree ha<sup>-1</sup> (upper altitude) to 640 tree ha<sup>-1</sup> (lower altitude). The highest total carbon density (TCD) of above and belowground carbon was 66.33 ± 29.92 Mg ha<sup>-1</sup> at lower altitude followed by 57.64 ± 16.75 Mg ha<sup>-1</sup> in middle altitude and 52.92 ± 6.52 Mg ha<sup>-1</sup> in upper altitude.

Pala *et al.* (2013a) assessed biomass and carbon stock estimation of Sem Mukhem sacred forest in district Tehri of Garhwal Himalaya, Uttarakhand, India. They reported that the highest values of below ground biomass density, total biomass density and total carbon density were (34.81±1.68) Mg ha<sup>-1</sup>, (168.26±9.04) Mg ha<sup>-1</sup> and (84.13±4.18) Mg ha<sup>-1</sup> for *Pinus wallichiana*. Overall values of total biomass density and total carbon density calculated were 1549.704 Mg ha<sup>-1</sup> and 774.77 Mg ha<sup>-1</sup>, respectively.

Pala *et al.* (2013b) assessed biomass and carbon stock of Chandrabadni sacred grove, located in temperate zone in Tehri district of Garhwal Himalaya. They reported a tree density of 688 trees ha<sup>-1</sup>, total carbon density of 587.19 Mg ha<sup>-1</sup>, and total biomass density of 1159.90

Mg ha<sup>-1</sup>. Highest tree density was found in *Quercus leucotrichophora*, while highest biomass and carbon density was observed for *Cedrus deodara*.

Shah *et al.* (2014) studied carbon stocks of chir pine in subtropical forest, covering 33 compartments in two forest ranges of Solan district of Himachal Pradesh, India. The total carbon density was 247.87 t ha<sup>-1</sup> in chir pine forest.

Wani *et al.* (2014) attempted to estimate growth, biomass production, carbon stock and carbon dioxide mitigation potential of 19 years old *Cedrus deodara* plantation under different diameter classes. The volume of trees in the stand varied from 0.072 to 0.596 m<sup>3</sup>. The average dry stem biomass varied between 27.60 to 226.67 kg, branch dry biomass between 7.88 to 64.14 kg, needle dry biomass between 1.57 to 18.19 kg, total above ground dry biomass between 37.06 to 309.0 kg and root dry biomass varied from 8.88 to 77.25 kg. The stem carbon varied from 12.80 to 105.15 kg, branch carbon between 3.62 to 29.53 kg, needle carbon between 0.67 to 7.78 kg, root carbon between 4.09 to 35.66 kg and total carbon between 21.18 to 178.12 kg. The stem carbon dioxide mitigation potential varied from 46.83 to 384.84 kg, branch from 12.91 to 108.07 kg, needle from 2.44 to 28.47 kg, root from 14.99 to 130.51 kg and total carbon dioxide mitigation varied from 73.92 to 651.91 kg.

Ahmad *et al.* (2014) estimated the biomass of the native tree species *Picea smithiana* in Kumrat valley. The results revealed that the mean biomass of stem was 1919.64 ± 244.44, while the mean biomass of branches, twigs, foliage and root was 299.26 ± 32.32, 55.46 ± 5.57, 65.90 ± 2.87 and 435.81 ± 77.15 kg respectively. In total biomass the contribution of stem biomass was 66.28 per cent, while the contribution of branches, twigs, foliage, and roots was 11.28, 2.193, 2.62 and 17.05 percent. The mean above ground biomass was 2104.055 ± 264.814 kg while the mean total biomass was 2539.87 ± 341.80 kg.

Ahmad *et al.* (2014) estimates total biomass and carbon stocks of the coniferous forest of Dir Kohistan. The biomass and carbon stocks were assessed by using inventory data. The results indicated that estimated average biomass was 258.98 Mg ha<sup>-1</sup>. The mean carbon stock was 129.49 Mg ha<sup>-1</sup>. The total calculated biomass from coniferous forest was 16.12 Tg. The total carbon stored by forest was 8.06 Tg.

Dar and Sundarapandian (2015) studied carbon stock of trees in seven forest types, viz., *Populus deltoides*, *Juglans regia*, *Cedrus deodara*, *Pinus wallichiana*, mixed coniferous,

*Abies pindrow*, and *Betula utilis* in temperate forests of Anantnag district of Jammu and Kashmir, India. The results showed that the tree biomass ranged from 100.8 Mg ha<sup>-1</sup> in *Betula utilis* forest to 294.8 Mg ha<sup>-1</sup> for the *Abies pindrow* forest. The understory biomass ranged from 0.16 Mg ha<sup>-1</sup> in *Populus deltoides* forest to 2.36 Mg ha<sup>-1</sup> in *Pinus wallichiana* forest. The total ecosystem carbon stocks varied from 112.5 to 205.7 Mg C ha<sup>-1</sup> across all the forest types.

Amir *et al.* (2015) assessed biomass and carbon stock in pure *Cedrus deodara* forest of Kumrat Valley Dir Kohistan. The result showed that average tree density was 238 trees ha<sup>-1</sup>. Average stem volume was measured as 1839.41 m<sup>3</sup> ha<sup>-1</sup>. The mean stem biomass was 857.40 t ha<sup>-1</sup>. The mean total tree biomass was estimated 1281.26 t ha<sup>-1</sup>. Total carbon (above and below ground biomass) in *Cedrus deodara* forest was 640.63 t ha<sup>-1</sup>.

Wani *et al.* (2016) estimated undergrowth biomass carbon variability under different strata in temperate Himalayan region and conclude results that shrub biomass carbon was found to be highest under Deodar (closed) strata 0.65 t ha<sup>-1</sup> (± 0.48) and minimum under Deodar (open) 0.17 t ha<sup>-1</sup> (± 0.20) with p<0.05. For herb biomass carbon the highest values were observed under Fir-Spruce (closed) 1.32 t ha<sup>-1</sup> (± 0.46) and minimum under Blue Pine (open) 0.59 t ha<sup>-1</sup> (± 0.49) with p<0.05. The open forests were subjected to a high biotic interference as a result of uncontrolled grazing, fuel wood and fodder collection that led to the lower values for undergrowth biomass carbon. However, these strata were found to have a promising potential to fix atmospheric carbon into herbs and shrubs once the conservative interventions are brought into practice.

Rajput *et al.* (2017) studied factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate northwestern Himalaya and reported that maximum total biomass of 404.35 Mg C ha<sup>-1</sup> was accumulated by forest landuse and followed a decreasing trend in the order as: forest > silvi-pasture > agri-horticulture > horticulture > agriculture. Similar trends were also seen with respect to biomass carbon (C) density and C-sequestration potential of different land uses. Biomass and carbon density potential increased with the increase in the altitudinal range from 1100–1400 to 2000–2300 m a.m.s.l. The rate of C-sequestration potential increased from 1100 to 2000 m and then declined at 2000–2300 m a.m.s.l. Maximum carbon density (393.29 Mg C ha<sup>-1</sup>) of both plant as well as soil was displayed by forests situated at altitudinal gradient of 2000–2300 m a.m.s.l.

## 2.4. SOIL CARBON STOCKS

Total organic matter accumulated in soils constitutes a major portion of the world's fixed carbon reserves. Bohn (1976) estimated that the soil contains approximately  $30 \times 10^{14}$  kg organic carbon. Distribution of this organic matter among soil types is highly variable and generally not easily predictable from above ground vegetation types. The quantity of organic material retained within the soil matrix is the difference between total biomass production and decomposition.

Soil is the largest pool of terrestrial carbon, estimated as 2200 Pg; tropical top soils contain about 13 per cent of world's soil carbon (Young 1977). Estimation of biomass and sequestered carbon on farm forest plantations in northern New South Wales, Australia (Specht and West 2003) revealed that organic carbon content of soil below plantations and adjacent pasture paddocks decline with time following establishment.

Ruecker *et al.* (1980) while studying the effect of trees on the amelioration of degraded soils observed that in eastern Spain natural tree establishment on degraded soils significantly increased soil organic carbon content in the 0-10 cm layer after 30 years of growth. In north-eastern Sudan, Alstad and Vctas (1994) observed improvement in soil quality due to increased SOC content under the stand of *Acacia tortilis*.

Trees improve soil productivity through ecological and physico-chemical changes that depend upon the quantity and quality of litter reaching soil surface and rate of litter decomposition and nutrient release (Meentemeyer and Berg 1986).

Post *et al.* (1990) reported that the ratio between SOC and biomass carbon is 2.5 to 3 times in the terrestrial ecosystem. According to Adger *et al.* (1991) the high forests in Britain contained 30.4 million t C in coniferous stands and 50.5 million t C in broad leaved wood lands.

Gracia *et al.* (1990) studied the effect of slash and burn management on soil aggregates, organic carbon and nitrogen in a tropical deciduous forest soils and reported that approximately 80 per cent of the total carbon and nitrogen content in the soil was due to slash and burn in these forests. They also stated that slash and burn activities did not destroy micro aggregates but the soil organic carbon associated with micro aggregates decreased by 32 per cent due to combustion during burning. Knowalenko and Lwarson, 1978 observed that CO<sub>2</sub>

evolution was greater from clay loam soil ( $6.2 \text{ Kg CO}_2 \text{ ha}^{-1} \text{ day}^{-1}$ ) than sandy soil ( $3.3 \text{ CO}_2 \text{ Kg ha}^{-1} \text{ day}^{-1}$ ).

Global warming and its effect on soils in terms of SOC management have led to several quantitative estimates for global C content in the soils (Eswaran *et al.* 1999; Batjes 1996 and Kimble *et al.* 1990).

The greenhouse effect has been of great concern during the past one decade which has led to several studies on the quality, kind, distribution and behaviour of SOC (Eswaran *et al.* 1993; Batjes 1996 and Velayutham *et al.* 2000). Deforestation, changes in land use and predicted climate change has been reported to alter the amount of organic carbon held in the superficial soil layer (Batjes 1996).

Farm forestry plantations raised on farmer's fields on marginal and sub marginal lands with low levels of soil carbon had been reported to attain high SOC and the soil carbon in such area raises normal forest soil status in a period of 15-20 years (Sampson and Sedja 1997).

Conversion of natural forests to agriculture in the humid tropics had been reported to reduce ecosystem carbon storage due to removal of above ground biomass and a gradual subsequent reduction in soil carbon. Whereas, forest conversion to well managed grasslands was found to increase soil carbon storage, after an initial decline (Van *et al.* 1997).

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 2002). Soil organic matter can also increase or decrease depending on numerous factors, including climate, vegetation type, nutrient availability, disturbance, land use and management practices (Six and Jastro 2002 and Baker 2007).

The release of nutrients from litter decomposition is a fundamental process in the initial biogeochemical cycle of an ecosystem, and decomposers recycle a large amount of carbon that is bounded in the plants or trees (Sevgi and Tecimcn 2008).

To sustain the quality and productivity of soils, knowledge of SOC in terms of its amount and quality is essential. The first comprehensive study of organic carbon status in

Indian soils was conducted by collecting 500 soil samples from different cultivated fields and forests with variable rainfall and temperature patterns. However, the study did not make any estimate of the total carbon reserves in the soils (Jenny and Raychaudhary 1960). The first estimate of the organic carbon stock in Indian soils was 24.3 Pg (1 Pg = 10<sup>15</sup> g) based on 48 soil samples (Gupta and Rao 1984).

Sharma (1991) and Malik (1992) conducted a study on soils under chirpine in Solan forest division of Himachal Pradesh and found organic carbon in the range of 0.17 to 3.37 and 0.33 to 3.27 per cent, respectively.

Tiessen *et al.* (1992) studied the carbon sequestration and its turnover in semi arid savannas and dry forests in north-east Brazil and West Africa. In north east Brazil about 40 per cent of the land has near climax native vegetation, less than 10 per cent of the area was affected by shifting cultivation with an average cycle of 5 years arable use, followed by 20 years or more recovery. Litter fall contribute around 1-2 Mg C ha<sup>-1</sup> yr<sup>-1</sup> was partially decomposed and partially consumed by animals resulting in low average soil C levels near 8 g kg<sup>-1</sup> or 20 Mg C ha<sup>-1</sup> under cultivation. Carbon sequestration decreased and soils used to lose approximately half their carbon stock, before being abandoned. In West Africa 50-70 per cent of the land was under a management regime with minimal carbon returns to the soils.

Singh *et al.* (1995) compared the bamboo forest soil with the soils of natural forest and jhum fallow in Jorhat district of Assam and found that total NPK and organic carbon were highest in natural forest followed by bamboo forest and lowest content were observed in jhum fallow. They further observed that in bamboo soil the concentration of all the nutrients including SOC was fairly high in the upper soil layers, which followed a gradual decrease with increase in soil depth.

In western Nigeria, Lal (1996) observed that the soil organic carbon (SOC) of the surface 10 cm layer declined by about 50 per cent within 10 years after deforestation and cultivation.

Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter and root residues into the soil. There is a large potential of sequestering carbon in soil and vegetation by adopting suitable agroforestry systems on salt affected soils (Singh and Singh 1997). In Haryana, a large increase in soil organic carbon content by

reclamation of sodic soils through growing *Prosopis juliflora* was recorded by (Bhojvaid *et al.* 1998).

Lal (2002) reported that most soils in mid Western USA have lost 30 to 50 per cent of their original pool or 25 to 40 Mg C ha<sup>-1</sup> upon conversion from natural to agricultural ecosystems. About 60 to 70 per cent of the carbon thus depleted can be resequenced through adoption of recommended soil and crop management practices. The gross rate of soil organic carbon sequestration ranges from 500-800 Kg ha<sup>-1</sup> yr<sup>-1</sup> in cold and humid regions and 100-300 Kg ha<sup>-1</sup> yr<sup>-1</sup> in dry and warm regions. And there is also a large potential to sequester soil inorganic carbon in arid and semi arid regions.

Guo and Gifford (2002) reported that when pasture changes to a secondary broad leaf forest, soil carbon stock is not affected but when arable land is converted to coniferous forest an increase in soil C is usually apparent. The soil C pool is determined by the balance between C input by litter fall and rhizodeposition on the one hand and the release of C during decomposition on the other side. The turnover of SOM (Soil Organic Matter) depends on the chemical quality of the C compound (labile or stable C), site condition (climate), and soil properties (clay content, soil moisture, pH, nutrient status. Several of these factors are directly influenced by forest management.

Chhabra *et al.* (2003) measured soil organic carbon (with depth) containing information on location, soil type, texture, measured/estimated bulk density and forest type in Indian forests. It was used for estimating soil organic C densities for various forest types for two-depth classes (0-50 and 0-100 cm). The mean soil organic C density estimates for top 50 cm based on 175 observations ranged from 37.5 t ha<sup>-1</sup> in tropical dry deciduous forest to 92.1 t ha<sup>-1</sup> in littoral and swamp forest. The mean soil organic C density estimates based on 136 observations ranged from 70 t ha<sup>-1</sup> in tropical dry deciduous forest to 162 t ha<sup>-1</sup> in montane temperate forest for top 1 m soil depth. The estimated soil organic C densities were combined with remote sensing based recent forest area inventory (64.20 M ha<sup>-1</sup>) by Forest Survey of India to arrive at estimates of soil organic C pool by major forest types of India. The total soil organic C pools in Indian forests have been estimated as 4.13 Pg C in top 50 cm and 6.81 Pg C in top 1 m soil depth.

Indian soils are largely carbon depleted but can be brought back to their native carbon carrying capacity by reforestation. Moreover, wastelands in India cover more than 100

million ha of which 70 per cent is low in carbon. These soils have been reported to have relatively high potential for accumulating organic carbon in vegetation and soil by growing suitable trees along with proper soil conservation measures (Rai and Sharma 2003).

Sun *et al.* (2004) investigated variation in carbon stock in soils and detritus (forest floor and woody debris) in chronosequences that represent the range of forest types in the US Pacific Northwest. Stands range in age from <13 to >600 years. Soil carbon, to a depth of 100 cm, was highest in coastal Sitka spruce/western hemlock forests ( $36 \pm 10 \text{ kg C m}^{-2}$ ) and lowest in semiarid ponderosa pine forests ( $7 \pm 10 \text{ kg C m}^{-2}$ ). Forests distributed across the Cascade Mountains had intermediate values between 10 and  $25 \text{ kg C m}^{-2}$ . Soil carbon stocks were best described as a linear function of net primary productivity ( $r^2=0.52$ ), annual precipitation ( $r^2=0.51$ ), and a power function of forest floor mean residence time ( $r^2=0.67$ ). The highest rates of soil and detritus carbon turnover were recorded on mesic sites of Douglas-fir/western hemlock forests in the Cascade Mountains with lower rates in wetter and drier habitats, similar to the pattern of site productivity. The relative contribution of soil and detritus carbon to total ecosystem carbon decreased as a negative exponential function of stand age to a value of 35 per cent between 150 and 200 years across the forest types. These age dependent trends in the portioning of carbon between biomass and necromass were not different among forest types. Model estimates of soil carbon storage based on decomposition of legacy carbon and carbon accumulation following stand-replacing disturbance showed that soil carbon storage reached an asymptote between 150 and 200 years, which has significant implications to modeling carbon dynamics of the temperate coniferous forests following a stand-replacing disturbance.

Soil can act as a sink or source for carbon in the atmosphere depending on the changes happening to soil organic matter. Equilibrium between the rate of decomposition and rate of supply of organic matter is disturbed when forests are cleared and land use is changed (Lal 2004). Forest soils are one of the major carbon sinks on earth, because of their higher organic matter content (Dev 2005).

Total organic matter accumulated in the soil constitutes a major portion of the world's soil carbon reserves. The distribution of organic matter among soil types is highly variable and generally not easily predictable from above ground vegetation type. Decreased soil carbon content with time in agricultural plot in arid region with a loss of SOC by 56 per cent during 5 years period was studied by Singh *et al.* (2005). They further reported that integration of

trees reduced SOC loss, which was 3.2 per cent under *Embllica officinalis*, 22 per cent under *Hardwickia binnata* and 35.5 per cent under *Colophospermum mopen* based agroforestry system as compared to 56 per cent under agricultural plots.

Soil organic carbon (SOC) and total nitrogen stocks in 0-0.3 and 0.3-1 m soil layers were estimated under three vegetation communities viz., *Schefflera-Hagenia*, *Hypericum-Erica-Schefflera* and *Erica arborea* (shrub size) at different topographic aspects (east, west, north and south facing) on the Bale Mountains in the south-eastern highlands of Ethiopia. The results showed that SOC and total N in the top 0.3 m depth varied significantly among vegetation communities and aspects. At all aspects studied, the overall mean SOC and total N stocks to a depth of 1 m ranged from 32.67 to 46.03 kg C m<sup>-2</sup> and 2.89 to 3.61 kg N m<sup>-2</sup> among the vegetation communities. The overall mean SOC and total N stocks to a depth of 1 m varied from 35.13 to 44.97 kg C m<sup>-2</sup> and 2.90 to 3.75 kg N m<sup>-2</sup> among aspects. The study pointed out that vegetation community types and microclimatic differences induced by topographic aspects were found to be important factors for the significant variations in SOC and total N stocks in the Bale Mountains. The study revealed that about 45 per cent of the SOC stock was held in the top 0.3 m of the soil layer, and hence this layer was projected to emit CO<sub>2</sub> to the atmosphere or exposed to various disturbances, like deforestation, grazing and cultivation (Fantaw *et al.*, 2006).

Melo and Durigan (2006) studied the carbon sequestration of native and planted riparian forests growing in different soil conditions (cerrado and forest soils) with ages ranging from 1 to 28 years, in the Paranapanema valley, Sao Paulo State Brazil. The carbon storage in the mature native stands was 79.7 t/ha in forest soils and 50 t /ha in cerrado soil. That means the carbon storage potential was approximately 60 per cent higher in the fertile and clayish forest soils than in the sandy and poor cerrado soils in that region.

After 10 years of conversion of pasture land to Australian pine (*Casuarina* spp.) forests in the reclaimed mine soils of southern Ohio the SOC pool increased by 6 Mg ha<sup>-1</sup> in the top 50 cm layer. However, the nitrogen pool in the top 50 cm was not affected by land use conversion from pasture to Australian pine. Conversion to Black locust increased the SOC pool in the top 50 cm by 24 Mg ha<sup>-1</sup> (42 per cent) while the N pool increased by 10 per cent under Black locust in 10 years. Establishment of tree plantation has been reported to have a greater potential for SOC sequestration than pastures in the reclaimed mine soils (Ussiri *et al.*, 2006).

Tangsinmankong *et al.* (2007) examined carbon stocks in soil of mixed deciduous forest and teak plantation of 6, 15 and 24 years of age. The study was conducted in 2 areas; mixed deciduous forest at Huay Kha Khaeng Wildlife Sanctuary and teak plantation of Thai Plywood Co., Ltd. in Lansak District, Uthaitхани Province. The soil samples were collected in September 2003. Results revealed that soil organic carbon from all sites decreased generally with the increasing depth. From the surface soil down to the level of 100 cm. The highest carbon stocks in soil were recorded at the 6-year-old teak plantation followed by the 24 and 15-year-old teak plantations and mixed deciduous forest 157.03, 105.67, 78.78 and 70.96 t C ha<sup>-1</sup> respectively. The dissimilarity of soil organic carbon may be due to forest fire, forest management and topography. Ramchandran *et al.* (2007) estimated 3.48 Tg soil carbon in the natural forests in Eastern Ghats of Tamil Nadu, India.

The Himalayan zones, with dense forest vegetation, cover nearly 19 per cent of India and contain 33 per cent of SOC reserves of the country (Bhattacharyya *et al.* 2008). The forests are recognized for their unique conservation value and richness of economically important biodiversity. Managing these forests may be useful technique to increase soil carbon status because the presence of trees affects carbon dynamics directly or indirectly.

Jina *et al.* (2008) studied the rate of carbon sequestration of degraded and non-degraded oak and pine forest of central Himalaya. He reported that in degraded and non-degraded sites of ban oak the rate of CSP was 1.47 and 6.23 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. Whereas, in the chir pine forest the rate of CSP was 1.07 and 6.66 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively.

Kaonga and Smith (2009) studied tree and soil C stocks and their response to different tree species and clay contents in improved fallow of eastern Zambia. During the study significant difference in above ground tree C stocks and net organic C (NOC) intake rates across coppicing tree species at Msekera and Kalunga were observed. Above ground C stock ranged from 2.9 to 9.8 t ha<sup>-1</sup> equivalent to NOC intakes of 0.8-4.9 t ha<sup>-1</sup> yr<sup>-1</sup>. SOC stock in non coppiced fallows at Kalichero and Msekera differed significantly across treatments. SOC stocks of 200 cm soil layer ranged from 64.7 t C ha<sup>-1</sup> under non coppicing fallow at Kalunga to 184 t ha<sup>-1</sup> in 10 year old coppicing fallow at Msekera. The study recorded that tree and soil C stocks in improved fallow can be increased by planting selected tree species on soils with high clay content.

Kumar (2010) while studying the distribution, growth and biological yield potential of bamboos in Himachal Pradesh found organic carbon in the range of 2.43-3.0 per cent which decreased with increasing soil depth.

Singh *et al.* (2010) evaluated the effect of pure stands of tree species and poplar-based agroforestry system on soil organic carbon (SOC) and available N, P and K contents. They observed that soil organic carbon and available nutrients in the surface were significantly higher in the surface soil (0-15 cm) than the lower depths, irrespective of tree species. Organic carbon and available nutrients were significantly more under all the tree species compared to control in the surface layer. Organic carbon increased by 90.3 per cent under Siris followed by Kikar (84.5 per cent), Sissoo (82.2 per cent) and Subabul (80.8 per cent) over control. In poplar-based agroforestry system, the average content of organic carbon was higher by 22.2 per cent than pure pearl millet-wheat rotation. Further, the interaction effects of soil depths and cropping systems were significantly related to organic carbon.

A study was undertaken by Sharma *et al.* (2011) in seven major forest types of temperate zone of Garhwal Himalaya to understand the effect of slope aspects on carbon (C) density. 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* were assessed. Total carbon density ranged between 77.3 CMg ha<sup>-1</sup> on SE aspect (*Quercus leucotrichophora* forest) and 291.6 C Mg ha<sup>-1</sup> on NE aspect (moist *Cedrus deodara* forest). SOC varied between 40.3 C Mg ha<sup>-1</sup> on SW aspect (Himalayan *Pinus roxburghii* forest) and 177.5 CMg ha<sup>-1</sup> on NE aspect (moist *Cedrus deodara* forest). Total C density (SOC+TCD) ranged between 118.1 C Mg ha<sup>-1</sup> on SW aspect (Himalayan *Pinus roxburghii* forest) and 469.1 C Mg ha<sup>-1</sup> on NE aspect (moist *Cedrus deodara* forest). SOC and TCD were significantly higher on northern aspects as compared with southern aspects.

Singh *et al.* (2011) studied two forest types: *Quercus leucotrichophora* and *Pinus roxburghii* in Garhwal Himalaya, for vegetation analysis and soil carbon stock along altitudinal gradient and soil depth. The soil carbon was assessed in each forest type by collecting soil samples from three different altitudes and depths. In both the forest types, soil carbon has positive relation with leaf litter production, density and basal cover of the forests which decreased significantly with increasing altitude and soil depth. The results indicated

that a change in vegetation type and a shift of vegetation belts as expected in most climate change scenario might have a profound impact on SOC in the Himalayas. Between the forests; oak forest soil had more capacity to sequester carbon compared to pine forest. The study further suggested that to enhance carbon sequestration potential, the forests should be managed by promoting more regeneration for high density and basal cover to mitigate future carbon level.

Chiti *et al.* 2012 studied contribution of the different forest types in sequestering and keeping soil C in the Mediterranean region, Spain. Quantification of the soil organic C (SOC) stock was done in the 0–30 and 0–100 cm depths of mineral soil, according to the main forest types—conifers, broadleaf and evergreen broadleaf and the different climatic zones of Spain, using a database comprising records of 1,974 pedons. Conifers and broadleaf forests show a trend in SOC stock distribution, with the stocks decreasing with increasing Mediterranean conditions. On average, in the 0–30 cm depth, the soils under broadleaved species store the highest amount of SOC ( $5.9 \pm 0.1 \text{ kg m}^{-2}$ ), followed by conifers ( $5.6 \pm 0.1 \text{ kg m}^{-2}$ ) and evergreen broadleaved species soils with an amount always lower ( $3.4 \pm 0.2 \text{ kg m}^{-2}$ ).

Dar and Sundarapandian (2013) examined Soil organic carbon (SOC) in the temperate forests of the Himalayas. Carbon stocks were assessed at different soil depths (0-10, 10-20 and 20-30 cm) in *Pinus wallichiana* and *Abies pindrow* forest types in the western Kashmir Himalayas of India. SOC stocks in these temperate forests were relatively low ranging from 50.37 to 55.38 Mg C ha<sup>-1</sup> in the top 30 cm of soils. Significantly greater SOC stock was observed in *Pinus wallichiana* forest type compared to *Abies pindrow* forest type. Tree density, shrub density, shrub biomass, herb biomass, and forest floor litter were greater in the *Pinus wallichiana* forest type as compared to *Abies pindrow* forest type, which could be the reason for greater accumulation of organic carbon in soil.

Panwar and Gupta (2013) studied organic carbon pool in the soils up to the depth of 0-30 cm under different forest types in Himachal Pradesh. Soil organic carbon (SOC) pool was also estimated in all forests sub-group types available in Himachal Pradesh. Maximum pool was in the soils under moist Alpine Scrub (73.26 tonnes ha<sup>-1</sup>) followed by Himalayan Moist Temperate Forests (55.20 tonnes ha<sup>-1</sup>), Himalayan Dry Temperate Forests (47.61 tonnes ha<sup>-1</sup>) and Sub-alpine Forests (45.67 tonnes ha<sup>-1</sup>) and the least was under Tropical Dry Deciduous Forests (36.04 tonnes ha<sup>-1</sup>). Moist Alpine Forests had maximum mitigation potential (2.03) and the least was in Tropical Dry Deciduous Forests (1.00). Maximum share

was occupied by Moist Alpine Scrub (28 per cent) followed by Himalayan Moist Temperate Forests (21 per cent), Himalayan Dry Temperate Forests (19 per cent), Sub-alpine Forests (18 per cent) and the least was occupied by Tropical Dry Deciduous Forests (14 per cent). SOC pool under Moist Alpine Forests was statistically significantly different from the SOC pool under Himalayan Moist Temperate Forests, Himalayan Dry Temperate Forests, Sub-alpine Forests and Tropical Dry Deciduous Forests.

Ahmad *et al.* (2015) studied soil organic carbon stocks at three depths (0–10, 10–20, and 20–30 cm) in seven altitudes dominated by different tree species *viz.*, *Populus deltoides*, 1550–1800 m; *Juglans regia*, 1800–2000 m; *Cedrus deodara*, 2050–2300 m; *Pinus wallichiana*, 2000–2300 m; mixed type, 2200–2400 m; *Abies pindrow*, 2300–2800 m; and *Betula utilis*, 2800–3200 m in temperate mountains of Kashmir Himalayas by Javid and Somaiah (2105). The mean range of soil organic carbon (SOC) stocks varied from 39.07 to 91.39 Mg C ha<sup>-1</sup> in *J. regia* and *B. utilis* forests at 0–30 cm depth, respectively. Among the forest types, the lowest mean range of SOC at three depths (0–10, 10–20, and 20–30 cm) was observed in *J. regia* (18.55, 11.31, and 8.91 Mg C ha<sup>-1</sup>, respectively) dominated forest, and the highest was observed in *B. utilis* (54.10, 21.68, and 15.60 Mg C ha<sup>-1</sup>, respectively) forest type. SOC stocks showed significantly ( $R^2=0.67$ ,  $P=0.001$ ) an increasing trend with increase in altitude. On an average, the percentages of SOC at 0–10-, 10–20-, and 20–30-cm depths were 53.2, 26.5, and 20.3 per cent, respectively. Bulk density increased significantly with increase in soil depth and decreased with increase in altitude.

Davood *et al.* (2015) studied soil organic carbon (SOC) estimation in temperate forest in the northern region of Kashmir Himalayas India. Physico-chemical properties of soil were quantified to assess soil organic carbon density and mitigation density at two soil depths (0-10 and 10-20 cms). He reported that conductance, moisture content, organic carbon and organic matter were significantly higher while as pH and bulk density were lower at Gulmarg forest site. SOC per cent ranged from 2.31± 0.96 at Gulmarg meadow site to 2.31 ± 0.26 in Gulmarg forest site. SOC stocks in these temperate forests were from 36.39 ±15.40 to 50.09 ± 15.51 Mg C ha<sup>-1</sup>.

Soil organic carbon stock estimation was conducted by Mahato *et al* (2016) in a Ghotla van Panchayat forest in district Pauri of Garhwal Himalaya, Uttarakhand, India. The mean value of organic carbon was 1.28 per cent, while the highest SOC percentage was

found in depth 0-10 cm ( $2.29 \pm 0.42$  per cent). The per hectare mean SOC stock for van Panchayat was 218.57t.

Krishan *et al.* (2017) investigated belowground carbon density in the forest ecosystem in temperate region of the Garhwal Himalaya. Investigators have studied the component wise belowground carbon flux in trees, soil organic carbon (SOC) and litter carbon of six different forest types for measuring total belowground carbon allocation (TBCA). The total belowground carbon of live trees varies 20.02 to 60.58 Mg C ha<sup>-1</sup>, whereas stock root carbon (14.01-38.27 Mg C ha<sup>-1</sup>), lateral roots carbon (5.24-17.57 Mg C ha<sup>-1</sup>) and fine root carbon (0.67-12.2 Mg C ha<sup>-1</sup>) in selected forest types were recorded. The maximum SOC was exhibited by *Abies pindrow* forest ( $110.83 \pm 5.04$  MgC ha<sup>-1</sup>), followed by *Pinus roxburghii* forest ( $108.22 \pm 13.03$  MgC ha<sup>-1</sup>), *Quercus floribunda* forest ( $97.37 \pm 7.64$  Mg C ha<sup>-1</sup>), whereas minimum SOC was recorded for *Cedrus deodara* forest ( $56.94 \pm 5.13$  Mg C ha<sup>-1</sup>). The maximum value of litter carbon was recorded for *Abies pindrow* forest ( $2.94 \pm 1.02$  Mg C ha<sup>-1</sup>), followed by *Quercus semecarpifolia* forest ( $2.22 \pm 0.33$  Mg C ha<sup>-1</sup>), *Quercus floribunda* forest ( $2.06 \pm 0.28$  Mg C ha<sup>-1</sup>), *Cedrus deodara* forest ( $1.86 \pm 0.26$  Mg C ha<sup>-1</sup>), *Quercus leucotrichophora* forest ( $1.44 \pm 0.27$  Mg C ha<sup>-1</sup>), *Pinus roxburghii* forest ( $0.84 \pm 0.10$  Mg C ha<sup>-1</sup>). Forest ecosystem in Garhwal Himalaya appears to be the most conducive soil-climatic environment for higher accumulation of SOC, thus helping in maintaining the soil quality. The study showed that belowground carbon stocks in *Abies pindrow* forests is maximum in carbon accumulation capacity, whereas *Cedrus deodara* forest has minimum BGC stocks.

Gandhi & Sundarapandian (2017) quantified soil organic carbon (SOC) stock on a large scale (30 ha<sup>-1</sup> plots) in the dry deciduous forest of the Sathanur reserve forest of Eastern Ghats. The SOC stock ranged from 16.92 to 44.65 Mg ha<sup>-1</sup> with a mean value of  $28.26 \pm 1.35$  Mg ha<sup>-1</sup>. SOC exhibited a negative trend with an increase in soil depth. A significant positive correlation was obtained between SOC stocks and vegetation characteristics *viz.*, tree density, shrub basal area, and herb species richness, while a significant negative correlation was observed with bulk density. The variation in SOC stock among the plots obtained in the present study could be due to differences in tree abundance, herb species richness, shrub basal area, soil pH, soil bulk density, soil texture etc.

## 2.5 SOIL PHYSICO-CHEMICAL PROPERTIES

Soil physico-chemical properties are related to field morphology and regulate to a considerable degree the qualitative and quantitative aspects of plant growth. Thus, the

importance of physico-chemical properties of soil in the domain of system analysis need to be taken into consideration.

Sharma and Tripathi (2003) conducted field experiment in Himachal Pradesh, on sandy loam soils to study the effect of resource constraints, *i.e.* nutrient and moisture on the growth performance of *Pinus roxburghii*. The amount of available nutrients decreased with the increase in the soil depth. The study indicated that plant growth parameters were positively and significantly correlated with available N, P and Ca in surface and subsurface soil layers.

A study was conducted (Guleria *et al.* 2003) in Solan (H.P.) to determine the maximum mineral contents of grasses under chir pine and open grasslands. He found that soil pH was approximately neutral in open grasslands but it was acidic under the natural forest.

Pande (2004) studied seasonal variations in soil nutrients and organic carbon under plantations of sal, teak, eucalyptus and chir pine. These variations were significantly greater for available K and P in all the plantations, more in pine soils for all the nutrients, excepting Ca. The available per cent nutrients of P, K, Ca and Mg were highest in eucalyptus and lowest in sal. The order of importance was teak>sal>eucalyptus>pine for N and teak>eucalyptus>sal>pine for organic carbon.

Singh *et al.* (2009) conducted a study in oak and pine forest for community composition and soil characteristics along altitudinal gradients of Garhwal Himalaya. The soil pH of oak forest was acidic while in pine forest it was slightly acidic. The soil organic carbon was higher in oak forest.

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

Mehraj *et al.* (2010) studied the soil of two forest type *i.e.* Oak (*Quercus leucotrichophora* A. Camus) and pine (*Pinus roxburghii* Sargent) of Garhwal Himalaya. Higher percent of moisture and water holding capacity was recorded in oak forest and lower in pine forest. The soil of oak forest was acidic and slightly acidic to pine forest. The average soil organic carbon (SOC) in oak forest was 2.19, followed by 1.63 in pine. The nitrogen for

oak and pine forests was 0.15 and 0.19 respectively. The available phosphorus in oak forest was higher (17.99 kg ha<sup>-1</sup>) than in pine forest (16.88 kg ha<sup>-1</sup>). The exchangeable potassium was 188.92 kg ha<sup>-1</sup> in oak forest and 166.43 kg ha<sup>-1</sup> in pine forest. The total nutrients generated by soils, as an ecosystem service in oak and pine forests were calculated for market costs. The total market cost of nutrients in oak was 1372.00 Rs. ha<sup>-1</sup> and in pine 1227.50 Rs. ha<sup>-1</sup>. The maximum contribution among the nutrients was of potassium followed by phosphorus and nitrogen. In both the forests, Oak forest was rich in nutrients than pine forest. Thus, oak forest should be preferred to protect, enhance their nutrients level for enhancing the forest ecosystem services.

Gairola *et al.* (2012) conducted studies on moist temperate forest of Mandal-Chopta area in the Garhwal region of Uttarakhand, India to assess the chemical properties of soils in relation to the forest structure and composition. Twelve forest types according to the altitude, slope aspect, and species composition were selected for the study. Chemical properties of the soil, *i.e.* total nitrogen (N), available phosphorus (P), available potassium (K), organic carbon (C), soil organic matter (SOM), pH and C:N ratios were analyzed for three different depths *viz.*, (i) 'Upper' (0–10 cm), (ii) 'Middle' (11–30 cm), and (iii) 'Lower' (31–60 cm) in all the selected forest types. Phytosociological and diversity parameters *viz.*, total basal cover (G ha<sup>-1</sup>), stem density (N ha<sup>-1</sup>), tree species richness (SR), Simpson concentration of dominance and Shannon–Wiener diversity index (H) were also calculated for each forest type. Values of N, P, K, C, SOM, C:N ratio and pH ranged from 0.17 to 0.45 per cent, 2.73 to 20.17 ppm, 40.67 to 261.17 ppm, 2.29 to 4.31 per cent, 3.95 to 7.43 per cent, 8.12 to 14.49 and 5.47 to 6.67, respectively. N showed a positive relationship with C and K. P was positively correlated with C and negatively correlated with altitude. P was higher in the soil of lower horizons of all the forest types. K was found to be positively correlated with altitude, C and N. pH of all the forest types was slightly acidic. C was comparatively higher in mixed broad-leaved forest types. No relationship between altitude and C was observed, which may be due to different composition of forest types along the altitudinal gradient and their differential decomposition rates. C content decreased with the depth of the soil. C showed positive correlation with N, P, and K. N showed a positive correlation with total basal area. K showed a negative correlation with species richness and pH showed no relationship with the phytosociological parameters.

Chaturvedi and Melkania (2013) measured the soil organic carbon (SOC) stock and soil characteristics in mixed oak and mixed pine forest for two year (2008-10) at different

altitudes of Kumaon Himalaya. The study revealed that soil organic carbon stock were 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<sup>-1</sup> in non degraded mixed oak forest site and 43.81 to 53.47 ton ha<sup>-1</sup> at degraded mixed pine forest site. P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, total nitrogen and C: N ratio were found to be higher in mixed oak forest than mixed pine forest.

Raina and Gupta (2013) estimated the fertility status of soil and sequestered organic carbon under different forest tree species covers viz., *Shorea robusta*, *Pinus roxburghii*, *Quercus leucotrichophora*, *Cedrus deodara*, *Picea smithiana* and *Abies pindrow* and Miscellaneous forests, in Gharwal region of Uttarakhand. Soils were well enriched by primary nutrients i.e. available nitrogen, phosphorus and potassium. Available nitrogen was higher under *P. smithiana* and *A. pindrow* followed by *C. deodara* and the least was under miscellaneous forests. In general, nutrients decreased with increasing soil depth under all the forest stands. Soil pH was mild acidic at all the depths under different forest stands. Exchangeable Ca, Mg, K and Na were higher in surface layer and decreased with increasing the depth. SOC stock was maximum *P. smithiana* and *A. pindrow* (138.01 t ha<sup>-1</sup>) followed by *C. Deodara* (122.63 t ha<sup>-1</sup>), *Q. Leucotrichophora* (109.37 t ha<sup>-1</sup>), *P. roxburghii* (66.04 t ha<sup>-1</sup>), *S. robusta* (65.26 t ha<sup>-1</sup>) and the least was in the soils under miscellaneous forests (65.02 t ha<sup>-1</sup>). Forests like *P. smithiana* & *A. pindrow*, *Q. leucotrichophora* and *C. deodara*, growing at higher altitudes have higher potential to store more organic carbon in the soils as compared to the forests, like *S. robusta*, *P. roxburghii* and miscellaneous situated at lower altitude.

Sharma *et al.* (2014) studied chemical properties of the soil, i.e. total nitrogen (N), available phosphorus (P), available potassium (K), organic carbon (C), soil organic matter (SOM), pH and C:N ratios to determine their relationship with altitude and phytosociological and diversity parameters, viz., total basal cover (Gha<sup>-1</sup>), stem density (N ha<sup>-1</sup>), tree species richness (SR), Simpson concentration of dominance and Shannon–Wiener diversity index (H) of various forest types of Mandal- Chopta area of Garhwal Himalayas. Values of N, P, K, C, SOM, C: N ratio and pH ranged from 0.17 to 0.45 per cent, 2.73 to 20.17 ppm, 40.67 to 261.17 ppm, 2.29 to 4.31 per cent, 3.95 to 7.43 per cent, 8.12 to 14.49 and 5.47 to 6.67, respectively. N showed a positive relationship with C and K. P was positively correlated with C and negatively correlated with altitude. P was higher in the soil of lower horizons of all the forest types. K was found to be positively correlated with altitude, C and N. pH of all the forest types was slightly acidic. C was comparatively higher in mixed broad-leaved forest

types. No relationship between altitude and C was observed, which may be due to different composition of forest types along the altitudinal gradient and their differential decomposition rates. C content decreased with the depth of the soil. C showed positive correlation with N, P, and K. N showed a positive correlation with total basal cover. While, K showed a negative correlation with species richness and Shanon-Wiener diversity showed no relationship with the phytosociological parameters.

Mahajan and Sharma (2015) studied soil physico-chemical properties at different elevation ranges from 900 m to 2100 m in Solan (H.P.). Soils along elevational classes showed that the values of bulk density increased with increase in elevation from 900-1200 m to 1800-2100 m. There was a decrease in per cent organic carbon with increase in soil depth at all the elevations. The soil organic carbon decreased with increase in elevation with minimum of 0.24 per cent at 1800-2100 m and maximum of 2.63 per cent at 900-1200 m elevation. Overall pH values varied from 6.00 to 6.90 and showed an increasing trend with soil depth. Available nitrogen varied from 271.33 kg ha<sup>-1</sup> (20-40 cm) to 533.20 kg ha<sup>-1</sup> (10-20 cm) at 900-1200 m elevation and showed a decreasing trend with increasing depth. Available phosphorus varied from 8.90 (20-40 cm) to 34.5 (10-20 cm) at elevation of 1200- 1500 m and decreased from 10-20 cm to 20-40 cm depth, as is in case of per cent organic carbon and available nitrogen. Available potassium showed an increasing trend with increase in soil.

Kumar and Sharma (2016) conducted studies on soil physico-chemical analysis of major forest communities in Chail wildlife sanctuary of Himachal Pradesh and concluded that Soil pH of Chail wildlife sanctuary ranged from 5.2-6.89. The mixed and oak + deodar dominated communities had rich organic carbon than chir dominated forests. The mixed and oak + deodar dominated communities were rich in available nitrogen, phosphorus and potassium than chir dominated ones. Oak and oak mixed forest community soils were found rich in available nitrogen, phosphorus and potassium over other forest communities

## *Chapter-3*

# **MATERIALS AND METHODS**

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The present investigation entitled “**Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh**” was conducted during the year 2015-16 to know the status of floral diversity, regeneration status, carbon stock and soil physico-chemical properties in dry temperate and alpine forests area of Kinnaur district in Himachal Pradesh. The details of the study area, sampling sites, methodologies adopted and materials used for the investigation is described as under:

### **3.1 STUDY AREA**

The present study was carried out in dry temperate and alpine forests of Kinnaur district of Himachal Pradesh situated at 77°45'00" and 79°00'35" E longitude and between 31°05'50" and 32°05'15" N latitude. Different forest types ranging from Group 9 to Group 16 were identified as per classification of Champion and Seth (1968). The study area falls in Kinnaur Forest Division which works under Rampur Circle of Himachal Pradesh. The district of Kinnaur adjoins part of western Tibet with which it shares its eastern boundary by following a well defined ridge generally along the Zaskar Mountains. Its southern boundary adjoins the ultra-kashi district of Uttarakhand and Rohru Tehsil of Shimla district. Its western boundary adjoins Rampur tehsil of Shimla district. The Northern boundary of Kinnaur adjoins Spiti Sub Division of Lahaul-Spiti district by following mostly the ridge of Spiti and Satluj river basin until near the international boundary it follows the Spiti river and its main tributary, the Parechhu.

#### **3.1.1 Climate**

By virtue of elevation, all the forest types lie in dry temperate zone which is located in the North-Eastern part of Himachal Pradesh. The area is characterized by long winters from October to April and short summers from June to August. Heavy rain fall in monsoon is found in outer Himalayas to the arid Tibetan type with a winter snowfall and practically no summer rain. In winter season, whole of the Kinnaur district experiences heavy snowfall.

### 3.1.2 Edaphic Factors

Parent material consists of gneiss, schist, phyllites, quartzite and granites. Among the member of the schistose series micaceous-schists, talcose rocks, phyllites and gneisses are commonest and support good forest of Deodar, Kail and Fir. The soil profiles are well developed under dense forest. On ridges, precipitous and southern slopes the soil is shallow. On the other hand it is moderately deep on the cooler aspects and on gentle slopes.

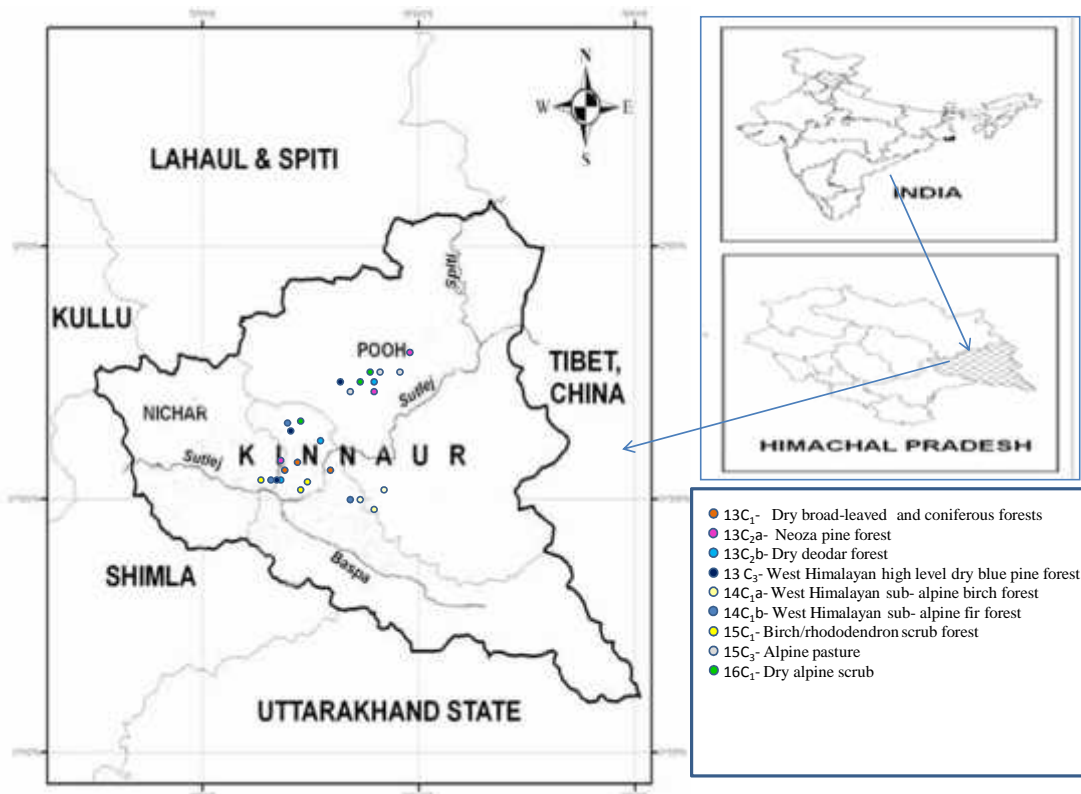


Figure 1. Location of study area and forest type map of Kinnaur district (H.P.)

### 3.1.2 Vegetation

The distribution of vegetation in Kinnaur Forest Division is classified in to three main zones as under.

- i) **Wet Zone:** This zone is comprised of the lower or outer valley, extending from Nichar Range to Kilba along the north upto Wangtu along the southern aspects. It includes all forests of Kilba Range. This zone receives bulk of rainfall during rainy season from south west monsoon and heavy snowfall during winter.
- ii) **Dry Zone:** This zone lies between Kilba and Purbani on the left bank of Sutluj. It extended over Kilba and Kalpa Range. The rainfall show progressive decline, as we go eastward. Snow falls heavily during winter.

iii) **Arid Zone:** This zone lies beyond Purbani and Kalpa extending to Indo-Tibetan border. This zone does not get practically any rainfall. The winter is severe and the tract experiences heavy snow fall during winter.

Different forest types noticed in the study area are 13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex – Pinus gerardiana*), 13C<sub>2a</sub>- Neoza pine forest (*Pinus gerardiana*), 13C<sub>2b</sub>- Dry deodar forest (*Cedrus deodara*) , 13 C<sub>3</sub>- West Himalayan high level dry blue pine forest (*Pinus wallichiana*), 14C<sub>1a</sub>- West Himalayan sub- alpine birch forest, 14C<sub>1b</sub>- West Himalayan sub- alpine fir forest, 15C<sub>1</sub>- Birch-rhododendron scrub forest, 15C<sub>3</sub>- Alpine pasture, 16C<sub>1</sub>-Dry alpine scrub (Champion and Seth 1968).

Forest types having different dominant tree, shrub and herb are shown in Table 1.

**Table 1. Different forest types and their location in Kinnaur (H.P.)**

Treatments (Forest Types)	Altitude range (m)	Type (according to Champion & Seth 1968)	Coordinate	
			Latitude	Longitude
T <sub>1</sub> - Dry broad-leaved and coniferous forests	2000-2450 m	13C <sub>1</sub>	31°30'05" and 31°32'11" N	78°08'59" and 78°10'05" E
T <sub>2</sub> - Neoza pine forest	2300-2750 m	13C <sub>2a</sub>	31°30'29" and 31°47'51" N	78°08'04" and 78°25'18" E
T <sub>3</sub> - Dry deodar forest	2450-3000m	13C <sub>2b</sub>	31°28'31" and 31°40'48" N	78°09'45" and 78°26'17" E
T <sub>4</sub> - West Himalayan high level dry blue Pine forest	3000-3450 m	13 C <sub>3</sub>	31°29'21" and 31°39'32" N	78°09'58" and 78°19'05" E
T <sub>5</sub> - West Himalayan sub- alpine birch forest	3100-3550m	14C <sub>1a</sub>	31°20'50" and 31°21'20" N	78°27'17" and 78°27'29" E
T <sub>6</sub> - West Himalayan sub- alpine fir forest	3150-3550m	14C <sub>1b</sub>	31°22'25" and 31°29'17" N	78°21'43" and 78°09'47" E
T <sub>7</sub> -Birch-rhododendron scrub forest	3300-3600m	15C <sub>1</sub>	31°25'15" and 31°28'33" N	78°12'47" and 78°08'53" E
T <sub>8</sub> - Alpine pasture	2900-3350m	15C <sub>3</sub>	31°39'48" and 31°41'29" N	78°18'032" and 78°25'53" E
T <sub>9</sub> - Dry alpine scrub	3300-3750m	16C <sub>1</sub>	31°33'05" and 31°41'22" N	78°13'42" and 78°25'23" E

### 3.2 EXPERIMENTAL METHODOLOGY

#### EXPERIMENT No.1. Studies on floral diversity of dry temperate and alpine forest in Kinnaur district of Himachal Pradesh

**Treatments (T):** Each district forest type of the study area is designated as a treatment as below:

T<sub>1</sub>-Dry broad-leaved and coniferous forests

T<sub>2</sub>- Neoza pine forest

T<sub>3</sub>- Dry deodar forest

T<sub>4</sub>- West Himalayan high level dry blue pine forest

T<sub>5</sub>- West Himalayan sub- alpine birch forest

T<sub>6</sub>- West Himalayan sub- alpine fir forest

T<sub>7</sub>- Birch-rhododendron scrub forest

T<sub>8</sub>- Alpine pasture

T<sub>9</sub>- Dry alpine scrub

**Replication = 3**

**SAMPLE PLOT SIZE:**

Trees: 20 m × 20 m

Shrubs: 5 m × 5m

Herbs: 1 m × 1m

Regeneration status: 2 m × 2 m

**Statistical design:** Randomized Block Design (RBD)

**3.2.1. Phytosociological studies**

To study the status of plant diversity, regeneration and soil nutrient status of Kinnaur district of Himachal Pradesh. Himalayan dry temperate and alpine forest ecosystem was divided into nine forest types based on dominance of forest species and their association with other forest species. Community analysis was carried out during rainy season when majority of the plants were at the peak of their growth. In each nine forest type, 9 quadrates of size 20 m × 20 m for trees were laid out randomly across the slope distributed along the elevation gradient (lower, medium and high). Within each quadrate (20 m × 20 m), three sub-quadrates of size of 5 m × 5 m for shrubs and 1 m × 1 m for herbs were laid out.

Density of trees was calculated by counting trees in each sample plot. Diameter of each tree in the sample plot was determined by tree calliper or tap. Density of shrubs was calculated by counted plants of different species in each sub-plot. The diameter of shrub was calculated by using digital calliper. While in case of herbaceous vegetation, each quadrate was segregated species wise and identified with the help of herbarium at Dr Y S Parmar University of Horticulture and Forestry experts, FRI Dehradun scientists, Journals and research books. Each species was analyzed quantitatively for various parameters, viz., basal area, density and frequency *etc.*

**Basal Area (m<sup>2</sup> ha<sup>-1</sup>)**

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

$$\text{Basal area} = \frac{d^2}{4} \dots\dots\dots (1)$$

Where:

d = Diameter

**Per cent frequency (% F)**

This term refers to the degree of dispersion of individual species in an area and usually expressed in terms of percentage occurrence. It was studied by sampling the study

area at several places at random and recorded the name of the species that occurred in each sampling units. It is calculated by the equation:

$$\text{Percent frequency (\% F)} = \frac{\text{Number of quadrates in which the species occurred}}{\text{Total number of quadrates studied}} \times 100 \text{ ----- (2)}$$

**Density (No. ha<sup>-1</sup>)**

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 equation:

$$\text{Density (D)} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates studied}} \text{ ----- (3)}$$

**Importance value index (IVI)**

This index is used to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance are summed up together and this value is designated as the Importance Value Index (IVI) of the species (Curtis, 1959).

$$\text{IVI} = \text{Relative Basal Area (RBA)} + \text{Relative Density (RD)} + \text{Relative Frequency (RF)} \text{ - (4)}$$

**(a) Relative density**

Relative density is the study of numerical strength of a species in relation to the total number of individuals of all the species and can be calculated as:

$$\text{Relative density (RD)} = \frac{\text{Number of individuals of the species}}{\text{Number of individual of all species}} \times 100 \text{ ----- (5)}$$

**(b) Relative frequency**

The degree of dispersion of individual species in an area in relation to the number of all the species occurred.

$$\text{Relative Frequency (RF)} = \frac{\text{Number of occurrence of the species}}{\text{Number of occurrence of all species}} \times 100 \text{ ----- (6)}$$

**(c) Relative dominance (Relative basal area)**

Dominance of a species is determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

$$\text{Relative basal area (RBA)} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all the species}} \times 100 \quad \text{----- (7)}$$

The total basal area was calculated from the sum of the total diameter of immersing Stems. In trees, poles and saplings, the basal area was measured at breast height (1.37m) and by using the formula  $r^2$ , but in case of herbaceous vegetation it was measured on the ground level by using calipers.

**Similarity (S) and dissimilarity (D) indices**

Indices of similarity (S) and dissimilarity (D) were calculated by using formulae as per Mishra (1989) and Sorensen (1948).

$$\text{Index of Similarity (S)} = \frac{2C}{A+B} \quad \text{----- (8)}$$

Where, A = Number of species in community A  
B = Number of species in community B  
C = Number of common species in both the communities

$$\text{Index of Dissimilarity (D)} = 1-S \quad \text{----- (9)}$$

**Species richness, diversity and dominance indices**

The Species richness was calculated by using the method ‘Margalef’s index of richness’ ( $D_{mg}$ ) (Magurran, 1988)

$$D_{mg} = (S-1) / \ln N \quad \text{----- (10)}$$

Where, S = Total number of species.  
N = Total number of individual per hectare.

Species diversity and dominance were evaluated by using the following methods. Shannon’s diversity index and Simpson’s index of dominance was calculated using important value index (IVI) of the species.



**Plate 1. T<sub>1</sub>:13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex* – *Pinus gerardiana*)**



**Plate 2. T<sub>2</sub>: 13C<sub>2a</sub>- Neoza Pine forest (*Pinus gerardiana*)**



**Plate 3.T<sub>3</sub>: 13C<sub>2</sub>b- Dry Deodar forest (*Cedrus deodara*)**



**Plate 4. T<sub>4</sub>: 13 C<sub>3</sub>- West Himalayan high level dry Blue Pine forest (*Pinus wallichiana*)**



**Plate 5. T<sub>5</sub>:14C<sub>1</sub>a- West Himalayan sub- alpine birch forest**



**Plate 6. T<sub>6</sub>:14C<sub>1</sub>b- West Himalayan sub- alpine fir forests (*Abies* spp.)**



**Plate 7. T<sub>7</sub>:15C<sub>1</sub>- Birch-rhododendron scrub forest**



**Plate 8. T<sub>8</sub>: 15C<sub>3</sub>- Alpine pasture**



**Plate 9. T<sub>9</sub>: 16C<sub>1</sub>-Dry alpine scrub**



**Plate 10. Regeneration status of different forest types in dry temperate and alpine forest of Kinnaur district (H.P.)**

**A) Shannon-Wiener (1963) Index of diversity**

The formula for calculating the Shannon-weaver Index of diversity is

$$H = - \sum p_i \ln p_i \quad \text{----- (11)}$$

Where,  $H$  = Shannon Index of diversity  
 $p_i$  = the proportion of important value of the  $i^{\text{th}}$  species  
( $p_i = n_i/N$ ,  $n_i$  is the important value index of  $i^{\text{th}}$  species and  $N$  is the important value index of all the species).

**B) Simpson (1949) index of dominance.**

The equation is used to calculate Simpson's index was

$$D = \frac{1}{\sum (p_i)^2} \quad \text{----- (12)}$$

Where,  $D$  = Simpson index of dominance.  
 $P_i$  = The proportion of important value of the  $i^{\text{th}}$  species ( $p_i = n_i/N$ ,  $n_i$  is the important value index of  $i^{\text{th}}$  species and  $N$  is the important value index of all the species).

**3.2.2. Regeneration survey**

The regeneration survey was carried out in all the identified/demarcated sample plots. To study the regeneration status of dominant forest species, 9 sub-quadrates of 2 m × 2 m within each quadrat of size 20 m × 20 m were laid out.

The main object of regeneration survey was to assess whether or not there is adequate regeneration in the forest area. The adequacy of regeneration is judged on the basis of number of established plants in a unit area. According to Chacko (1965), desired numbers of established plants are 2500 per hectare and the quadrat is considered fully stocked when it contained one established plant. Observations on regeneration were made in a recording unit quadrat size of 2 m × 2 m (4 sq m). For a detailed assessment of the status of regeneration following observations were made for each quadrat.

**Recruits, un-established established and per cent regeneration**

- i) The total number of recruits ( $r$ ) - which may be defined as current year seedlings,
- ii) The number of un-established regeneration ( $u$ ) - Seedling other than recruits which has not established by not reaching established height of 2 m. Four un-established plants were considered equivalent to one established plant and,
- iii) The number of established regeneration ( $e$ ) - Seedlings above 2m height.

The recruits, un-established and established regeneration were computed using formulae given by Chacko (1965) as:

$$\text{Recruits (r)/ha} = \frac{2500 \times \text{total number of recruits}}{\text{Total number of recording units}} \quad \text{----- (13)}$$

$$\text{Un-established (u)/ha} = \frac{2500 \times \text{total number of un-established plants in sampling units}}{\text{Total number of recording units}} \quad \text{----- (14)}$$

$$\text{Established (e)/ha} = \frac{2500 \times \text{total number of established plants in sampling units}}{\text{Total number of recording units}} \quad \text{----- (15)}$$

$$\text{Weighted Average height (cm)} = \frac{\text{Total height of unestablished regeneration} + (\text{Number of established plants} \times \text{establishment height})}{\text{Total unestablished plants} + \text{Total established plants}} \quad \text{.. 16)}$$

On the basis of above estimates following indices were calculated:

$$\text{Establishment index (I}_1\text{)} = \frac{\text{Weighted average height}}{\text{Establishment height}} \quad \text{.....(17)}$$

$$\text{Regeneration success (\%)} = \text{Stocking index (I}_2\text{)} \times 100 \quad \text{..... (18)}$$

$$\text{Stocking index (I}_2\text{)} = 1/2500 \times \frac{\text{Unestablished regeneration ha}^{-1}}{4} + \text{Established regeneration ha}^{-1} \quad \text{....(19)}$$

$$\text{Established stocking per cent} = 100 (I_1 \times I_2) \quad \text{..... (20)}$$

## Experiment No.2: Assessment of carbon stock of dry temperate and alpine forest in Kinnaur district of Himachal Pradesh

### Treatment detail:

Treatments (Forest types)	Attitudinal gradient (m a.m.s.l)		
	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>
T <sub>1</sub> - Dry broad-leaved and coniferous forests	2000-2150 m	2150-2300 m	2300-2450 m
T <sub>2</sub> - Neoza pine forest	2300-2450 m	2450-2600 m	2600-2750 m
T <sub>3</sub> - Dry deodar forest	2450-2600 m	2650-2800 m	2850-3000 m
T <sub>4</sub> - West Himalayan high level dry blue Pine forest	3000-3150 m	3150-3300 m	3300-3450 m
T <sub>5</sub> - West Himalayan sub- alpine birch forest	3100-3250 m	3250-3400 m	3400-3550 m
T <sub>6</sub> - West Himalayan sub- alpine fir forest	3150-3300 m	3300-3450 m	3450-3600
T <sub>7</sub> - Birch-rhododendron scrub forest	3300-3400 m	3400-3500 m	3500-3600m
T <sub>8</sub> - Alpine pasture	2900-3050 m	3050-3200 m	3200-3350 m
T <sub>9</sub> - Dry alpine scrub	3300-3450 m	3450-3600 m	3600-3750 m

### **SAMPLE PLOT SIZE:**

Trees: 20 m × 20 m

Shrubs: 5 m × 5m

Herbs: 1 m × 1m

Leaf litter: 1 m × 1 m

### **SOIL DEPTHS:**

**L<sub>1</sub>:** 0-20 cm layer

**L<sub>2</sub>:** 21-40 cm layer

**For biomass and carbon related studies:** Two way ANOVA.

**For soil related studies:** RBD factorial

**Replication:** 3

**No. of treatment combinations:** 18 [(9 forest types) × 2 (Soil depth)]

Sample plots under each forest type shown in experiment 1, will be enumerated to find out the spatial distribution of carbon stock under the different forest type of dry temperate and alpine region of Kinnaur district of Himachal Pradesh.

## **3.2. OBSERVATIONS RECORDED**

### **3.2.1. Stem biomass (t ha<sup>-1</sup>)**

To estimate the biomass, the entire trees falling in the plot (20 m × 20 m) were enumerated. The diameter at breast height (DBH) was measured with meter tape. Stem volume of trees was determined by number of stem in different diameter class multiply by respective volume factor given in working plan of Kinnaur Forest Division (Government of Himachal Pradesh Forest Department, 1999-2015).

**Specific gravity:** Specific gravity was determined from the available literature (Rajput *et al.* 1985)

Stem biomass = Average specific gravity of stem wood × Stem volume

### **3.2.2. Above ground tree biomass (t ha<sup>-1</sup>)**

The total tree biomass was calculated by multiplying the stem biomass with the biomass expansion factor of the given species (Brown *et al.* 2002).

### **3.2.3. Below ground tree biomass (t ha<sup>-1</sup>)**

Below ground biomass of trees was calculated by using the guidelines of IPCC (1996) and Cairns *et al.* (1997).

### **3.2.4. Tree biomass (t ha<sup>-1</sup>)**

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

### **3.2.5 Shrub biomass (t ha<sup>-1</sup>)**

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 calliper 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.

### **3.2.6 Herb biomass (t ha<sup>-1</sup>)**

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

### **3.2.7 Surface litter (t ha<sup>-1</sup>)**

Surface litter was collected in nine quadrates of 1 m × 1 m. Samples were weighed, sub-sampled and oven dried at 65 + 5°C to a constant weight, grounded and ashes. Corrected dry ash was assumed to contain 50 per cent of carbon.

### **3.2.8 Carbon estimation**

#### **3.2.8.1 Vegetation carbon density (t ha<sup>-1</sup>)**

$$\text{Vegetation carbon density} = \text{Tree biomass (t ha}^{-1}\text{)} + \text{Shrub Biomass (t ha}^{-1}\text{)} + \text{Herb carbon (t ha}^{-1}\text{)}$$

#### **3.2.8.2 Ecosystem carbon density (t ha<sup>-1</sup>)**

$$\text{Ecosystem carbon density (t ha}^{-1}\text{)} = \text{Vegetation carbon density (t C ha}^{-1}\text{)} + \text{Detritus carbon density (t C ha}^{-1}\text{)} + \text{Soil carbon density (t C ha}^{-1}\text{)}$$

### 3.3 SOIL ANALYSIS

#### 3.3.1 Collection and preparation of soil samples

Soil sampling was done within each clustered plot by digging profiles up to 0-20 and 21-40 cm. Composite samples from all sub area were obtained for each depth. Samples were air dried in shade, grinded in wooden pestle, passed through 2 mm sieve and stored in cloth bags for further laboratory analysis.

#### 3.3.2 Methods employed for soil chemical analysis

The details of methods employed for estimating different soil chemical parameters are as follow:

Sr. No.	Particular Method	Method employed
1	Bulk density ( $\text{g cm}^{-3}$ )	Specific gravity method (Singh 1980).
2	Organic carbon (%)	Walkley and Black method (1954).
3	Available nitrogen ( $\text{kg ha}^{-1}$ )	Alkaline potassium permanganate method of Subbiah and Asija (1956).
4	Available phosphorous ( $\text{kg ha}^{-1}$ )	Olsen <i>et. al.</i> (1954).
5	Available potassium ( $\text{kg ha}^{-1}$ )	Flame photometer method of Merwin and Peach (1951).
6	Soil pH	1:2.5 soil: water suspension, with the help of digital pH meter (Jackson, 1973).
7	Soil EC ( $\text{dSm}^{-3}$ )	1:2.5 soil: water suspension, with the help of digital conductivity bridge (Jackson, 1973).
8	Soil carbon ( $\text{t ha}^{-1}$ )	[Soil bulk density ( $\text{g cm}^{-3}$ ) $\times$ Soil depth (cm) $\times$ Carbon] (Nelson and Sommers, 1996).
9	Available Cu ( $\text{mg kg}^{-1}$ )	Diethylene Triamine Pentaacetic Acid (DTPA) method
10	Available Mn ( $\text{mg kg}^{-1}$ )	Diethylene Triamine Pentaacetic Acid (DTPA) method
11	Available Fe ( $\text{mg kg}^{-1}$ )	Diethylene Triamine Pentaacetic Acid (DTPA) method
12	Available Zn ( $\text{mg kg}^{-1}$ )	Diethylene Triamine Pentaacetic Acid (DTPA) method

### 3.4. STATISTICAL ANALYSIS

The data obtained were subjected to statistical analysis as per the procedure suggested by Gomez and Gomez (1984). Statistical analysis was conducted using the SPSS system software. One-way ANOVA was used to detect statistically significant differences of C density among the vegetation types. Two way ANOVA for carrying out the soil related studies. Regression and correlation study was also carried out using SPSS and Microsoft Excel softwares.

**ANOVA for RBD shall be as follows:**

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F <sub>cal</sub>
Treatments	(t-1)	S <sub>t</sub>	$M_t = \frac{S_t}{(t-1)}$	$\frac{M_t}{M_e}$
Replications	(r-1)	S <sub>r</sub>	$M_r = \frac{S_r}{(r-1)}$	$\frac{M_r}{M_e}$
Error	(r-1)(t-1)	S <sub>e</sub>	$M_e = \frac{S_e}{(r-1)(t-1)}$	
Total	(rt-1)	S <sub>T</sub>		

Where,

- r = Number of replications
- t = Number of treatments
- S<sub>r</sub> = Sum of squares due to replications
- S<sub>t</sub> = Sum of squares due to treatments
- S<sub>e</sub> = Sum of squares due to error
- S<sub>T</sub> = Total sum of squares
- M<sub>r</sub> = Mean sum of squares due to replications
- M<sub>t</sub> = Mean sum of squares due to treatments
- M<sub>e</sub> = Mean sum of squares due to error

The replication and treatment mean sum of square shall be tested against Mean sum of squares 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:**

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

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

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

Where,

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

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

CD<sub>0.05</sub> = Critical difference at 5 per cent level of significance

## Chapter-4

# RESULTS AND DISCUSSION

The results emerging out of present investigation entitled “**Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh**” was carried out under different forest types in dry temperate and alpine region of Kinnaur district of Himachal Pradesh. In the present study various forest communities that exists in dry temperate and alpine region of Kinnaur district were classified into different forest types viz., 13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex* – *Pinus gerardiana*), 13C<sub>2a</sub>- Neoza pine forest (*Pinus gerardiana*), 13C<sub>2b</sub>- Dry deodar forest (*Cedrus deodara*), 13 C<sub>3</sub>- West Himalayan high level dry dry blue pine forest (*Pinus wallichiana*), 14C<sub>1a</sub>- West Himalayan sub- alpine birch forest, 14C<sub>1b</sub>- West Himalayan sub- alpine fir forest, 15C<sub>1</sub>- Birch-rhododendron scrub forest, 15C<sub>3</sub>- Alpine pasture and 16C<sub>1</sub>-Dry alpine scrub (Table 2).

**Table 2. Forest types under dry temperate and alpine region of Kinnaur district of Himachal Pradesh**

Treatments (Forest types)	Altitude range (m)	Type (accoding to Champion & Seth 1968)	Dominant tree species
<b>T<sub>1</sub>- Dry broad-leaved and coniferous forests</b>	2000-2450	13C <sub>1</sub>	<i>Quercus ilex</i> , <i>Pinus gerardiana</i>
<b>T<sub>2</sub>- Neoza pine forest</b>	2300-2750	13C <sub>2a</sub>	<i>Pinus gerardiana</i>
<b>T<sub>3</sub>- Dry deodar forest</b>	2450-2950	13C <sub>2b</sub>	<i>Cedrus deodara</i>
<b>T<sub>4</sub>- West Himalayan high level dry blue Pine forest</b>	3000-3450	13 C <sub>3</sub>	<i>Pinus wallichiana</i>
<b>T<sub>5</sub>- West Himalayan sub-alpine birch forest</b>	3100-3550	14C <sub>1a</sub>	<i>Betula utilis</i>
<b>T<sub>6</sub>- West Himalayan sub-alpine fir forest</b>	3150-3550	14C <sub>1b</sub>	<i>Abies pindrow</i> , <i>Abies spectabilis</i>
<b>T<sub>7</sub>- Birch-rhododendron scrub forest</b>	3300-3600	15C <sub>1</sub>	<i>Betula utilis</i>
<b>T<sub>8</sub>- Alpine pasture</b>	2900-3350	15C <sub>3</sub>	-
<b>T<sub>9</sub>- Dry alpine scrub</b>	3300-3750	16C <sub>1</sub>	-

Different forest communities due to their structure, tree species, altitudinal ranges and topography to which each forest community is subjected to reflect a wide variability in terms of floral diversity, biomass production potential, carbon storage ability and physico-chemical characteristics in them. Floristic diversity and carbon stock potential derived from different forest communities in dry temperate and alpine region has been described under the following headings:

**4.1 FLORISTIC DIVERSITY**

**4.2 PHYTOSOCIOLOGY**

**4.3 REGENERATION STATUS**

**4.4 CARBON STOCK**

**4.5 SOIL PHYSICO-CHEMICAL PROPERTIES**

**4.6 PRINCIPAL COMPONENT ANALYSIS (PCA) AND FACTOR ANALYSIS**

**4.7 CORRELATION AND REGRESSION STUDIES**

**4.1 FLORISTIC DIVERSITY**

Data demonstrated in Table 3 reveal that plant vegetation study under different forest communities comprised of 139 species, out of which 7 tree species, 26 shrub species and 106 herbs species were recorded that belong to 102 genera and 44 families. The number of plant species (Tree + shrub + herb) as counted under different types of dry temperate and alpine forest were recorded maximum in dry deodar forest (40) followed by dry broad-leaved and coniferous forests (34), dry blue pine forest (33), sub alpine fir forest and neoza pine forest (32), alpine pasture (23), sub-alpine birch forest (22), birch-rhododendron scrub forest (16) and dry alpine scrub (15).

Seven trees species that existed under major forest types of dry temperate and alpine forest are depicted in Table 4. Maximum trees species (4) were recorded in sub alpine fir forest, whereas, no trees species was found in alpine pasture and dry alpine scrub. The shrubs that existed under major forest communities are also demonstrated in Table 5. Maximum number of shrub species (12) was recorded in dry deodar forest followed by dry broad-leaved and coniferous forests (9) and neoza pine forest (9), dry blue pine forest (6) and sub alpine fir forest (5), sub-alpine birch forest (4), birch-rhododendron scrub forest (3) and dry alpine scrub (3), respectively. Herbaceous vegetation that existed under different forest communities are also displayed in Table 6. The numbers of herb species were recorded maximum (25) in

dry deodar forest followed by dry blue pine forest (24), sub alpine fir forest (23) and alpine pasture (23), dry broad-leaved and coniferous forests (22) and neoza pine forest (20), and, sub-alpine birch forest (15), dry alpine scrub (12) and birch-rhododendron scrub forest (11), respectively.

**Table 3. Inventory of trees, shrubs and herbs in different forest types in dry temperate and alpine forest ecosystem of Kinnaur district of Himachal Pradesh**

Category	Treatments (Forest types)									
	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neoza pine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
Trees	3	3	3	3	3	4	2	0	0	<b>21</b>
Shrubs	9	9	12	6	4	5	3	0	3	<b>51</b>
Herbs	22	20	25	24	15	23	11	23	12	<b>175</b>
<b>Total</b>	<b>34</b>	<b>32</b>	<b>40</b>	<b>33</b>	<b>22</b>	<b>32</b>	<b>16</b>	<b>23</b>	<b>15</b>	<b>247</b>

**Table 4. Trees species under different forest type in dry temperate and alpine forest ecosystem of Kinnaur district (H.P.)**

Sr. No.	Trees	Family	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neoza pine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
1.	<i>Betula utilis</i>	Betulaceae	-	-	-	-	+	+	+	-	-	<b>3</b>
2.	<i>Abies pindrow</i>	Pinaceae	-	-	-	-	+	+	+	-	-	<b>3</b>
3.	<i>Abies spectabilis</i>	Pinaceae	-	-	-	+	-	+	-	-	-	<b>2</b>
4.	<i>Cedrus deodara</i>	Pinaceae	-	+	+	+	-	-	-	-	-	<b>3</b>
5.	<i>Pinus gerardiana</i>	Pinaceae	+	+	+	-	-	-	-	-	-	<b>3</b>
6.	<i>Pinus wallichiana</i>	Pinaceae	-	+	+	+	+	+	-	-	-	<b>5</b>
7.	<i>Quercus ilex</i>	Fagaceae	+	-	-	-	-	-	-	-	-	<b>1</b>
	<b>Total</b>		<b>2</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>4</b>	<b>2</b>	<b>0</b>	<b>0</b>	<b>20</b>

**Table 5. Shrubs species under different forest type in dry temperate and alpine forest ecosystem of Kinnaur district (H.P.)**

Sr. No.	Shrubs	Family	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neozoa pine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
1	<i>Abelia triflora</i>	Fabaceae	+	+	-	-	-	-	-	-	-	2
2	<i>Berberis erythroclada</i>	Berberidaceae	-	-	-	+	-	+	-	-	-	2
3	<i>Berberis aristata</i>	Berberidaceae	-	+	+	-	-	-	-	-	-	2
4	<i>Berberis lycium</i>	Berberidaceae	+	+	-	-	-	-	-	-	-	2
5	<i>Berberis vulgaris</i>	Berberidaceae	-	-	-	-	+	-	-	-	-	1
6	<i>Cotoneaster bacillaris</i>	Rosaceae	-	-	+	-	+	+	-	-	-	3
7	<i>Daphne oleoides</i>	Thymelaeaceae	+	-	+	-	-	-	-	-	-	2
8	<i>Desmodium confertum</i>	Leguminosae	-	-	+	+	-	-	-	-	-	2
9	<i>Desmodium elegans</i>	Leguminosae	+	-	-	-	-	-	-	-	-	1
10	<i>Desmodium tilaefolium</i>	Leguminosae	+	+	-	-	-	-	-	-	-	2
11	<i>Ephedra gerardiana</i>	Ephedraceae	-	+	+	-	-	-	-	-	-	2
12	<i>Indigofera heterantha</i>	Fabaceae	+	-	+	-	-	-	-	-	-	2
13	<i>Indigofera gerardiana</i>	Fabaceae	-	-	+	+	-	-	-	-	-	2
14	<i>Juniperus communis</i>	Cupressaceae	-	-	-	-	-	-	-	-	+	1
15	<i>Juniperus indica</i>	Cupressaceae	-	-	-	-	-	-	-	-	+	1
16	<i>Lonicera hypoleuca</i>	Caprifoliaceae	-	+	+	-	-	-	-	-	-	2
17	<i>Lonicera quinquelocularis</i>	Caprifoliaceae	+	+	+	-	-	-	-	-	-	3
18	<i>Plectranthus rugosus</i>	Lamiaceae	+	+	+	+	-	-	-	-	-	4
19	<i>Rhamnus variegata</i>	Rhamnaceae	+	-	-	-	-	-	-	-	-	1
20	<i>Ribes orientale</i>	Grossulariaceae	-	-	-	-	-	-	-	-	+	1
21	<i>Rosa macrophylla</i>	Rosaceae	-	-	+	+	+	+	-	-	-	4
22	<i>Rosa webbiana</i>	Rosaceae	-	+	+	-	-	-	-	-	-	2
23	<i>Salix hastata</i>	Salicaceae	-	-	-	+	-	+	+	-	-	3
24	<i>Sorbus foliolosa</i>	Rosaceae	-	-	-	-	-	+	-	-	-	1
25	<i>Rhododendron anthopogon</i>	Ericaceae	-	-	-	-	+	-	+	-	-	2
26	<i>Rhododendron campanulatum</i>	Ericaceae	-	-	-	-	-	-	+	-	-	1
			<b>9</b>	<b>9</b>	<b>12</b>	<b>6</b>	<b>4</b>	<b>5</b>	<b>3</b>	<b>0</b>	<b>3</b>	<b>51</b>

**Table 6. Herbs species under different forest community in dry temperate and alpine forest ecosystem of Kinnaur district (H.P.)**

Sr. No.	Herbs	Family	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neoza pine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
1	<i>Aconitum heterophyllum</i>	Ranunculaceae	-	-	-	+	-	-	-	-	-	1
2	<i>Aconogonon alpinum</i>	Polygonaceae	-	-	-	-	-	-	+	-	-	1
3	<i>Aconitum molli</i>	Lamiaceae	-	-	-	-	+	+	-	-	-	2
4	<i>Ainsliaea aptera</i>	Asteraceae	-	-	-	-	+	-	-	-	-	1
5	<i>Anaphalis busua</i>	Asteraceae	-	-	+	-	-	+	-	+	-	3
6	<i>Anemone polyanthes</i>	Ranunculaceae	-	+	-	-	-	-	-	-	-	1
7	<i>Anemone tetrasepala</i>	Ranunculaceae	-	-	-	-	-	-	+	-	-	1
8	<i>Aquilegia fragrans</i>	Ranunculaceae	-	-	-	-	+	-	-	-	-	1
9	<i>Artemisia brevifolia</i>	Asteraceae	-	+	-	-	-	-	-	+	+	3
10	<i>Artemisia maritime</i>	Asteraceae	-	+	-	-	-	-	-	-	-	1
11	<i>Artemisia parviflora</i>	Asteraceae	+	-	-	-	-	-	-	+	-	2
12	<i>Artemisia scoparia</i>	Asteraceae	+	+	+	+	-	-	-	-	-	4
13	<i>Artemisia roxburghiana</i>	Asteraceae	+	-	-	-	-	-	-	-	-	1
14	<i>Asparagus filicinus</i>	Asparagaceae	-	-	+	-	-	-	-	-	-	1
15	<i>Arisaema flavum</i>	Araceae	-	-	+	-	-	-	-	-	-	1
16	<i>Aster albescens</i>	Asteraceae	+	-	-	-	-	-	-	-	-	1
17	<i>Aster amellus</i>	Asteraceae	-	-	+	-	-	-	-	-	-	1
18	<i>Astragalus candoleanus</i>	Fabaceae	-	+	+	-	-	-	-	-	-	2
19	<i>Astragalus chlorostachys</i>	Fabaceae	-	-	-	-	-	+	-	-	-	1
20	<i>Astragalus frigidus</i>	Fabaceae	-	-	-	+	-	-	-	-	-	1
21	<i>Bergenia stracheyi</i>	Saxifragaceae	-	-	-	-	+	-	-	-	+	2
22	<i>Bistorta affinis</i>	Polygonaceae	-	-	-	-	+	-	+	-	-	2
23	<i>Bunium persicum</i>	Apiaceae	-	+	-	-	-	-	-	-	-	1
24	<i>Carum carvi</i>	Apiaceae	-	-	-	-	-	-	-	+	-	1
25	<i>Cassiope fastigiata</i>	Ericaceae	-	-	-	-	-	-	+	-	-	1
26	<i>Chenopodium botrys</i>	Amaranthaceae	-	+	-	-	-	-	-	-	-	1
27	<i>Chenopodium album</i>	Amaranthaceae	-	-	-	-	-	-	-	+	-	1
28	<i>Chenopodium opulifolium</i>	Amaranthaceae	-	-	-	-	+	-	-	-	-	1
29	<i>Cirsium falconeri</i>	Asteraceae	-	-	-	-	-	-	-	+	-	1
30	<i>Cirsium verutum</i>	Asteraceae	-	-	-	-	-	-	-	+	-	1

Table 6. Contd.....

Sr. No.	Herbs	Family	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neozapine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
31	<i>Cynoglossum glochidiatum</i>	Boraginaceae	-	-	-	+	-	-	-	-	-	1
32	<i>Cynoglossum micranthum</i>	Boraginaceae	-	-	-	-	-	-	-	+	-	1
33	<i>Datura stramonium</i>	Solanaceae.	-	-	-	-	-	-	-	+	+	2
34	<i>Dianthus angulatus</i>	Caryophyllaceae	-	+	-	-	-	-	-	-	-	1
35	<i>Echinops cornigerus</i>	Asteraceae	-	-	-	-	-	-	-	+	+	2
36	<i>Equisetum arvense</i>	Equisetaceae	-	-	-	-	-	+	-	-	-	1
37	<i>Erigeron annuus</i>	Asteraceae	+	-	+	-	-	-	-	-	-	2
38	<i>Fragaria nubicola</i>	Rosaceae	+	-	-	+	-	+	-	-	-	3
39	<i>Fragaria vesca</i>	Rosaceae	-	-	+	+	-	-	-	-	-	2
40	<i>Galium aparine</i>	Rubiaceae	-	+	-	-	-	-	-	-	-	1
41	<i>Geranium wallichianum</i>	Geraniaceae	-	-	-	+	-	+	-	-	-	2
42	<i>Geum elatum</i>	Rosaceae	-	-	-	-	-	-	+	-	-	1
43	<i>Geum sikkimense</i>	Rosaceae	+	-	-	-	-	-	-	-	-	1
44	<i>Heracleum candicans</i>	Apiaceae	-	-	-	-	-	-	-	+	-	1
45	<i>Impatiens brachycentra</i>	Balsaminaceae	-	+	-	-	-	-	-	-	-	1
46	<i>Impatiens sulcata</i>	Balsaminaceae	+	-	+	+	+	+	-	-	-	5
47	<i>Iris hookeriana</i>	Iridoideae	-	-	-	-	-	-	+	-	+	2
48	<i>Jurinea dolomiaea</i>	Asteraceae	-	-	-	-	-	+	-	-	-	1
49	<i>Lactuca benthamii</i>	Asteraceae	-	+	+	-	-	-	-	-	-	2
50	<i>Laminas album</i>	Asteraceae	-	-	-	+	-	+	-	-	-	1
51	<i>Lespedeza gerardiana</i>	Fabaceae	+	-	-	-	-	-	-	-	-	1
52	<i>Ligularia fischeri</i>	Fabaceae	-	-	-	-	-	+	-	-	-	1
53	<i>Medicago falcata</i>	Fabaceae	-	-	-	-	-	-	-	+	-	1
54	<i>Mentha longifolia</i>	Lamiaceae	-	-	-	-	-	-	-	+	+	2
55	<i>Nepeta ruderalis</i>	Lamiaceae	-	-	+	-	-	-	-	-	-	1
56	<i>Origanum vulgare</i>	Lamiaceae	-	+	+	-	-	-	-	-	-	2
57	<i>Picrorhiza kurroa</i>	Plantaginaceae	-	-	-	-	-	+	-	-	-	1
58	<i>Pimpinella diversifolia</i>	Apiaceae.	-	-	-	+	-	-	-	-	-	1
59	<i>Polygonum polygaloides</i>	Polygonaceae	-	-	-	-	-	-	-	+	+	2
60	<i>Potentilla atrosanguinea</i>	Rosaceae	-	+	-	-	-	+	+	-	+	4
61	<i>Primula macrophylla</i>	Primulaceae	-	-	-	-	+	-	-	-	-	1

Table 6. Contd.....

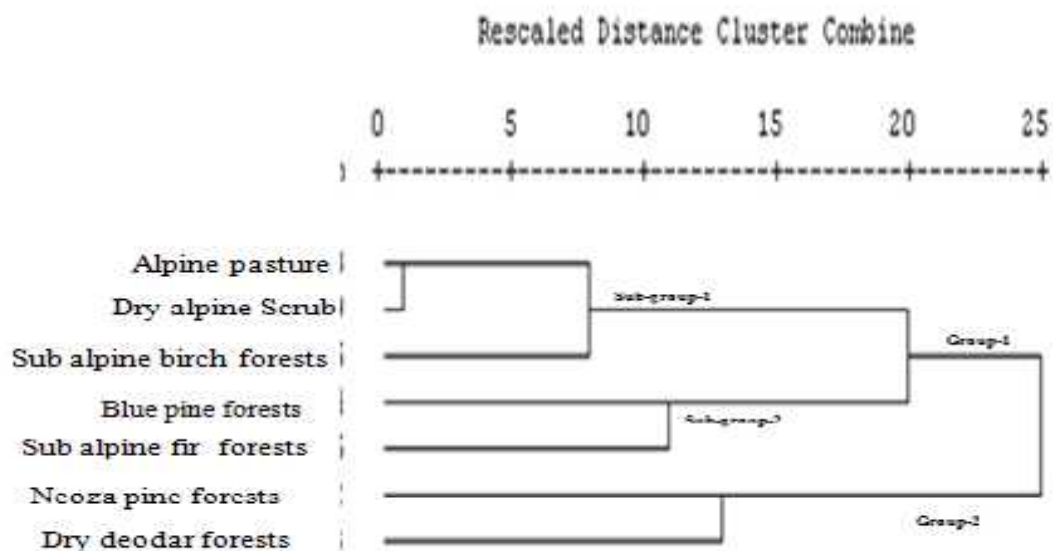
Sr. No.	Herbs	Family	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neoza pine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
62	<i>Rumex nepalensis</i>	Polygonaceae	-	-	-	+	+	+	-	+	-	4
63	<i>Senecio chrysanthemoides</i>	Compositae	-	+	-	+	-	-	-	-	-	2
64	<i>Salvia glutinosa</i>	Lamiaceae	-	+	+	+	-	-	-	-	-	3
65	<i>Salvia nubicola</i>	Lamiaceae	-	-	-	+	-	+	-	-	-	2
66	<i>Saussurea albescens</i>	Asteraceae	+	-	-	-	-	-	-	-	-	1
67	<i>Saussurea lappa</i>	Asteraceae	-	-	-	-	-	+	-	-	-	1
68	<i>Sedum ewersii</i>	Crassulaceae	-	-	-	-	-	-	-	-	+	1
69	<i>Selinum tenuifolium</i>	Apiaceae	-	-	-	-	-	+	-	-	-	1
70	<i>Senecio cappa</i>	Asteraceae	-	-	+	-	-	-	-	-	-	1
71	<i>Silene edgeworthii</i>	Balsaminaceae	+	-	-	-	+	-	-	+	-	3
72	<i>Smilacina purpurea</i>	Asparagaceae	-	-	+	-	-	-	-	-	-	1
73	<i>Sopubia trifida</i>	Scrophulariaceae	-	+	-	-	-	-	-	-	-	1
74	<i>Stachys sylvatica</i>	Lamiaceae	-	-	-	-	-	-	+	-	-	1
75	<i>Thalictrum alpinum</i>	Ranunculaceae	-	-	-	-	-	+	-	-	-	1
76	<i>Thalictrum javanicum</i>	Ranunculaceae	-	-	-	-	+	-	-	+	-	2
77	<i>Thymus serpyllum</i>	Lamiaceae	-	+	+	+	-	+	-	-	-	4
78	<i>Stachys melissifolia</i>	Lamiaceae	+	-	-	-	-	+	-	-	-	2
79	<i>Trifolium repens</i>	Fabaceae	+	-	-	-	-	-	-	+	-	2
80	<i>Urtica dioica</i>	Urticaceae	-	-	-	-	+	-	-	-	-	1
81	<i>Verbascum thapsus</i>	Scrophulariaceae	+	+	+	+	-	-	-	+	-	5
82	<i>Viola canescens</i>	Solanaceae	-	-	+	-	-	+	-	-	-	2
83	<i>Viola serpens</i>	Solanaceae	-	-	+	+	-	-	-	-	-	2
84	<i>Agropyron longearistatum</i>	Poaceae	+	+	+	-	-	-	-	-	-	3
85	<i>Agropyron semicostatum</i>	Poaceae	-	+	+	-	-	-	-	+	+	4
86	<i>Agrostis alba</i>	Poaceae	+	-	-	-	-	-	-	-	-	1
87	<i>Agrostis canina</i>	Poaceae	-	-	-	-	-	-	-	+	-	1
88	<i>Arthraxon lancifolius</i>	Poaceae	+	-	-	-	-	-	-	-	-	1
89	<i>Alopecurus arundinaceus</i>	Poaceae	-	-	+	-	-	-	-	+	-	1
90	<i>Brachypodium distachyon</i>	Poaceae	-	-	-	+	-	-	-	-	-	1
91	<i>Chrysopogon gryllus</i>	Poaceae	-	-	-	+	-	-	-	-	-	1
92	<i>Dactylis glomerata</i>	Poaceae	-	-	-	+	-	+	-	-	-	2

Table 6. Contd.....

Sr. No	Herbs	Family	T <sub>1</sub> -Dry broad-leaved and coniferous forests	T <sub>2</sub> -Neozapine forest	T <sub>3</sub> -Dry deodar forest	T <sub>4</sub> -Dry blue pine forest	T <sub>5</sub> -Sub alpine birch forest	T <sub>6</sub> -Sub alpine fir forest	T <sub>7</sub> -Birch-rhododendron scrub forest	T <sub>8</sub> -Alpine pasture	T <sub>9</sub> -Dry alpine scrub	Total representation in forest type
93	<i>Danthonia cachemyriana</i>	Poaceae	-	-	-	-	+	-	-	-	-	1
94	<i>Danthonia jacquemonti</i>	Poaceae	-	-	-	-	-	-	+	-		1
95	<i>Danthonia schneideri</i>	Poaceae	-	-	-	+	+	+	-	-	+	4
96	<i>Deyaurcia pulchella</i>	Poaceae	-	-	-	-	+	-	+	-	+	3
97	<i>Elymus dasystachyum</i>	Poaceae	-	-	-	-	-	-	-	+	-	1
98	<i>Hemarthria altissima</i>	Poaceae	-	-	+	-	-	-	-	-	-	1
99	<i>Oryzopsis aequiglumis</i>	Poaceae	+	-	-	-	-	-	-	-	-	1
100	<i>Oryzopsis munrio</i>	Poaceae	+	-	-	-	-	-	-	-	-	1
101	<i>Pennisetum orientale</i>	Poaceae	+	-	-	-	-	-	-	-	-	1
102	<i>Piptatherum spp</i>	Poaceae	+	-	-	-	-	-	-	-	-	1
103	<i>Setaria viridis</i>	Poaceae	-	-	-	+	-	-	-	-	-	1
104	<i>Stipa sibirica</i>	Poaceae	+	-	+	+	-	-	-	-	-	3
105	<i>Pteridium aquilinum</i>	Dennstaedtiaceae	-	-	+	+	-	-	-	-	-	2
106	<i>Dryopteris barbigera</i>	Dryopteridaceae	-	-	-	-	-	+	+	-	-	2
	<b>Total</b>		<b>22</b>	<b>20</b>	<b>25</b>	<b>24</b>	<b>15</b>	<b>23</b>	<b>11</b>	<b>23</b>	<b>12</b>	<b>175</b>

Forests are the most extensive, complex and biologically productive entities amongst all the terrestrial ecosystems. Understanding forest structures is a prerequisite to describe various ecological processes and also to model the functioning and dynamics of forest (Elouard *et al.* 1997). Quantitative studies of forest communities lead to a deeper insight into the form and structure of their vegetation. It has been realized that for a sound management of the Himalayan ecosystem, knowledge of plant communities, diversity, population and distribution is essential to the conservation and restoration of the environment. Knowledge of distribution and dynamics of biological resources can provide a rational basis for planning and management decisions; otherwise, the conservation of these resources in their natural habitat would be very difficult (Khoshoo 1992).

The number of plants recorded in the present study is comparable with the results of other workers on the vegetation of Himalayas (Verma and Kapoor 2013; Deshmukh and Jain 2016; Kumar *et al.* 2016). While, some workers have reported more number of genera (159-427), plant species (231-832) and families (69-128) in Himalayan vegetation in their studies (Rai *et al.* 2012; Shaheen *et al.* 2012; Sharma *et al.* 2014; Dar and Sundarapandian 2016). The lower number of plant species recorded in present area may be attributed to harshness of the climatic and edaphic conditions and high biotic interference.



**Figure 2. Cluster dendrogram of different forest types (trees + shrubs + herbs) of Kinnaur, Himachal Pradesh**

The data obtained from the survey of nine different forest types was analysed using rescaled distance cluster analysis (Figure 2). Cluster analysis divided forest types of dry

temperate and alpine forest into two major groups based on similarities of species in them. Group -1 consists of alpine pasture, dry alpine scrub, sub alpine birch forest, dry blue pine forest and sub alpine fir forest whereas, group -2 is comprised of neoza pine forest and dry deodar forest. Group-1 was further divided into sub-groups in which sub- group -1 consists of alpine pasture and dry alpine scrub which were very close to each other than sub alpine birch forest in terms of similar species. Sub-group-2 consists of dry blue pine forest and sub alpine fir forest. Dry broad-leaved and coniferous forests and birch-rhododendron scrub forest showed non significant relation with other forest types of dry temperate and alpine forest. Hence, they were not forming any distance cluster. The presence of any species in any area is determined by the prevailing environmental conditions and its tolerance and adaptation by it (Bhandari *et al.* 1999). The range of niches available and occupied by these species in turn suggests their long biotic range as contended by Goodall (1979).

#### **4.1.1 Vegetation indices**

The results in respect of Shannon-Wiener diversity, Simpson's dominance and Species richness for various plant categories *viz.*, trees, shrubs and herbs are being presented in Tables 7.

##### **4.1.1.1 Species richness**

The data pertaining to species richness for trees ranged from 0.00-0.56. Alpine pasture and dry alpine scrub did not showed any richness in their forest communities type whereas, maximum species richness (0.56) were showed for sub-alpine fir forest. The shrubs species richness ranged from 0.00-1.76. Alpine pasture did not showed any richness in their forest communities type whereas, maximum species richness (1.76) were recorded for dry deodar forest. Herbaceous vegetation richness ranged from 0.84-1.97. The maximum species richness (1.97) was observed in dry deodar forest and minimum richness (0.84) was recorded in birch-rhododendron scrub forest. Kharkwal *et al.* (2009) and Pandey *et al.* (2010) also contended that species richness changes with amount of rainfall and temperature owing to secondary succession when environmental and edaphic conditions are favorable with low fluctuations. Similar changes along the altitude on species richness have also been reported by Whittaker 1960; Whittaker and Niering 1965; Saxena *et al.* 1985; Lieberman *et al.* 1996; Kessler (2000); Grytnes and Vetaas (2002); Grytnes (2003) and Kharkwal *et al.* (2009). The species richness in these forest types was lower than the values reported for high altitude areas of Himalaya by Adhikari *et al.* 1991; Bankoti *et al.* 1992 and Sharma *et al.* 2014. The

high richness of shrubs and herbs in dry deodar forest may be due to diverse habitats and suitable edaphic and climatic factors supporting growth and survival of the species. The species richness for trees in alpine pasture and dry alpine scrub and shrubs in alpine pasture were reported zero due to non-presence of trees and shrubs in the respective forest types. In general, vegetation indices are highest for herbaceous layer followed by shrubs and trees layer.

**Table 7. Vegetation indices of trees, shrubs and herbs in different forest communities in Kinnaur district of Himachal Pradesh**

Treatments (Forest Types)	Plant categories	Vegetation indices		
		Shannon –weiner diversity	Simpson 's dominance	Species richness
<b>T<sub>1</sub>-Dry broad leaf and coniferous forests</b>	<i>Herbs</i>	2.78	0.08	1.69
	<i>Shrubs</i>	1.90	0.19	1.25
	<i>Trees</i>	0.68	0.51	0.18
<b>T<sub>2</sub>-Neoza pine forest</b>	<i>Herbs</i>	2.77	0.09	1.59
	<i>Shrubs</i>	1.95	0.17	1.34
	<i>Trees</i>	0.81	0.52	0.38
<b>T<sub>3</sub>-Dry deodar forest</b>	<i>Herbs</i>	3.04	0.06	1.97
	<i>Shrubs</i>	2.36	0.10	1.76
	<i>Trees</i>	0.39	0.82	0.38
<b>T<sub>4</sub>- Dry blue pine forest</b>	<i>Herbs</i>	2.91	0.07	1.88
	<i>Shrubs</i>	1.95	0.24	0.82
	<i>Trees</i>	0.78	0.56	0.37
<b>T<sub>5</sub>-Sub alpine birch forest</b>	<i>Herbs</i>	2.32	0.12	1.16
	<i>Shrubs</i>	1.13	0.38	0.51
	<i>Trees</i>	0.83	0.52	0.37
<b>T<sub>6</sub>-Sub alpine fir forest</b>	<i>Herbs</i>	2.78	0.08	1.80
	<i>Shrubs</i>	1.55	0.23	0.70
	<i>Trees</i>	1.12	0.37	0.56
<b>T<sub>7</sub>-Birch-rhododendron scrub forest</b>	<i>Herbs</i>	2.08	0.16	0.84
	<i>Shrubs</i>	0.37	0.84	0.32
	<i>Trees</i>	0.20	0.91	0.19
<b>T<sub>8</sub>-Alpine pasture</b>	<i>Herbs</i>	2.67	0.10	1.77
	<i>Shrubs</i>	0.00	0.00	0.00
	<i>Trees</i>	0.00	0.00	0.00
<b>T<sub>9</sub>-Dry alpine scrub</b>	<i>Herbs</i>	2.27	0.12	0.96
	<i>Shrubs</i>	0.89	0.47	0.37
	<i>Trees</i>	0.00	0.00	0.00

#### 4.1.1.2 Species diversity

The species diversity for trees ranged from 0.00-1.12. Alpine pasture and dry alpine scrub did not show any diversity in their forest types whereas, maximum species diversity (1.12) was observed in sub-alpine fir forest. The shrubs species diversity ranged from 0.00-2.36. Alpine pasture did not show any diversity in their forest types whereas, maximum species diversity (2.36) was showed by dry deodar forest. However, herbaceous vegetation

diversity ranged from 2.08-3.04. Maximum species diversity (3.04) was observed in dry deodar forest and minimum diversity (2.08) was recorded in birch-rhododendron scrub forest. The slow rate of evolution and community stabilization along with relatively drier climatic conditions can be the reason for the low diversity values of alpine pasture and dry alpine scrub as compared to other forest types. The recorded index values (2.08-3.04) for herbaceous vegetation in the forest of the present study is similar to the range reported by Pande (2001); Mishra *et al.* (2003); Kumar and Thakur (2008) and Sharma *et al.* (2009) for forests in central Himalayan region.

#### **4.1.1.3 Species dominance**

The species dominance for trees ranged from 0.00-0.91. Alpine pasture and dry alpine scrub did not show any species dominance in their forest types whereas, maximum species dominance (0.91) was shown by birch-rhododendron scrub forest. The shrubs species dominance ranged from 0.00-0.84. Alpine pasture did not show any dominance in their forest communities type whereas, maximum species dominance (0.84) were shown by birch-rhododendron scrub forest. Herbaceous vegetation dominance ranged from 0.06-0.16. Maximum species dominance (0.16) was observed in birch-rhododendron scrub forest and minimum dominance (0.06) was recorded in dry deodar forest. The lower concentration of dominance indicates the sharing of dominance by many species. In present study Simpson's index of dominance (tree + shrubs + herbs) ranged between 0.10-1.91 with maximum in birch-rhododendron scrub forest and minimum in alpine pasture. This is in line with the findings of other workers, who found concentration of dominance for certain Himalayan forest (Whittaker 1965, Risser and Rice 1971).

#### **4.1.1.4 Similarity index (SI)**

The data pertaining to number of species present in different major forest type communities was used to find similarity and dissimilarity among shrubs and herbs (Table 8 and 9). In shrubs, similarity index ranges from 0-0.57. It is maximum for neoza pine forest and dry deodar forest (0.57), each displaying equal value and minimum in dry broad leaf coniferous forests and sub alpine birch forest, dry broad leaf coniferous forests and sub alpine fir forest, dry broad leaf coniferous forests and birch-rhododendron scrub forest, dry broad leaf coniferous forests and alpine pasture, dry broad leaf coniferous forests and dry alpine scrub, neoza pine forest and dry blue pine forest, neoza pine forest and sub alpine birch forest, neoza pine forest and sub alpine fir forest, neoza pine forest and birch-rhododendron

**Table 8. Index of similarity & dissimilarity of shrubs in different forest types of Himalayan dry temperate and alpine forest of Kinnaur (H.P.)**

Similarity (S) Dissimilarity (D)	T <sub>1</sub> - Dry broad-leaved and coniferous forests	T <sub>2</sub> - Neoza pine forest	T <sub>3</sub> - Dry deodar forest	T <sub>4</sub> - West Himalayan high level dry blue pine forest	T <sub>5</sub> - West Himalayan sub- alpine birch forest	T <sub>6</sub> - West Himalayan sub- alpine fir forest	T <sub>7</sub> - Birch-rhododendron scrub forest	T <sub>8</sub> - Alpine pasture	T <sub>9</sub> - Dry alpine scrub
T <sub>1</sub> - Dry broad-leaved and coniferous forests	-	0.56	0.38	0.13	0.00	0.00	0.00	0.00	0.00
T <sub>2</sub> - Neoza pine forest	0.44	-	0.57	0.13	0.00	0.00	0.00	0.00	0.00
T <sub>3</sub> - Dry deodar forest	0.62	0.43	-	0.44	0.25	0.24	0.00	0.00	0.00
T <sub>4</sub> - West Himalayan high level dry blue pine forest	0.87	0.87	0.56	-	0.20	0.55	0.22	0.00	0.00
T <sub>5</sub> - West Himalayan sub- alpine birch forest	1.00	1.00	0.75	0.80	-	0.44	0.28	0.00	0.00
T <sub>6</sub> - West Himalayan sub- alpine fir forest	1.00	1.00	0.76	0.45	0.56	-	0.25	0.00	0.00
T <sub>7</sub> - Birch-rhododendron scrub forest	1.00	1.0	1.00	0.78	0.72	0.75	-	0.00	0.00
T <sub>8</sub> - Alpine pasture	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-	0.00
T <sub>9</sub> - Dry alpine scrub	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-

**Table 9. Index of similarity & dissimilarity of herbs in different forest types of Himalayan dry temperate and alpine forest of Kinnaur (H.P.)**

Similarity (S)	T <sub>1</sub> - Dry broad-leaved and coniferous forests	T <sub>2</sub> - Neoza pine forest	T <sub>3</sub> - Dry deodar forest	T <sub>4</sub> - West Himalayan high level dry blue pine forest	T <sub>5</sub> - West Himalayan sub- alpine birch forest	T <sub>6</sub> - West Himalayan sub- alpine fir forest	T <sub>7</sub> - Birch-rhododendron scrub forest	T <sub>8</sub> - Alpine pasture	T <sub>9</sub> - Dry alpine scrub
Dissimilarity (D)									
T <sub>1</sub> - Dry broad-leaved and coniferous forests	-	0.14	0.21	0.17	0.11	0.13	0.00	0.18	0.00
T <sub>2</sub> - Neoza pine forest	0.86	-	0.40	0.23	0	0.09	0.06	0.14	0.19
T <sub>3</sub> - Dry deodar forest	0.79	0.60	-	0.28	0.05	0.17	0.00	0.17	0.05
T <sub>4</sub> - West Himalayan high level dry blue pine forest	0.83	0.77	0.72	-	0.15	0.38	0.00	0.09	0.06
T <sub>5</sub> - West Himalayan sub- alpine birch forest	0.89	1.00	0.95	0.85	-	0.21	0.15	0.16	0.15
T <sub>6</sub> - West Himalayan sub- alpine fir forest	0.87	0.91	0.83	0.62	0.79	-	0.12	0.09	0.11
T <sub>7</sub> - Birch-rhododendron scrub forest	1.00	0.94	1.00	1.00	0.85	0.88	-	0.00	0.26
T <sub>8</sub> - Alpine pasture	0.82	0.86	0.83	0.91	0.84	0.91	1.00	-	0.34
T <sub>9</sub> - Dry alpine scrub	1.00	0.81	0.95	0.94	0.85	0.89	0.74	0.66	-

scrub forest, neoza pine forest and alpine pasture, neoza pine forest and dry alpine scrub, dry deoder forest and birch-rhododendron scrub forest, dry deoder forest and alpine pasture, dry deoder forest and dry alpine scrub, dry blue pine forest and alpine pasture, dry blue pine forest and dry alpine scrub, sub alpine birch forest and alpine pasture, sub alpine birch forest and dry alpine scrub, sub alpine fir forest and alpine pasture, sub alpine fir forest and dry alpine scrub, birch-rhododendron scrub forest and alpine pasture, birch-rhododendron scrub forest and dry alpine scrub, alpine pasture and dry alpine scrub all had no similarity index (0).

The dissimilarity index ranged from 0.43-1.00 (Table 8). The dissimilarity index is maximum (1) for dry broad leaf coniferous forest and dry blue pine forest, dry broad leaf coniferous forests and sub alpine birch forest, dry broad leaf coniferous forests and sub alpine fir forest, dry broad leaf coniferous forests and birch-rhododendron scrub forest, dry broad leaf coniferous forests and alpine pasture, dry broad leaf coniferous forests and dry alpine scrub, neoza pine forest and dry blue pine forest, neoza pine forest and sub alpine birch forest, neoza pine forest and sub alpine fir forest, neoza pine forest and birch-rhododendron scrub forest, neoza pine forest and alpine pasture, neoza pine forest and dry alpine scrub, dry deoder forest and birch-rhododendron scrub forest, dry deoder forest and alpine pasture, dry deoder forest and dry alpine scrub, dry blue pine forest and alpine pasture, dry blue pine forest and dry alpine scrub, sub alpine birch forest and alpine pasture, sub alpine birch forest and dry alpine scrub, sub alpine fir forest and alpine pasture, sub alpine fir forest and dry alpine scrub, birch-rhododendron scrub forest and alpine pasture, birch-rhododendron scrub forest and dry alpine scrub, alpine pasture and dry alpine scrub. The minimum dissimilarity index was recorded in sub alpine fir forest and dry blue pine forest (0.43).

The similarity index in respect of herbs is presented in Table 9 and it ranged from 0-0.40. It is maximum for dry deoder forest and neoza pine forest (0.40) and minimum in dry broad leaf coniferous forests and birch-rhododendron scrub forest, dry broad leaf coniferous forests and dry alpine scrub, dry deoder forest and birch-rhododendron scrub forest, dry blue pine forest and birch-rhododendron scrub forest, birch-rhododendron scrub forest and alpine pasture. The dissimilarity index ranged from 0.62-1.00. The dissimilarity index was maximum (1) for dry broad leaf coniferous forests and birch-rhododendron scrub forest, dry broad leaf coniferous forests and dry alpine scrub, dry deoder forest and birch-rhododendron scrub forest, dry blue pine forest and birch-rhododendron scrub forest, birch-rhododendron

scrub forest and alpine pasture and minimum (0.60) for dry deodar forest and neoza pine forest.

In the present study it was observed that highest similarity index for both shrubs and herbs was observed between dry deodar forest and neoza pine forest, which is indicative of uniform distribution of vegetation in these forest types. The maximum similarity in the shrub and herb species in the above forest might be due to proximity and continuity of the ranges, resulting in similar climatic, edaphic and topographic features. Suyal *et al.* (2010) also opined that close proximity results in high similarity index of vegetation, the same could be related to grouping of forest based on similarity index of the present study.

## 4.2 PHYTOSOCIOLOGY

The phytosociological attributes *i.e.* density (D), basal area (BA) and importance values Index (IVI) of various forest types *viz.*, 13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex* – *Pinus gerardiana*), 13C<sub>2a</sub>- Neoza pine forest (*Pinus gerardiana*), 13C<sub>2b</sub>- Dry deodar forest (*Cedrus deodara*), 13 C<sub>3</sub>- West Himalayan high level dry blue pine forest (*Pinus wallichiana*), 14C<sub>1a</sub>- West Himalayan sub- alpine birch forest, 14C<sub>1b</sub>- West Himalayan sub-alpine fir forest, 15C<sub>1</sub>- Birch-rhododendron scrub forest, 15C<sub>3</sub>- Alpine pasture, 16C<sub>1</sub>-Dry alpine scrub are presented in Tables 10 - 19 and described under following heads:

### 4.2.1 Dry broad-leaved and coniferous forests

The dry broad-leaved and coniferous forest community (Table 10) is comprised of *Quercus ilex* and *Pinus gerardiana* (tree species) recorded a total density 275 N ha<sup>-1</sup> and basal area of 17.03 m<sup>2</sup> ha<sup>-1</sup>. The *Quercus ilex* showed dominance in term of density (181 N ha<sup>-1</sup>), basal area (10.21 m<sup>2</sup> ha<sup>-1</sup>) and IVI (175.87) in this community.

There were nine species of shrub which recorded a total density of 593 N ha<sup>-1</sup> and basal area of 0.36 m<sup>2</sup> ha<sup>-1</sup> (Table 10). A maximum values for density (222 N ha<sup>-1</sup>) and IVI (92.59) was observed for *Plectranthus rugosus* whereas, basal area (0.11 m<sup>2</sup> ha<sup>-1</sup>) was recorded maximum for *Lonicera quinquelocularis*. Contrary to this, minimum density (15 N ha<sup>-1</sup>) was observed in *Abelia triflora*, *Daphne oleoides* and *Rhamnus variegata*. Whereas, minimum basal area (0.01 m<sup>2</sup> ha<sup>-1</sup>) was recorded for *Daphne oleoides* and *Rhamnus variegata* and IVI (8.81) was observed in *Rhamnus variegata*.

Herbaceous vegetation is comprised of 14 herb species and 8 species of grasses. On the whole they resulted in a total density of 245185 N ha<sup>-1</sup> and basal area 5.70 m<sup>2</sup> ha<sup>-1</sup> (Table 10). Among herbs, *Artemisia parviflora* showed maximum values for density (16296 N ha<sup>-1</sup>), basal area (0.51 m<sup>2</sup> ha<sup>-1</sup>) and IVI (25.91). On the other hand, *Verbascum thapsus* showed minimum values for density (370 N ha<sup>-1</sup>), basal area (0.004 m<sup>2</sup> ha<sup>-1</sup>) and IVI (2.00). In grasses, *Piptatherum* spp showed maximum values for density (35556 N ha<sup>-1</sup>), whereas basal area (1.08 m<sup>2</sup> ha<sup>-1</sup>) and IVI (51.94) were observed maximum in *Stipa sibirica* and minimum values for density (7407 N ha<sup>-1</sup>), basal area (0.12 m<sup>2</sup> ha<sup>-1</sup>) and IVI (7.50) were recorded in case of *Arthraxon lancifolius*.

**Table 10. Floristic composition of trees, shrubs and herbs in dry broad-leaved and coniferous forests**

		Tree	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Trees	<i>Quercus ilex</i>	181	10.25	65.66	50.00	60.21	175.87
2		<i>Pinus gerardiana</i>	94	6.78	34.34	50.00	39.79	124.13
		<b>Total</b>	<b>275</b>	<b>17.03</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Shrubs</b>						
1	Shrubs	<i>Abelia triflora</i>	15	0.03	2.50	3.57	6.89	12.97
2		<i>Berberis lycium</i>	59	0.03	10.00	7.14	8.06	25.20
3		<i>Daphne oleoides</i>	15	0.01	2.50	3.57	2.80	8.87
4		<i>Desmodium elegens</i>	44	0.04	7.50	7.14	9.81	24.45
5		<i>Desmodium tiliacifolium</i>	44	0.05	7.50	10.71	13.46	31.67
6		<i>Indigofera heterantha</i>	74	0.01	12.50	7.14	3.51	23.16
7		<i>Lonicera quienquelocularis</i>	104	0.11	17.50	25.00	29.78	72.28
8		<i>Plectranthus rugosus</i>	222	0.08	37.50	32.14	22.95	92.59
9		<i>Rhamnus variegata</i>	15	0.01	2.50	3.57	2.74	8.81
		<b>Total</b>	<b>593</b>	<b>0.36</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Herbs</b>						
1	Herbs	<i>Artemisia parviflora</i>	16296	0.51	7.36	8.77	9.78	25.91
2		<i>Artemisia scoparia</i>	2222	0.22	1.00	3.51	4.24	8.75
3		<i>Artemisia roxburghiana</i>	4074	0.13	1.84	3.51	2.46	7.80
4		<i>Aster ablescens</i>	1852	0.15	0.84	1.75	2.95	5.54
5		<i>Erigeron annuus</i>	8889	0.01	4.01	3.51	0.15	7.67
6		<i>Fragaria nubicola</i>	5185	0.15	2.01	3.51	0.89	6.40
7		<i>Geum sikkimense</i>	1481	0.01	0.67	5.26	0.23	6.16
8		<i>Impatiens sulcata</i>	13333	0.19	6.02	5.26	3.61	14.89
9		<i>Lespedeza gerardiana</i>	9259	0.11	4.18	10.53	2.21	16.92
10		<i>Saussurea albescens</i>	2963	0.36	1.34	3.51	6.92	11.77
11		<i>Silene edgeworthii</i>	4444	0.05	2.01	3.51	0.89	6.40
12		<i>Stachys melissefolia</i>	7778	0.04	3.51	5.26	0.74	9.52
13		<i>Trifolium pretense</i>	1111	0.08	0.50	1.75	1.53	3.79
14		<i>Verbascum thapsus</i>	370	0.004	0.17	1.75	0.08	2.00
15	Grasses	<i>Agropyron longearistatum</i>	19259	0.32	8.70	8.77	6.18	23.65
16		<i>Agrostis alba</i>	17037	0.52	7.69	3.51	10.05	21.25
17		<i>Arthraxon lancifolius</i>	7407	0.12	3.34	1.75	2.40	7.50
18		<i>Oryzopsis aequiglumis</i>	18148	0.18	8.19	7.02	3.42	18.63
19		<i>Oryzopsis munroi</i>	22963	0.33	10.37	7.02	6.36	23.75
20		<i>Pennisetum orientale</i>	10741	0.53	4.85	1.75	10.21	16.81
21		<i>Piptatherum spp</i>	35556	0.94	11.20	5.26	10.23	26.70
22		<i>Stipa sibirica</i>	34815	1.08	20.57	10.53	20.84	51.94
		<b>Total</b>	<b>245185</b>	<b>5.70</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

#### 4.2.2 Neoza pine forest

The neoza pine forest community is represented by *Pinus gerardiana*, *Cedrus deodara* and *Pinus wallichiana* (trees species) recording a total density of 189 N ha<sup>-1</sup> and basal area 18.45 m<sup>2</sup> ha<sup>-1</sup> (Table 11). The *Pinus gerardiana* showed maximum dominance in term of density (150 N ha<sup>-1</sup>), basal area (13.85 m<sup>2</sup> ha<sup>-1</sup>) and IVI (199.48).

**Table 11. Floristic composition of trees, shrubs and herbs in neoza pine forest**

		Tree	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Tree	<i>Pinus gerardiana</i>	150	13.85	79.41	45.00	75.07	199.48
2		<i>Cedrus deodara</i>	33	3.62	17.65	45.00	19.60	82.24
3		<i>Pinus wallichiana</i>	6	0.98	2.94	10.00	5.33	18.27
		<b>Total</b>	<b>189</b>	<b>18.45</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Shrub</b>						
1	Shrubs	<i>Lonicera quinquelocularis</i>	44	0.05	11.54	8.51	13.52	33.57
2		<i>Berberis lycium</i>	15	0.01	3.85	4.26	1.93	10.03
3		<i>Plectranthus rugosus</i>	44	0.01	11.54	8.51	2.91	22.95
4		<i>Abelia triflora</i>	15	0.02	3.85	4.26	5.52	13.63
5		<i>Berberis aristata</i>	30	0.02	7.69	8.51	6.50	22.71
6		<i>Desmodium tilaefolium</i>	15	0.01	3.85	4.26	3.35	11.45
7		<i>Lonicera hypoleuca</i>	74	0.10	19.23	27.66	28.60	75.49
8		<i>Ephedra gerardiana</i>	74	0.01	19.23	12.77	2.51	34.51
9		<i>Rosa webbiana</i>	74	0.13	19.23	21.28	35.16	75.66
		<b>Total</b>	<b>385</b>	<b>0.36</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Herbs</b>						
1	Herbs	<i>Anemone polyanthes</i>	5185	0.02	3.41	3.31	0.69	7.41
2		<i>Artemisia brevifolia</i>	9259	1.58	6.08	11.60	45.86	63.54
3		<i>Artemisia maritima</i>	7407	0.09	4.87	3.31	2.72	10.90
4		<i>Artemisia scorparia</i>	15926	0.20	10.46	11.60	5.73	27.80
5		<i>Astragalus candoleanus</i>	741	0.21	0.49	1.66	6.04	8.19
6		<i>Bunium persium</i>	9630	0.04	6.33	4.97	1.03	12.33
7		<i>Chelnonopodium botrys</i>	12222	0.05	8.03	4.97	1.42	14.42
8		<i>Dianthus angulatus</i>	1481	0.01	0.97	1.66	0.38	3.01
9		<i>Galium aparine</i>	4074	0.10	2.68	1.66	2.98	7.31
10		<i>Impatiens brachycentra</i>	7037	0.06	4.62	3.31	1.82	9.75
11		<i>Lactuca benthamii</i>	4815	0.16	3.16	3.31	4.69	11.16
12		<i>Origanum vulgare</i>	6667	0.02	4.38	6.63	0.58	11.59
13		<i>Potentilla atrosanguinea</i>	3333	0.11	2.19	1.66	3.33	7.18
14		<i>Salvia glutinosa</i>	7778	0.08	5.11	3.31	2.19	10.62
15		<i>Senecio chrysanthemoides</i>	5185	0.05	3.41	3.87	1.44	8.72
16		<i>Sopubia trifida</i>	20741	0.13	13.63	8.29	3.83	25.75
17		<i>Thymus serpyllum</i>	8889	0.04	5.84	6.63	1.07	13.54
18		<i>Verbascum thapsus</i>	3704	0.26	2.43	9.94	7.55	19.92
19	Grasses	<i>Agropyron semicostatum</i>	9259	0.16	6.08	4.97	4.50	15.56
20		<i>Agropyron longearistatum</i>	8889	0.07	5.84	3.31	2.15	11.30
		<b>Total</b>	<b>152222</b>	<b>3.45</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

There were nine species of shrubs which recorded a total density of 385 N ha<sup>-1</sup> and basal area of 0.36 m<sup>2</sup> ha<sup>-1</sup> (Table 11). Maximum values for density (74 N ha<sup>-1</sup>) was recorded in *Rosa webbiana*, *Ephedra gerardiana* and *Lonicera hypoleuca* each displaying identical values whereas, basal area (0.13 m<sup>2</sup> ha<sup>-1</sup>) and IVI (75.66) were recorded maximum for *Rosa webbiana*. In contrary, a minimum density (15 N ha<sup>-1</sup>) was observed in *Berberis lycium*, *Desmodium tilaefolium* and *Abelia triflora*, whereas basal area (0.01 m<sup>2</sup> ha<sup>-1</sup>) was recorded in *Berberis lycium*, *Plectranthus rugosus*, *Desmodium tilaefolium* and *Ephedra gerardiana* and IVI (10.03) was observed in case of *Berberis lycium*.

Herbaceous vegetation is comprised of 18 species of herbs and 2 species of grasses. On the whole they resulted in a total density of 152222 N ha<sup>-1</sup>, basal area of 3.45 m<sup>2</sup> ha<sup>-1</sup> and IVI of 300 (Table 11). Among herbs, *Artemisia scorparia* showed maximum values for density (15926 N ha<sup>-1</sup>) whereas, maximum basal area (1.58 m<sup>2</sup> ha<sup>-1</sup>) and IVI (63.54) were recorded in *Artemisia brevifolia*. On the other hand, *Astragalus candoleanus* showed minimum values for density (741 N ha<sup>-1</sup>) whereas, basal area (0.01 m<sup>2</sup> ha<sup>-1</sup>) and IVI (3.01) were recorded for *Dianthus angulatus*. In grasses, *Agropyron semicostatum* showed maximum values for density (9259 N ha<sup>-1</sup>), basal area (0.16 m<sup>2</sup> ha<sup>-1</sup>) and IVI (15.56) and minimum values for density (8889 N ha<sup>-1</sup>), basal area (0.07 m<sup>2</sup> ha<sup>-1</sup>) and IVI (11.30) were observed in *Agropyron longearistatum*.

#### 4.2.3 Dry deodar forest

The dry deodar forest community is comprised of *Cedrus deodara*, *Pinus gerardiana* and *Pinus wallichiana* (trees species) recording a total density 194 N ha<sup>-1</sup> and basal area of 34.78 m<sup>2</sup> ha<sup>-1</sup> (Table 12). The *Cedrus deodara* showed maximum dominance in term of density (183 N ha<sup>-1</sup>), basal area (34.10 m<sup>2</sup> ha<sup>-1</sup>) and IVI (270.61).

There are twelve species of shrub which recorded a total density of 518 N ha<sup>-1</sup> and basal area of 0.39 m<sup>2</sup> ha<sup>-1</sup> (Table 12). Maximum values for density (119 N ha<sup>-1</sup>) and IVI (51.87) were recorded in *Plectranthus rugosus* whereas, basal area (0.06 m<sup>2</sup> ha<sup>-1</sup>) was recorded maximum for *Cotoneaster bacillaris* and *Desmodium confertum*. Contrary to this, a minimum density (15 N ha<sup>-1</sup>) was observed in *Berberis aristata*, *Ephedra gerardiana* and *Lonicera quinquelocularis* whereas, basal area (0.003 m<sup>2</sup> ha<sup>-1</sup>) was recorded in *Ephedra gerardiana* and IVI (10.05) was observed in *Berberis aristata*.

Herbaceous vegetation is comprised of 19 species of herbs, 5 species of grasses and 1 species of fern. On the whole, they resulted in a total density of 194444 N ha<sup>-1</sup>, basal area of 3.65 m<sup>2</sup> ha<sup>-1</sup> and IVI of 300 (Table 12). Among herbs, *Impatiens sulcata* showed maximum values for density (12222 N ha<sup>-1</sup>) and IVI (20.59) whereas, maximum basal area (0.45 m<sup>2</sup> ha<sup>-1</sup>) was recorded for *Astragalus candoleanus*.

**Table 12. Floristic composition of trees, shrubs and herbs in dry deodar forest**

		<b>Tree</b>	<b>Density (N ha<sup>-1</sup>)</b>	<b>Basal area (m<sup>2</sup> ha<sup>-1</sup>)</b>	<b>Relative Density</b>	<b>Relative frequency</b>	<b>Relative Dominance</b>	<b>IVI</b>
1	Tree	<i>Cedrus deodara</i>	183	34.10	94.29	78.26	98.06	270.61
2		<i>Pinus wallichiana</i>	3	0.18	1.43	8.70	0.52	10.64
3		<i>Pinus gerardiana</i>	8	0.49	4.29	13.04	1.42	18.75
		<b>Total</b>	<b>194</b>	<b>34.78</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Shrub</b>						
1	Shrubs	<i>Berberis aristata</i>	15	0.01	2.86	3.85	3.35	10.05
2		<i>Cotoneaster bacillaris</i>	30	0.06	5.71	7.69	14.61	28.01
3		<i>Daphne oleoides</i>	30	0.02	5.71	7.69	4.05	17.46
4		<i>Desmodium confertum</i>	59	0.06	11.43	11.54	15.46	38.42
5		<i>Ephedra gerardiana</i>	15	0.003	2.86	7.69	0.69	11.24
6		<i>Indigofera heterantha</i>	44	0.01	8.57	3.85	3.26	15.68
7		<i>Indigofera gerardiana</i>	74	0.04	14.29	7.69	9.85	31.83
8		<i>Lonicera hypoleuca</i>	59	0.05	11.43	15.38	12.26	39.07
9		<i>Lonicera quinquelocularis</i>	15	0.02	2.86	3.85	5.09	11.79
10		<i>Plectranthus rugosus</i>	119	0.05	22.86	15.38	13.63	51.87
11		<i>Rosa macrophylla</i>	30	0.02	5.71	7.69	6.19	19.59
12		<i>Rosa webbiana</i>	30	0.05	5.71	7.69	11.57	24.98
		<b>Total</b>	<b>518</b>	<b>0.39</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Herbs</b>						
1	Herbs	<i>Anaphalis busua</i>	1852	0.02	0.95	1.61	0.63	3.19
2		<i>Arisaema flavum</i>	1111	0.03	0.57	3.23	0.89	4.69
3		<i>Artemisia scoparia</i>	15185	0.09	7.81	9.68	2.43	19.91
4		<i>Asparagus filicinus</i>	3333	0.06	1.71	3.23	1.52	6.46
5		<i>Aster indamellus</i>	7407	0.04	3.81	6.45	0.99	11.25
6		<i>Astragalus candoleanus</i>	2593	0.45	1.33	3.23	12.23	16.79
7		<i>Erigeron annuus</i>	7037	0.04	3.62	3.23	1.06	7.91
8		<i>Fragaria vesca</i>	4444	0.004	2.29	3.23	0.11	5.62
9		<i>Impatiens sulcata</i>	12222	0.40	6.29	3.23	11.08	20.59
10		<i>Lactuca benthami</i>	2963	0.03	1.52	4.84	0.74	7.10
11		<i>Nepeta ruderalis</i>	4444	0.10	2.29	1.61	2.72	6.62
12		<i>Origanum vulgare</i>	6667	0.02	3.43	3.23	0.65	7.30
13		<i>Salvia glutinosa</i>	7407	0.23	3.81	3.23	6.33	13.36
14		<i>Senecio cappa</i>	4815	0.06	2.48	4.84	1.68	9.00
15		<i>Smilacina purpurea</i>	5556	0.34	2.86	1.61	9.42	13.89
16		<i>Thymus serpyllum</i>	4444	0.03	2.29	1.61	0.73	4.63
17		<i>Verbascum thapsus</i>	6667	0.10	3.43	8.06	2.62	14.11
18		<i>Viola canescens</i>	5926	0.02	3.05	3.23	0.47	6.74
19		<i>Viola serpens</i>	6667	0.05	3.43	4.84	1.37	9.64
20	Grasses	<i>Agropyron longearistatum</i>	31481	0.63	16.19	8.06	17.27	41.52
21		<i>Agropyron semicostatum</i>	11481	0.20	5.90	3.23	5.47	14.61
22		<i>Alopecurus arundinaceus</i>	16667	0.33	8.57	4.84	8.97	22.38
23		<i>Hemarthris altissima</i>	12593	0.15	6.48	4.84	4.08	15.39
24		<i>Stipa sibirica</i>	9259	0.16	4.76	3.23	4.45	12.44
25	Fern	<i>Pteridium aquilinum</i>	2222	0.08	1.14	1.61	2.10	4.85
		<b>Total</b>	<b>194444</b>	<b>3.65</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

On the other hand, *Arisaema flavum* showed minimum values for density (1111 N ha<sup>-1</sup>) whereas, basal area (0.004 m<sup>2</sup> ha<sup>-1</sup>) for *Fragaria vesca* and IVI (3.19) were recorded for *Anaphalis busua*. In grasses, *Agropyron longearistatum* showed maximum values for density (31481 N ha<sup>-1</sup>), basal area (0.63 m<sup>2</sup> ha<sup>-1</sup>) and IVI (41.56) while, minimum values for density (9259 N ha<sup>-1</sup>) and IVI (12.44) were recorded in case of *Stipa sibirica* whereas, basal area (0.15 m<sup>2</sup> ha<sup>-1</sup>) was observed for *Hemarthris altissima*. There was one species of fern (*Pteridium aquilinum*), which had a density of 2222 N ha<sup>-1</sup> and basal area of 0.08 m<sup>2</sup> ha<sup>-1</sup> and showing IVI of 4.85.

#### 4.2.4 Dry blue pine forest

Dry blue pine forest community is comprised of *Pinus wallichiana*, *Cedrus deodara* and *Abies spectabilis* (trees species) recorded a total density of 233 N ha<sup>-1</sup>, basal area of 19.80 m<sup>2</sup> ha<sup>-1</sup> and IVI of 300 (Table 13). In this community, *Pinus wallichiana* showed maximum dominance in term of density (183 N ha<sup>-1</sup>), basal area (15.49 m<sup>2</sup> ha<sup>-1</sup>) and IVI (213.06).

There are six species of shrubs which recorded a total density of 459 N ha<sup>-1</sup> and basal area 0.37 m<sup>2</sup> ha<sup>-1</sup> (Table 13). Maximum values of density (148 N ha<sup>-1</sup>) was recorded in *Berberis erythroclada* whereas, basal area (0.17 m<sup>2</sup> ha<sup>-1</sup>) and IVI (110.05) were recorded to be maximum for *Salix hastata*. Contrary to this, minimum density (30 N ha<sup>-1</sup>) and basal area (0.02 m<sup>2</sup> ha<sup>-1</sup>) were observed in *Plectranthus rugosus* and *Rosa macrophylla*, respectively and IVI (14.95) was observed to be maximum in case of *Plectranthus rugosus*.

Herbaceous vegetation is comprised of 17 species of herbs, 6 species of grasses and 1 species of fern. On the whole, they resulted in a total density values of 210772 N ha<sup>-1</sup> and basal area of 5.53 m<sup>2</sup> ha<sup>-1</sup> (Table 13). Among herbs, *Salvia nubicola* showed maximum values for density (21111N ha<sup>-1</sup>), basal area (1.16 m<sup>2</sup> ha<sup>-1</sup>) and IVI (44.55). On the other hand, *Verbascum thapsus* and *Rumex nepalensis* showed minimum values for density (370 N ha<sup>-1</sup>) whereas, minimum basal area (0.003 m<sup>2</sup> ha<sup>-1</sup>) and IVI (1.74) were observed in *Rumex nepalensis*. In grasses, *Chrysopogon gryllus* showed maximum values for density (22222 N ha<sup>-1</sup>) and IVI (25.25). Whereas, maximum basal area (0.63 m<sup>2</sup> ha<sup>-1</sup>) were recorded in *Setaria viridis* and minimum density (7778 N ha<sup>-1</sup>) and IVI (8.37) were observed in *Brachypodium distachyon* whereas, basal area (0.15 m<sup>2</sup> ha<sup>-1</sup>) was recorded in *Dactylis glomerate*. There was

one species of fern (*Pteridium aquilinum*) which had a density of 4074 N ha<sup>-1</sup> and basal area of 0.19 m<sup>2</sup> ha<sup>-1</sup> and IVI having values of 9.91.

**Table 13. Floristic composition of trees, shrubs and herbs in dry blue pine forest**

		Tree	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Trees	<i>Pinus wallichiana</i>	183	15.49	78.57	56.25	78.24	213.06
2		<i>Cedrus ceodera</i>	39	3.53	16.67	31.25	17.81	65.73
3		<i>Abies spectabilis</i>	11	0.78	4.76	12.50	3.95	21.21
		<b>Total</b>	<b>233</b>	<b>19.80</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		Shrubs						
1	Shrubs	<i>Berberis erythroclada</i>	148	0.07	32.26	30.77	17.96	80.99
2		<i>Desmodium confertum</i>	44	0.06	9.68	11.54	14.92	36.14
3		<i>Indigofera gerardiana</i>	74	0.04	16.13	11.54	9.62	37.28
4		<i>Plectranthus rugosus</i>	30	0.02	6.45	3.85	4.65	14.95
5		<i>Rosa macrophylla</i>	30	0.02	6.45	7.69	6.45	20.60
6		<i>Salix hastata</i>	133	0.17	29.03	34.62	46.40	110.05
		<b>Total</b>	<b>459</b>	<b>0.37</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		Herbs						
1	Herbs	<i>Aconitum heterophyllum</i>	1852	0.01	0.88	1.51	0.19	2.59
2		<i>Artemisia scoparia</i>	15926	0.23	7.56	12.11	4.13	23.80
3		<i>Astragalus frigidus</i>	9630	0.18	4.57	3.03	3.18	10.77
4		<i>Cynoglossum glochidiatum</i>	2963	0.11	1.41	1.51	1.98	4.90
5		<i>Fragaris nubicola</i>	4815	0.01	2.28	3.03	0.10	5.41
6		<i>Fragaris vesca</i>	14074	0.04	6.68	6.05	0.80	13.53
7		<i>Geranium wallichianum</i>	6667	0.16	3.16	4.54	2.92	10.62
8		<i>Impatiens sulcata</i>	2222	0.04	1.05	1.51	0.77	3.34
9		<i>Lamium album</i>	10000	0.02	4.74	7.57	0.31	12.62
10		<i>Pimpinella diversifolia</i>	12500	0.28	5.93	10.21	5.14	21.29
11		<i>Rumex nepalensis</i>	370	0.003	0.18	1.51	0.05	1.74
12		<i>Salvia glutinosa</i>	7778	0.94	3.69	3.03	17.09	23.81
13		<i>Salvia nubicola</i>	21111	1.16	10.02	13.62	20.92	44.55
14		<i>Senecio chrysanthemoides</i>	2222	0.03	1.05	1.51	0.52	3.08
15		<i>Thymus serpyllum</i>	2963	0.01	1.41	1.51	0.13	3.05
16		<i>Verbascum thapsus</i>	370	0.004	0.18	1.51	0.07	1.76
17		<i>Viola serpens</i>	3333	0.004	1.58	1.51	0.07	3.17
18	Grasses	<i>Dactylis glomerate</i>	7901	0.15	3.75	2.02	2.73	8.50
19		<i>Setaria viridis</i>	21481	0.63	10.19	3.03	11.38	24.60
20		<i>Brachypodium distachyan</i>	7778	0.17	3.69	1.51	3.16	8.37
21		<i>Chrysopogon gryllus</i>	22222	0.39	10.54	7.57	7.14	25.25
22		<i>Danthonia schneideri</i>	14074	0.50	6.68	3.03	9.04	18.75
23	<i>Stipa sibirica</i>	14444	0.26	6.85	3.03	4.71	14.59	
24	Fern	<i>Pteridium aquilinum</i>	4074	0.19	1.93	4.54	3.44	9.91
		<b>Total</b>	<b>210772</b>	<b>5.53</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

#### 4.2.5 Sub-alpine birch forest

Sub-alpine birch forest community is comprised of *Betula utilis*, *Pinus wallichiana* and *Abies pindrow* (trees species) recording a total density of 211 N ha<sup>-1</sup> and basal area of 13.93 m<sup>2</sup> ha<sup>-1</sup> (Table 14). In this community *Betula utilis* showed maximum dominance in respect of density (169N ha<sup>-1</sup>), basal area (10.66 m<sup>2</sup> ha<sup>-1</sup>) and IVI (204.15).

In this forest types, there are four species of shrubs which recorded a total density of 355 N ha<sup>-1</sup> and basal area 0.27 m<sup>2</sup> ha<sup>-1</sup> (Table 14). Maximum values for density (207 N ha<sup>-1</sup>) basal area (0.12 m<sup>2</sup> ha<sup>-1</sup>) and IVI (161.48) were recorded in *Berberis vulgaris*. Whereas, minimum density (15 N ha<sup>-1</sup>), basal area (0.02 m<sup>2</sup> ha<sup>-1</sup>) and IVI (16.04) were observed for *Rhododendron anthopogon*.

Herbaceous vegetation is comprised of 12 species of herbs and 3 species of grasses. On the whole, they resulted in a total density of 179259 N ha<sup>-1</sup> and basal area of 6.41 m<sup>2</sup> ha<sup>-1</sup> (Table 14). Among herbs, *Chenopodium opulifolium* showed maximum density (38519 N ha<sup>-1</sup>), basal area (0.62 m<sup>2</sup> ha<sup>-1</sup>) and IVI values 46.61. While, *Primula macrophylla* showed minimum values for density (1111 N ha<sup>-1</sup>) and IVI (2.66) whereas, minimum basal area (0.005 m<sup>2</sup> ha<sup>-1</sup>) was observed in *Ainsliae aptera*. In grasses, *Danthonia schneideri* showed maximum values for density (21481 N ha<sup>-1</sup>), basal area (3.20 m<sup>2</sup> ha<sup>-1</sup>) and IVI (71.42) whereas minimum values for density (8519 N ha<sup>-1</sup>), basal area (0.30 m<sup>2</sup> ha<sup>-1</sup>) and IVI (11.36) were recorded in respect of *Danthonia cachemyriana*.

**Table 14. Floristic composition of trees, shrubs and herbs in sub alpine birch forest**

		Tree	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Trees	<i>Betula utilis</i>	169	10.66	80.26	47.37	76.52	204.15
2		<i>Abies pindrow</i>	31	2.06	14.47	36.84	14.78	66.09
3		<i>Pinus wallichiana</i>	11	1.21	5.26	15.79	8.70	29.76
		<b>Total</b>	<b>211</b>	<b>13.93</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Shrubs</b>						
1	Shrubs	<i>Berberis vulgaris</i>	207	0.12	58.33	56.52	46.63	161.48
2		<i>Rosa macrophylla</i>	89	0.07	25.00	26.09	24.69	75.78
3		<i>Cotoneaster bacillaris</i>	44	0.06	12.50	13.04	21.16	46.70
4		<i>Rhododendron anthopogon</i>	15	0.02	4.17	4.35	7.52	16.04
		<b>Total</b>	<b>355</b>	<b>0.27</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Herbs</b>						
1	Herbs	<i>Aconitum molli</i>	4815	0.19	2.69	1.92	3.01	7.62
2		<i>Ainsliae aptera</i>	2222	0.005	1.24	1.92	0.08	3.24
3		<i>Aquilegia fragranus</i>	9630	0.03	5.37	9.62	0.54	15.53
4		<i>Bergenia stracheyi</i>	11111	0.71	6.20	9.62	11.03	26.84
5		<i>Bistorta affinis</i>	4074	0.07	2.27	1.92	1.10	5.30
6		<i>Chenopodium opulifolium</i>	38519	0.62	21.49	15.38	9.74	46.61
7		<i>Impatiens sulcata</i>	34074	0.41	19.01	11.54	6.32	36.87
8		<i>Primula macrophylla</i>	1111	0.01	0.62	1.92	0.12	2.66
9		<i>Rumex nepalensis</i>	2963	0.08	1.65	5.77	1.24	8.66
10		<i>Silene edgeworthii</i>	11481	0.31	6.40	3.85	4.77	15.02
11		<i>Thalictrum javanicum</i>	3333	0.004	1.86	1.92	0.07	3.85
12		<i>Urtica dioica</i>	10741	0.12	5.99	17.31	1.87	25.17
13	Grasses	<i>Danthonia cachemyriana</i>	8519	0.30	4.75	1.92	4.69	11.36
14		<i>Danthonia schneideri</i>	21481	3.20	11.98	9.62	49.82	71.42
15		<i>Deyaurcia pulchella</i>	15185	0.36	8.47	5.77	5.62	19.86
		<b>Total</b>	<b>179259</b>	<b>6.41</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

#### 4.2.6 Sub-alpine fir forest

Sub-alpine fir forest community is comprised of *Abies pindrow*, *Abies spectabilis*, *Pinus wallichiana*, and *Betula utilis* (trees species) recorded a total density of 222 N ha<sup>-1</sup> and basal area of 21.07 m<sup>2</sup> ha<sup>-1</sup> (Table 15). The *Abies pindrow* showed maximum dominance in this community in term of density of 125 N ha<sup>-1</sup>, basal area (11.94 m<sup>2</sup> ha<sup>-1</sup>) and IVI value (152.95), respectively.

**Table 15. Floristic composition of trees, shrubs and herbs in sub alpine fir forest (*Abies* spp.)**

		Tree	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Tree	<i>Abies pindrow</i>	125	11.94	56.25	40.00	56.70	152.95
2		<i>Abies spectabilis</i>	64	6.02	28.75	20.00	28.56	77.31
3		<i>Pinus wallichiana</i>	31	2.95	13.75	33.33	14.00	61.08
4		<i>Betula utilis</i>	3	0.16	1.25	6.67	0.74	8.66
		<b>Total</b>	<b>222</b>	<b>21.07</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
1	Shrubs	<i>Berberis erythroclada</i>	74	0.04	25.00	23.53	18.38	66.91
2		<i>Cotoneaster bacillaris</i>	44	0.04	15.00	17.65	19.66	52.31
3		<i>Rosa macrophylla</i>	104	0.05	35.00	35.29	22.96	93.25
4		<i>Salix hastata</i>	59	0.05	20.00	17.65	23.04	60.69
5		<i>Sorbus foliolosa</i>	15	0.04	5.00	5.88	15.95	26.84
		<b>Total</b>	<b>296</b>	<b>0.22</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
1	Herbs	<i>Ainsliaea aptera</i>	2963	0.01	1.43	3.23	0.13	4.78
2		<i>Anaphalis busua</i>	2593	0.02	1.25	1.61	0.40	3.26
3		<i>Astragalus chlorostachys</i>	8148	0.23	3.92	3.23	3.99	11.13
4		<i>Equisetum arvense</i>	2963	0.003	1.43	1.61	0.05	3.09
5		<i>Fragaria nubicola</i>	10370	0.04	4.99	6.45	0.71	12.15
6		<i>Geranium wallichiana</i>	11852	0.16	5.70	4.84	2.87	13.41
7		<i>Laminus album</i>	8148	0.11	3.92	1.61	1.93	7.46
8		<i>Impatiens sulcata</i>	30370	0.98	14.62	11.29	17.20	43.10
9		<i>Jurinea dolomiaea</i>	1111	0.39	0.53	1.61	6.86	9.00
10		<i>Ligularia fischeri</i>	24074	0.66	11.59	11.29	11.60	34.48
11		<i>Picrorhiza kurroa</i>	4444	0.09	2.14	1.61	1.51	5.26
12		<i>Potential atrosanguinea</i>	9259	0.25	4.46	6.45	4.48	15.39
13		<i>Rumex napalensis</i>	1852	0.01	0.89	4.84	0.18	5.91
14		<i>Salvia nubicola</i>	8519	0.05	4.10	4.84	0.83	9.77
15		<i>Saussuria lappa</i>	741	0.07	0.36	1.61	1.19	3.16
16		<i>Selinum temifolium</i>	1111	0.08	0.53	1.61	1.35	3.50
17		<i>Thalictrum alpinum</i>	2593	0.01	1.25	1.61	0.20	3.06
18		<i>Thymus serphyllum</i>	1852	0.02	0.89	1.61	0.40	2.91
19		<i>Viola canescens</i>	9630	0.05	4.63	6.45	0.87	11.96
20	Grasses	<i>Dactylis glomerata</i>	5926	0.22	2.85	1.61	3.84	8.30
21		<i>Danthonia schneideri</i>	17407	0.54	8.38	4.84	9.41	22.63
22		<i>Stachys melissifolia</i>	25185	0.86	12.12	9.68	15.13	36.93
23	Fern	<i>Dryopteris barbigera</i>	16667	0.85	8.02	6.45	14.87	29.34
		<b>Total</b>	<b>207778</b>	<b>5.69</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

There were five species of shrubs which recorded a total density of 296 N ha<sup>-1</sup> and basal area 0.22 m<sup>2</sup> ha<sup>-1</sup> (Table 15). Maximum density (104 N ha<sup>-1</sup>) and IVI (93.25) were recorded in *Rosa macrophylla* whereas, basal area (0.05m<sup>2</sup> ha<sup>-1</sup>) was observed to be maximum in *Rosa macrophylla* and *Salix hastata*. Whereas, minimum density (15 N ha<sup>-1</sup>) and

IVI (26.84) were observed in *Sorbus foliolosa* whereas, minimum basal area (0.04 m<sup>2</sup> ha<sup>-1</sup>) was recorded for *Berberis erythroclada*, *Cotoneaster bacillaris* and *Sorbus foliolosa*, each displaying equal values.

Herbaceous vegetation is comprised of 19 species of herbs, 3 species of grasses and 1 species of fern. On the whole, they accounted for a total density of 207778 N ha<sup>-1</sup> and basal area of 5.69 m<sup>2</sup> ha<sup>-1</sup> (Table 15). Among herbs, *Impatiens sulcata* showed maximum density (30370 N ha<sup>-1</sup>), basal area (0.98 m<sup>2</sup> ha<sup>-1</sup>) and IVI (43.10). Whereas, *Saussuria lappa* showed minimum values for density (741 N ha<sup>-1</sup>) and IVI (3.16) whereas, minimum basal area (0.003 m<sup>2</sup> ha<sup>-1</sup>) was observed in *Equisetum arvense*. In grasses, *Stachys melissifolia* showed maximum values for density (25185 N ha<sup>-1</sup>), basal area (0.86 m<sup>2</sup> ha<sup>-1</sup>) and IVI (36.93) while minimum values for density (5926 N ha<sup>-1</sup>), basal area (0.22 m<sup>2</sup> ha<sup>-1</sup>) and IVI (8.30) were observed in *Dactylis glomerata*. There was one species of fern (*Dryopteris barbigera*) which had a density of 16667 N ha<sup>-1</sup> and basal area of 0.85 m<sup>2</sup> ha<sup>-1</sup> and IVI value of 29.34.

#### 4.2.7 Birch-rhododendron scrub forest

The birch-rhododendron scrub forest community is comprised of *Betula utilis* and *Abies pindrow* (trees species) which recorded a total density of 178 N ha<sup>-1</sup> and basal area of 6.66 m<sup>2</sup> ha<sup>-1</sup> (Table 16). The *Betula utilis* showed maximum dominance in term of density (169 N ha<sup>-1</sup>), basal area (6.10 m<sup>2</sup> ha<sup>-1</sup>) and IVI value (285.11).

There were three species of shrubs which accounted for a total density of 489 N ha<sup>-1</sup> and basal area 7.74 m<sup>2</sup> ha<sup>-1</sup> (Table 16). Maximum values of density (415 N ha<sup>-1</sup>), basal area (7.64 m<sup>2</sup> ha<sup>-1</sup>) and IVI (273.63) were recorded in *Rhododendron campanulatum*. Whereas, minimum density (30 N ha<sup>-1</sup>), basal area (0.04 m<sup>2</sup> ha<sup>-1</sup>) and IVI (9.93) were observed in *Rhododendron anthopogon*.

Herbaceous vegetation is comprised of 8 species of herbs, 2 species of grasses and 1 species of fern. On the whole they resulted in a total density of 143333 N ha<sup>-1</sup> and basal area 3.64 m<sup>2</sup> ha<sup>-1</sup> (Table 16). Among herbs, *Bistorta affinis* showed maximum values of density (26296 N ha<sup>-1</sup>), basal area (0.86 m<sup>2</sup> ha<sup>-1</sup>) and IVI (60.75). On the other hand, *Geum elatum* showed minimum values for density (2222 N ha<sup>-1</sup>), basal area (0.001 m<sup>2</sup> ha<sup>-1</sup>) and IVI (4.53). In grasses, *Deyaurcia pulchella* showed maximum values for density (8148 N ha<sup>-1</sup>), basal area (0.30 m<sup>2</sup> ha<sup>-1</sup>) and IVI (20.12) however, minimum values for density (5185 N ha<sup>-1</sup>), basal area (0.10 m<sup>2</sup> ha<sup>-1</sup>) and IVI (9.33) were observed for *Danthonia jacquemonti*. There was one

species of fern (*Dryopteris barbigera*), which had a density of 42963 N ha<sup>-1</sup> and basal area of 1.12 m<sup>2</sup> ha<sup>-1</sup> and IVI of 82.89.

**Table 16. Floristic composition of trees, shrubs and herbs in birch-rhododendron scrub forest**

		Tree	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Tree	<i>Betula utilis</i>	169	6.10	98.41	90.00	96.70	285.11
2		<i>Abies pindrow</i>	8	0.56	1.59	10.00	3.30	14.89
		<b>Total</b>	<b>178</b>	<b>6.66</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		Shrubs	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Shrubs	<i>Rhododendron campanulatum</i>	415	7.64	84.85	90.00	98.78	273.63
2		<i>Salix hastata</i>	44	0.05	9.09	6.67	0.69	16.45
3		<i>Rhododendron anthopogon</i>	30	0.04	6.06	3.33	0.53	9.93
		<b>Total</b>	<b>489</b>	<b>7.74</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		Herbs	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Herbs	<i>Cassiope fastigata</i>	10370	0.06	7.24	8.82	1.64	17.70
2		<i>Iris hookeriana</i>	3333	0.003	2.33	2.94	0.09	5.35
3		<i>Anemone tetrasepala</i>	4074	0.09	2.84	5.88	2.59	11.32
4		<i>Aconogonum alpinum</i>	21111	0.72	14.73	14.71	20.79	50.22
5		<i>Stachys sylvatica</i>	10741	0.16	7.49	5.88	4.65	18.02
6		<i>Geum elatum</i>	2222	0.001	1.55	2.94	0.04	4.53
7		<i>Bistorta affinis</i>	26296	0.86	18.35	17.65	24.75	60.75
8		<i>Potentilla atosanguinea</i>	8889	0.06	6.20	11.76	1.80	19.77
9	Grasses	<i>Danthonia jacquemonti</i>	5185	0.10	3.62	2.94	2.77	9.33
10		<i>Deyaurcia pulchella</i>	8148	0.30	5.68	5.88	8.55	20.12
11	Fern	<i>Dryopteris barbigera</i>	42963	1.12	29.97	20.59	32.33	82.89
		<b>Total</b>	<b>143333</b>	<b>3.46</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

#### 4.2.8 Alpine pasture

In alpine pasture, trees and shrubs species were absent and herbaceous vegetation is comprised of 19 species of herbs, 4 species of grasses. On the whole, they accounted for total density values of 258889 N ha<sup>-1</sup> and basal area of 6.82 m<sup>2</sup> ha<sup>-1</sup> (Table 17). Among herbs, *Silene edgeworthii* showed maximum values for density (15185 N ha<sup>-1</sup>) whereas, basal area (0.64 m<sup>2</sup> ha<sup>-1</sup>) and IVI (22.60) were maximum in *Artemisia parviflora*. Contrary to this, *Cynoglossum micranthum* showed minimum values for density (370 N ha<sup>-1</sup>), basal area (0.001 m<sup>2</sup> ha<sup>-1</sup>) and IVI (1.55). In grasses, *Agropyron semicostatum* showed maximum values

for density (70741 N ha<sup>-1</sup>), basal area (1.71 m<sup>2</sup> ha<sup>-1</sup>) and IVI (63.26) whereas, minimum values of density (13704 N ha<sup>-1</sup>), basal area (0.24 m<sup>2</sup> ha<sup>-1</sup>) and IVI (12.97) were recorded in *Elymus dasystachys*.

**Table 17. Floristic composition of herbs in alpine pasture**

		<b>Herbs</b>	<b>Density (N ha<sup>-1</sup>)</b>	<b>Basal area (m<sup>2</sup> ha<sup>-1</sup>)</b>	<b>Relative Density</b>	<b>Relative frequency</b>	<b>Relative Dominance</b>	<b>IVI</b>
1	Herbs	<i>Anaphalis busua</i>	5556	0.05	2.15	1.37	0.67	4.19
2		<i>Artemisia brevifolia</i>	4444	0.06	1.72	2.74	0.90	5.36
3		<i>Artemisia parviflora</i>	5926	0.64	2.29	10.96	9.35	22.60
4		<i>Carum carvi</i>	3704	0.08	1.43	2.74	1.10	5.27
5		<i>Chenopodium album</i>	1111	0.01	0.43	1.37	0.19	1.99
6		<i>Cirsium falconeri</i>	3333	0.29	1.29	4.11	4.21	9.61
7		<i>Cirsium verutum</i>	2222	0.17	0.86	4.11	2.43	7.40
8		<i>Cynoglossum micranthum</i>	370	0.001	0.14	1.37	0.03	1.55
9		<i>Datura stramonium</i>	2963	0.05	1.14	4.11	0.76	6.02
10		<i>Echinops cornigerus</i>	12963	0.58	5.01	4.11	8.49	17.60
11		<i>Heracleum candicans</i>	1481	0.15	0.57	2.74	2.19	5.50
12		<i>Medicago falcate</i>	5185	0.04	2.00	1.37	0.62	4.00
13		<i>Mentha longifolia</i>	9259	0.07	3.58	2.74	1.01	7.33
14		<i>Polygonum polygaloides</i>	13333	0.12	5.15	5.48	1.69	12.32
15		<i>Rumex nepalensis</i>	2222	0.05	0.86	4.11	0.75	5.72
16		<i>Silene edgeworthii</i>	15185	0.32	5.87	5.48	4.67	16.01
17		<i>Thalictrum javanicum</i>	3333	0.01	1.29	4.11	0.18	5.58
18		<i>Trifolium repens</i>	5556	0.004	2.15	2.74	0.06	4.95
19		<i>Verbascum thapsus</i>	741	0.002	0.29	2.74	0.01	3.04
20	Grasses	<i>Agropyron semicostatum</i>	70741	1.71	27.32	10.96	24.98	63.26
21		<i>Agrostis canina</i>	45185	1.68	17.45	5.48	24.68	47.61
22		<i>Alopecurus arundinaceus</i>	30370	0.51	11.73	10.96	7.45	30.14
23		<i>Elymus dasystachys</i>	13704	0.24	5.29	4.11	3.57	12.97
		<b>Total</b>	<b>258889</b>	<b>6.82</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

#### 4.2.9 Dry alpine Scrub

In dry alpine scrub tree species were absent and there were three species of shrubs which recorded a total density of 222 N ha<sup>-1</sup> and basal area of 2.05 m<sup>2</sup> ha<sup>-1</sup> (Table 18). Maximum values of density (133 N ha<sup>-1</sup>), basal area (1.52 m<sup>2</sup> ha<sup>-1</sup>) and IVI (191.23) were

recorded in *Juniperus communis*. While, minimum density (44 N ha<sup>-1</sup>), basal area (0.11 m<sup>2</sup> ha<sup>-1</sup>) and IVI (46.56) were observed in *Ribes orientale*.

Herbaceous vegetation is comprised of 9 species of herbs and 3 species of grasses. On the whole, they resulted in a total density of 99259 N ha<sup>-1</sup> and basal area of 1.25 m<sup>2</sup> ha<sup>-1</sup> (Table 18). Among herbs, *Potentilla atosanguinea* showed maximum values for density (12593N ha<sup>-1</sup>) whereas, basal area (0.24 m<sup>2</sup> ha<sup>-1</sup>) and IVI (38.81) were recorded in *Echinops cornigerus*. Whereas, *Datura stramonium* showed minimum values for density (741 N ha<sup>-1</sup>), basal area (0.004 m<sup>2</sup> ha<sup>-1</sup>) and IVI (4.93). In grasses, *Danthonia schneideri* showed maximum values of density (24074 N ha<sup>-1</sup>), basal area (0.30 m<sup>2</sup> ha<sup>-1</sup>) and IVI (67.63) whereas minimum values for density (2963 N ha<sup>-1</sup>), basal area (0.03 m<sup>2</sup> ha<sup>-1</sup>) and IVI (9.11) were recorded in respect of *Deyaurcia pulchella*.

**Table 18. Floristic composition of shrubs and herbs in dry alpine scrub**

		Shrub	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Relative Density	Relative frequency	Relative Dominance	IVI
1	Shrub	<i>Ribes orientale</i>	44	0.11	20.00	21.43	5.13	46.56
2		<i>Juniperus communis</i>	133	1.52	60.00	57.14	74.08	191.23
3		<i>Juniperus indica</i>	44	0.43	20.00	21.43	20.78	62.21
		<b>Total</b>	<b>222</b>	<b>2.05</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>
		<b>Herbs</b>						
1	Herbs	<i>Polygonum polygaloides</i>	12222	0.02	12.31	3.85	1.36	17.52
2		<i>Echinops cornigerus</i>	7778	0.24	7.84	11.54	19.44	38.81
3		<i>Datura stramonium</i>	741	0.004	0.75	3.85	0.34	4.93
4		<i>Artemisia brevifolia</i>	2593	0.05	2.61	7.69	4.35	14.65
5		<i>Potentilla atosanguinea</i>	12593	0.09	12.69	11.54	7.19	31.41
6		<i>Sedum ewersii</i>	4815	0.03	4.85	3.85	2.41	11.11
7		<i>Iris hookeriana</i>	10000	0.04	10.07	11.54	3.31	24.93
8		<i>Berginea stracheyi</i>	5556	0.19	5.60	7.69	15.44	28.73
9		<i>Mentha longifolia</i>	2593	0.02	2.61	3.85	1.59	8.05
10		Grasses	<i>Danthonia schneideri</i>	24074	0.30	24.25	19.23	24.14
11	<i>Agropyron semicostatatum</i>		13333	0.23	13.43	11.54	18.16	43.13
12	<i>Deyaurcia pulchella</i>		2963	0.03	2.99	3.85	2.28	9.11
		<b>Total</b>	<b>99259</b>	<b>1.25</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>300.00</b>

### Density and basal area of different forest types

The data of density, basal area and IVI of trees, shrubs and herbs is demonstrated in Table 19. It is evident from the data that maximum tree density (275 N ha<sup>-1</sup>) was recorded in

dry broad-leaved and coniferous forests which, remain statistically different to dry blue pine forest ecosystem. The density in different forest types follows the trend:  $T_1 > T_4 > T_6 > T_5 > T_3 > T_2 > T_7 = T_8 = T_9$ . While, in basal area significantly maximum value was recorded in dry deodar forest type ( $39.94 \text{ m}^2 \text{ ha}^{-1}$ ). The basal area recorded in dry blue pine forest, neoza pine forest, dry broad-leaved and coniferous forests, sub alpine fir forest and sub alpine birch forest remain statistically identical to one another.

**Table 19. Density, basal area and IVI of trees, shrubs and herbs in different forest types of dry temperate and alpine forest of Kinnaur district (H.P.)**

Treatments (Forest types)	Trees		Shrubs		Herbs	
	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )
T <sub>1</sub> - Dry broad-leaved and coniferous forests	275 <sup>a</sup>	17.03 <sup>bc</sup>	592 <sup>a</sup>	0.36 <sup>c</sup>	245185 <sup>ab</sup>	5.50 <sup>abcd</sup>
T <sub>2</sub> - Neoza pine forest	189 <sup>cd</sup>	18.45 <sup>bc</sup>	385 <sup>bcd</sup>	0.36 <sup>c</sup>	152223 <sup>de</sup>	3.45 <sup>d</sup>
T <sub>3</sub> - Dry deodar forest	197 <sup>bcd</sup>	34.94 <sup>a</sup>	518 <sup>ab</sup>	0.39 <sup>c</sup>	194444 <sup>cd</sup>	3.65 <sup>cd</sup>
T <sub>4</sub> - Dry blue pine forest	233 <sup>b</sup>	19.80 <sup>bc</sup>	459 <sup>abc</sup>	0.37 <sup>c</sup>	210772 <sup>bc</sup>	5.53 <sup>abcd</sup>
T <sub>5</sub> - Sub- alpine birch forest	211 <sup>bcd</sup>	13.93 <sup>bcd</sup>	355 <sup>cd</sup>	0.27 <sup>c</sup>	179259 <sup>cde</sup>	6.41 <sup>ab</sup>
T <sub>6</sub> - Sub- alpine fir forest	222 <sup>bc</sup>	21.07 <sup>b</sup>	296 <sup>de</sup>	0.22 <sup>c</sup>	207778 <sup>bc</sup>	5.69 <sup>abc</sup>
T <sub>7</sub> -Birch-rhododendron scrub forest	178 <sup>d</sup>	6.66 <sup>d</sup>	489 <sup>abc</sup>	7.74 <sup>a</sup>	143333 <sup>e</sup>	3.46 <sup>d</sup>
T <sub>8</sub> - Alpine pasture	0.00 <sup>e</sup>	0.00 <sup>e</sup>	0.00 <sup>f</sup>	0.00 <sup>d</sup>	258890 <sup>a</sup>	6.82 <sup>a</sup>
T <sub>9</sub> - Dry alpine scrub	0.00 <sup>e</sup>	0.00 <sup>e</sup>	222 <sup>e</sup>	2.05 <sup>b</sup>	99259 <sup>f</sup>	1.25 <sup>e</sup>
CD <sub>0.05</sub>	41.82	8.05	161.90	0.61	46111.65	2.12

In case of shrubs, maximum value of shrubs density was recorded in dry broad-leaved and coniferous forests ( $592 \text{ N ha}^{-1}$ ), which was found statistical identical to shrubs density recorded in dry deodar forest, birch-rhododendron scrub forest and dry blue alpine forest. In respect of basal area huge variation was observed. Shrubs basal area was recorded maximum in birch-rhododendron scrub forest ( $7.74 \text{ m}^2 \text{ ha}^{-1}$ ), which was found significantly higher than all forest types under investigation followed by dry alpine scrub ( $2.05 \text{ m}^2 \text{ ha}^{-1}$ ) which was also found significantly different than other forest types. The basal area in treatments:  $T_1, T_2, T_3, T_4, T_5, T_6$  remain statistically identical (Table 19).

The density values for herbs also displayed a marked variation (Table 19). Maximum herbage density was recorded in alpine pasture ( $2,58,890 \text{ N ha}^{-1}$ ). Whereas, minimum density was found in dry alpine scrub ( $99,259 \text{ N ha}^{-1}$ ). Herbage basal area also displayed a marked variation. The maximum density for herbage was recorded in alpine pasture ( $6.82 \text{ m}^2 \text{ ha}^{-1}$ )

which remains statistically at par with sub alpine birch forest, dry broad-leaved and coniferous forests, dry blue pine forest and sub alpine fir forest significantly, whereas lowest value for basal area was recorded in dry alpine scrub ecosystem ( $1.25 \text{ m}^2 \text{ ha}^{-1}$ ).

Phytosociology is the study of the characteristics, classification, relationships, and distribution of plant communities in an area. It is useful to collect such data to describe the population dynamics of each species and know how they relate to the other species in the same community. Subtle differences in species composition and structure may point to differing abiotic conditions such as soil moisture, light availability, temperature, exposure to prevailing wind, etc. When tracked over time, species and individual dynamics can reveal patterns of response to disturbance and how the community changes over time. Importance values index (IVI) represents the relative dominance of the species in a community, which indicates importance of the species with respect to its associates.

**Table 20. Comparison between estimates of different tree density and basal area reported in earlier studies for different temperate forests**

Sr. no.	Forest type	Density ( $\text{N ha}^{-1}$ )	Basal area ( $\text{m}^2 \text{ha}^{-1}$ )	Reference
1.	Upper West Himalayan <i>Abies pindrow</i> spach.	507.5±21.7	-	Sharma <i>et al.</i> 2010
2.	<i>Quercus floribunda</i> Lindle	535.0±30.6	-	Sharma <i>et al.</i> 2010
3.	Moist <i>Cedrus deodara</i> Loud	447.5± 36.03	-	Sharma <i>et al.</i> 2010
4.	Upper West Himalayan <i>Quercus semecarpifolia</i> Sm.	565.0±22.1	-	Sharma <i>et al.</i> 2010
5.	Himalayan <i>Cupressus torulosa</i> Don.	810.0±82.5	-	Sharma <i>et al.</i> 2010
6.	Moist temperate deciduous	547.5±62.6	-	Sharma <i>et al.</i> 2010
7.	Cold desert kinnaur	400.00	-	Verma and Kapoor 2013
8.	Dry temperate deciduous forest	193.00	49.90	Kumar and Sharma 2014
9.	Dry broad leaved and coniferous forests	179.00	42.40	Kumar and Sharma 2014
10.	Dry deodar forest	202.00	63.42	Kumar and Sharma 2014
11.	Western mixed coniferous forests	245.00	54.58	Kumar and Sharma 2014
12.	Western Himalayan birch/fir forest	204.00	69.16	Kumar and Sharma 2014
13.	<i>Betula utilis</i> forest	480.00	-	Sharma <i>et al.</i> 2014
14.	<i>Cedrus deodara</i>	403.33	-	Sharma <i>et al.</i> 2014
15.	<i>Pinus gerardiana</i>	490.00	-	Sharma <i>et al.</i> 2014
16.	<i>Betula utilis</i> - <i>Abies pindrow</i> mixed forest	440.00	-	Sharma <i>et al.</i> 2014
17.	Neoz pine forest	191.00	18.71	Kumar 2014
18.	Deodar forest (Chail wildlife sanctuary, Solan)	760	85.23	Kumar and Sharma 2016
19.	Himalayan dry temperate and alpine forest types (T <sub>1</sub> -T <sub>9</sub> )	0.00-275.00	0.00-34.94	Present study

In the presents study density ranged from 0.00-275 N ha<sup>-1</sup> and basal area ranged from 0.00-34.94 m<sup>2</sup> ha<sup>-1</sup> under different forest types of dry temperate and alpine forest of Kinnaur district of Himachal Pradesh. In several temperate forest, the values of total density and basal area ranged from 179-892.51 N ha<sup>-1</sup> and 42.40-69.16 m<sup>2</sup> ha<sup>-1</sup>, respectively (Sharma *et al.* 2010; Verma and Kapoor 2013; Kumar and Sharma 2014; Kumar 2014 and Kumar and Sharma 2016 (Table 20).

Among nine forest types, maximum trees density was observed in dry broad-leaved and coniferous forests (275 N ha<sup>-1</sup>) followed by dry blue pine forest (233 N ha<sup>-1</sup>), sub alpine fir forest (222 N ha<sup>-1</sup>), sub alpine birch forest (211N ha<sup>-1</sup>) dry deodar forest (197 N ha<sup>-1</sup>), neoza pine forest (189 N ha<sup>-1</sup>) and birch-rhododendron scrub forest (178 N ha<sup>-1</sup>) in descending order, respectively. The absence of tree in alpine pasture and dry alpine scrub is due to their location above the tree line. Maximum tree density in dry broad-leaved and coniferous forests can be ascribed to forking habit of *Quercus ilex* tree stem.

Basal area was found to be higher in dry deodar forest (34.94 m<sup>2</sup> ha<sup>-1</sup>) followed by sub alpine fir forest (21.07 m<sup>2</sup> ha<sup>-1</sup>), dry blue pine forest (19.80 m<sup>2</sup> ha<sup>-1</sup>), neoza pine forest (18.45 m<sup>2</sup> ha<sup>-1</sup>), dry broad-leaved and coniferous forests (17.03 m<sup>2</sup> ha<sup>-1</sup>), sub alpine birch forest (13.93 m<sup>2</sup> ha<sup>-1</sup>) and birch-rhododendron scrub forest (6.66 m<sup>2</sup> ha<sup>-1</sup>), respectively. The results are in agreement with the findings of Ahmed *et al.* 2011, who had reported highest basal area for deodar forest compared to other forest communities of Hind Kush and Himalayan ranges of Pakistan. Similarly, Singhal *et al.* 1986 reported dominance of deodar in regards to density and basal area in Kanasar Range of Chakrata forest division of Uttrakhand. Singh and Gupta (2009) also recorded higher basal area in all the periodic blocks of Koti forest range in Shimla Forest Division of Himachal Pradesh. This distribution pattern of basal area in different forest communities can be mainly attributed to its growth characteristics and average age. In general, deodar had older crop in their habitat as well as due to Metzger effect owing to high wind velocity in this locality.

The shrubs density ranged from 0.00-592 N ha<sup>-1</sup> attaining maximum value in dry broad-leaved and coniferous forests (592 N ha<sup>-1</sup>) followed by dry deodar forest (518 N ha<sup>-1</sup>), birch-rhododendron scrub forest (489 N ha<sup>-1</sup>), dry blue pine forest (459 N ha<sup>-1</sup>), neoza pine forest (385N ha<sup>-1</sup>), sub alpine birch forest (355 N ha<sup>-1</sup>), sub alpine fir forest (296 N ha<sup>-1</sup>), dry alpine scrub (222 N ha<sup>-1</sup>), and alpine pasture (0.00 N ha<sup>-1</sup>) in descending order, respectively.

Among shrub species, basal area ranged from 0.00-7.74 m<sup>2</sup> ha<sup>-1</sup> which was attained by birch-rhododendron scrub forest with a value of 7.74 m<sup>2</sup> ha<sup>-1</sup> followed by dry alpine scrub (2.05 m<sup>2</sup> ha<sup>-1</sup>), dry deodar forest (0.39 m<sup>2</sup> ha<sup>-1</sup>), dry blue pine forest (0.37 m<sup>2</sup> ha<sup>-1</sup>), dry broad-leaved and coniferous forests (0.36 m<sup>2</sup> ha<sup>-1</sup>), neoza pine forest (0.36 m<sup>2</sup> ha<sup>-1</sup>), sub alpine birch forest (0.27 m<sup>2</sup> ha<sup>-1</sup>), sub alpine fir forest (0.22 m<sup>2</sup> ha<sup>-1</sup>) and alpine pasture (0.00 m<sup>2</sup> ha<sup>-1</sup>) in descending order, respectively. The values of total density and basal area of shrubs in different temperate Himalayan forests (Table 21) ranged from 330-2286 N ha<sup>-1</sup> and 0-0.15-m<sup>2</sup> ha<sup>-1</sup>, respectively as reported by Kumar 2012 ; Sharma *et al.* 2014 and Deshmukh and Jain (2016).

**Table 21. Comparison between estimates of different shrub density and basal area reported in earlier studies for different temperate forests**

Sr. No	Forest type	Density (N ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	References
1.	Neoza pine forest (Kinnaur)	349.00	0.15	Kumar 2012
2.	<i>Betula utilis</i> forest (Kinnaur)	330.00	-	Sharma <i>et al.</i> 2014
3..	<i>Cedrus deodara</i> Forest (Kinnaur)	673.33	-	Sharma <i>et al.</i> 2014
4.	<i>Pinus gerardiana</i> Forest (Kinnaur)	606.29	-	Sharma <i>et al.</i> 2014
5.	<i>Betual utilis-Abies pindrow</i> mixed forest	717.00	-	Sharma <i>et al.</i> 2014
6.	Lower alpine zone (Lahaul and Spiti)	1580.00	-	Deshmukh and Jain 2016
7.	Lower zone (Lahaul and Spiti)	2286.00	-	Deshmukh and Jain 2016
8.	Deodar forest (Chail wildlife Sanctuary, Solan)	4840.00	2.98	Kumar and Sharma, 2016
9.	Himalayan dry temperate and alpine forest types (T <sub>1</sub> -T <sub>9</sub> )	0.00-592.00	0.00-7.74	Present study

The lower values of shrubs density and basal area as reported in the present study can be owed to its climatic conditions. The present study area falls in dry temperate and alpine region where harsh climatic, edaphic condition and high biotic interference prevails, which as the name itself indicate is not much conducive to emergence and survival of the shrubs. It is evident from the results that the shrub density recorded in the present study was highest in dry broad leaved and coniferous forests. In general, broad leaved forest nurture higher number of shrub species as also reported by Chavez and Macdonld (2010).

Herbs density ranged from 99259-258890 N ha<sup>-1</sup> attaining maximum values in alpine pasture (258890 N ha<sup>-1</sup>) followed by dry broad-leaved and coniferous forests (245185 N ha<sup>-1</sup>), dry blue pine forest (210772 N ha<sup>-1</sup>), sub alpine fir forest (207778 N ha<sup>-1</sup>), dry deodar forest (194444 N ha<sup>-1</sup>), sub alpine birch forest (179259 N ha<sup>-1</sup>), neoza pine forest (152223N ha<sup>-1</sup>), birch-rhododendron scrub forest (143333 N ha<sup>-1</sup>) and dry alpine scrub (99259 N ha<sup>-1</sup>) in descending order, respectively (Table 22). The basal area of herbaceous vegetation ranged from 1.25-6.82 m<sup>2</sup> ha<sup>-1</sup> with maximum values in alpine pasture (6.82 m<sup>2</sup> ha<sup>-1</sup>) followed by

dry broad-leaved and coniferous forests ( $5.50 \text{ m}^2 \text{ ha}^{-1}$ ), dry blue pine forest ( $5.53 \text{ N ha}^{-1}$ ), sub alpine fir forest ( $5.69 \text{ m}^2 \text{ ha}^{-1}$ ), dry deodar forest ( $3.65 \text{ m}^2 \text{ ha}^{-1}$ ), sub alpine birch forest ( $6.41 \text{ m}^2 \text{ ha}^{-1}$ ), neoza pine forest ( $3.45 \text{ m}^2 \text{ ha}^{-1}$ ), birch-rhododendron scrub forest ( $3.46 \text{ m}^2 \text{ ha}^{-1}$ ) and dry alpine scrub ( $1.25 \text{ m}^2 \text{ ha}^{-1}$ ) in descending order respectively. The herbs density recorded in the present study falls in the range of  $1982.43\text{-}614500 \text{ N ha}^{-1}$ . Similarly, herb density range have also been reported by other workers for other ecosystems of Himalaya (Kumar 2012; Verma and Kapoor 2013; Verma 2014; Sharma *et al.* 2014). The variations in the density and basal area of herbaceous vegetation in different forest types can be related to difference in over storey trees (species and their density) resulting in microclimate modification (Anderson *et al.* 1968; Alaback and Herman, 1988; Thomas *et al.* 1999) and microhabitat changes (Johnson 1995, Berg and Staaf 1981) caused by change in environmental variables along the altitude and amount of litter deposition on soil surface that is mainly determined by balance between litter production and amount of litter decomposition rate (Staelens *et al.* 2003) which may be influenced by tree density (Lebret *et al.* 2001), site type (Facelli and Pickett 1991) and climate characteristics (Bray and Gorham 1964).

**Table 22. Comparison between estimates of different herbs density and basal area (reported in earlier studies)**

Sr. no.	Forest type	Density ( $\text{N ha}^{-1}$ )	Basal area ( $\text{m}^2\text{ha}^{-1}$ )	References
1.	Neoza pine forest Kinnaur	1982.43	1.14	Kumar 2012
2.	Namgia valley Kinnaur (3000-3500m a.m.s.l)	421200	-	Verma and Kapoor 2013
3.	Namgia valley Kinnaur (3500-4000 a.m.s.l)	614500	-	Verma and Kapoor 2013
4.	Namgia valley Kinnaur (4000 -4500m a.m.s.l)	528500	-	Verma and Kapoor 2013
5.	Hango valley Kinnaur (3400-3800m a.m.s.l)	530600	-	Verma 2014
6.	Hango valley Kinnaur (3800-4200m a.m.s.l)	448000	-	Verma 2014
7.	Hango valley Kinnaur (4200-4600m a.m.s.l)	448500	-	Verma 2014
8.	Betula utilis forest Sangla valley Kinnaur	351600	-	Shrama <i>et al.</i> 2014
9.	Cedrus deodara forest Sangla valley Kinnaur	334400	-	Shrama <i>et al.</i> 2014
10.	Pinus gerardiana Sangla valley Kinnaur	352000	-	Shrama <i>et al.</i> 2014
11.	Betula utilis-Abies pindrow mixed forest Sangla valley Kinnaur	250300	-	Shrama <i>et al.</i> 2014
12.	Cedrus deodara- Pinus gerardiana mixed forest Sangla valley Kinnaur	382000	-	Shrama <i>et al.</i> 2014
13.	Deodar forest (Chail wildlife Sanctuary, Solan)	673000	34.6	Kumar and Sharma 2016
14.	Himalayan dry temperate and alpine forest types ( $T_1\text{-}T_9$ )	99259.00-258890.00	1.25-6.82	Present study

Seeds under litter are deprived of light and cannot root easily (Hamrick and Lee 1987; Facelli and Pickett 1991; Ellsworth *et al.* 2004) as they differ in their ability to penetrate litter (Sydes and Grimes 1981) thus fail to germinate many times. Plant exudates released into the soil on decomposition in the form of allelochemicals also play a great role in regulating vegetation patterns, distribution of plants in the community and growth & development of associate species (Saxena and Sharma 1996) beside inhibiting germination of seeds (Gupta *et al.* 2007).

There are reports about allelochemicals production in many woody species, from boreal conifer forest (Mallik 2003) to tropical forest (Mckey *et al.* 1978), temperate forest (Willianson *et al.* 1992) and sub-desert communities (Van Rooyen *et al.* 2004), which might be a reason for the low growth of vegetation in these forests. Altitudinal variation in herbage growth in forest has been reported by Jamwal and Uniyal 2008; Sevgi and Tecimen 2008; Sharma 2012.

### **4.3 REGENERATION STATUS**

The regeneration studies were also carried out on recruits, un-established and established in major forest communities of dry temperate forest ecosystem of Kinnaur district of Himachal Pradesh.

#### **Recruits, Un-established, Established and Height of un-established regeneration**

The results in the Table 23 reveal that maximum numbers of recruits were observed for dry deodar forest (25278 N ha<sup>-1</sup>) whereas, minimum was obtained in dry broad-leaved and coniferous forests [1574N ha<sup>-1</sup> (*Quercus ilex*) and 1759N ha<sup>-1</sup> (*Pinus gerardiana*)]. Un-established regeneration was maximum in dry blue pine forest (2778 N ha<sup>-1</sup>) while, minimum in dry broad-leaved and coniferous forests [1018 N ha<sup>-1</sup> (*Quercus ilex*), 370 N ha<sup>-1</sup> (*Pinus gerardiana*)]. However, established regeneration was higher in dry deodar forest (833N ha<sup>-1</sup>) and lower in sub alpine fir forest [(277 N ha<sup>-1</sup> *Abies pindrow*) and (0 N ha<sup>-1</sup> *Abies spectabilis*)]. The height of unestablished regeneration was recorded maximum in dry deodar forest (386.67 cm) whereas, minimum height was observed in neoza pine forest (116.67 cm) (Table 23). Highest number of recruits was recorded in deodar forest which may be due to adequate number of seed bearers and site condition as also reported by Kumar *et al.* (2017) in Chail wildlife sanctuary. Minimum number of recruits in dry broad-leaved and coniferous forests may be attributed to lack of seeds of oak due to frequent lopping of trees for fodder,

fuel and grazing, which was also reported by Ammer (1996). In addition, collection of cone of *Pinus gerardiana* by the local people for extracting seeds/nuts for cultural and commercial purposes (Peltier and Dauffy 2009; Kumar *et al.* 2016) has also caused lack of seeds for regeneration in this forest types. The established regeneration was maximum in dry deodar forest whereas, un-established regeneration was maximum in dry blue pine forest. It seems that there had been less proportionate conversion of un-established to established regeneration, for blue pine forest which may be attributed to thick litter layer which acts as a physical barrier between roots and soil (Troup 1921; Taylor *et al.* 1934; Glover 1936; Datta 1958; Dhillion 1961; Sufi 1970) and higher biotic interference (grazing and trampling by animals) at that site. The better regeneration of deodar forest might be attributed to less thickness of organic matter, higher available nitrogen, available potassium and soil pH (Table 23).

**Table 23. Regeneration status of different major forest type in Himalayan dry temperate and alpine forest of Kinnaur district (H.P.)**

Treatments (forest types)	Recruits ha <sup>-1</sup>	Un-establish ha <sup>-1</sup>	Establish ha <sup>-1</sup>	Height of un-established regeneration (cm)
T <sub>1</sub> -Dry broad-leaved and coniferous forests	1574*,1759***	1018 *, 370***	370 *,277 ***	174 .44*24.44 ***
T <sub>2</sub> -Neoza pine forest	11111***	1667***	278***	116.67***
T <sub>3</sub> -Dry deodar forest	25278**	2500**	833**	386.67**
T <sub>4</sub> -Dry blue pine forest	17222****	2778****	556****	380.00****
T <sub>5</sub> -Sub alpine birch forest	7222*****	1111*****	556*****	166.67*****
T <sub>6</sub> -Sub alpine fir forest	9722*****, 5000*****	1388*****, 555*****	277 *****, 0 *****	113.33*****, 116.67 *****

\**Quercus ilex*

\*\**Cedrus deodara*

\*\*\**Pinus gerardiana*

\*\*\*\* *Pinus wallichiana*

\*\*\*\*\**Abies pindrow*

\*\*\*\*\**Abies spectabilis*

\*\*\*\*\* *Betula utilis forest*

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

It is evidently clear from the Table 24 that maximum weighted average height was recorded in dry blue pine forest [400 cm (*Pinus wallichiana*)] and minimum in neoza pine forest [183.33 cm (*Pinus gerardiana*)], respectively. Establishment index is, however, found to be maximum in dry blue pine forest [2.00 (*Pinus wallichiana*)] and minimum was

observed for neoza pine forest [0.92(*Pinus gerardiana*). It was evident that Stocking index with maximum values of 0.58 which was recorded in both dry deodar forest, while it was minimum in neoza pine forest *i.e.*, 0.28 (*Pinus gerardiana*). The data revealed that the maximum values of establishment Stocking percent was found maximum in dry deodar forest *i.e.*, 49.65 per cent and minimum was recorded in neoza pine forest (15.97 %). The Regeneration success was recorded maximum in dry deodar forest (58.33 %) whereas; it was minimum for neoza pine forest *i.e.* 27.78 % (*Pinus gerardiana*). The data on regeneration establishment stocking and percent regeneration success (Table 24) revealed that both establishment stocking and percent regeneration success was maximum in dry deodar forest while, minimum values were obtained in neoza pine forests. It may be due to favourable conditions in dry deodar forests for regeneration and growth of seedlings resulting in high number of recruits and established regeneration in that forest type as compared to other forest types.

**Table 24. Establishment and regeneration success rate of different major forest in Himalayan dry temperate and alpine forest of Kinnaur district (H.P.)**

Treatments (forest types)	Weighted average height (cm)	Establishment index	Stocking index	Establishment Stocking (%)	Regeneration Success (%)
T <sub>1</sub> -Dry broad-leaved and coniferous forests	168.70*,77.78***	0.84*,0.39***	0.25*,0.15***	22.48*,11.02***	25*,14.81***
T <sub>2</sub> -Neoza pine forest	183.33***	0.92***	0.28***	15.97***	27.78***
T <sub>3</sub> -Dry deodar forest	388.33**	1.94**	0.58**	49.65**	58.33**
T <sub>4</sub> -Dry blue pine forest	400.00****	2.00****	0.50****	38.06****	50.00****
T <sub>5</sub> -Sub alpine birch forest	300.00*****	1.50*****	0.33*****	29.17*****	33.33*****
T <sub>6</sub> -Sub alpine fir forest	163.33*****, 90.00*****	0.82*****, ,0.45*****	0.25*****, 0.11*****	35.28*****, 4.86*****	25*****, 11.11*****

#### 4.4 CARBON STOCK

The biomass and carbon stock under different forest types *viz.*, 13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex – Pinus gerardiana*), 13C<sub>2a</sub>- Neoza pine forest (*Pinus gerardiana*), 13C<sub>2b</sub>- Dry deodar forest (*Cedrus deodara*), 13 C<sub>3</sub>- West Himalayan high level blue pine forest (*Pinus wallichiana*), 14C<sub>1a</sub>- West Himalayan sub- alpine birch forest, 14C<sub>1b</sub>- West Himalayan sub- alpine fir forest, 15C<sub>1</sub>- Birch-rhododendron scrub forest, 15C<sub>3</sub>- Alpine pasture, 16C<sub>1</sub>-Dry alpine scrub have been presented under following sub-heads:

**4.4.1** Tree above ground biomass (t ha<sup>-1</sup>)

**4.4.2** Tree below ground biomass (t ha<sup>-1</sup>)

**4.4.3** Tree biomass (above + below) (t ha<sup>-1</sup>)

- 4.4.4 Shrub biomass ( $t\ ha^{-1}$ )
- 4.4.5 Herb biomass ( $t\ ha^{-1}$ )
- 4.4.6 Total vegetation biomass ( $t\ ha^{-1}$ )
- 4.4.7 Total vegetation carbon density ( $t\ C\ ha^{-1}$ )
- 4.4.8 Soil and detritus carbon density ( $t\ C\ ha^{-1}$ )
- 4.4.9 Ecosystem carbon density ( $t\ C\ ha^{-1}$ ).
- 4.4.10 Total vegetation carbon pool (t C) under different land uses in Kinnaur district of Himachal Pradesh
- 4.4.11 Total soil carbon pool (t C) under different land uses in Kinnaur district of Himachal Pradesh
- 4.4.12 Total ecosystem carbon pool (t C) under different land uses in Kinnaur district of Himachal Pradesh

#### 4.4.1 Tree above ground biomass ( $t\ ha^{-1}$ )

Tree above ground biomass exhibited large variation among different forest types (Table 25). Significantly, maximum tree above ground biomass was observed in dry deodar forest ( $207.06\ t\ ha^{-1}$ ) which was found statistically different from all other forest types under investigation. While, in dry blue pine forest ( $123.83\ t\ ha^{-1}$ ) tree above ground biomass was found statistically at par with sub alpine fir forest ( $104.96\ t\ ha^{-1}$ ), dry broad-leaved coniferous forests ( $103.11\ t\ ha^{-1}$ ) and neoza pine forest ( $79.83\ t\ ha^{-1}$ ), respectively. However, minimum tree above ground biomass was recorded in birch-rhododendron scrub forest ( $49.00\ t\ ha^{-1}$ ) followed by alpine birch forest ( $39.50\ t\ ha^{-1}$ ), whereas nil for alpine pasture and dry alpine scrub.

#### 4.4.2 Tree below ground biomass ( $t\ ha^{-1}$ )

Data in the Table 25 reveals that tree below ground biomass varies significantly among different forest types. The maximum tree below ground biomass was observed in dry deodar forest ( $43.50\ t\ ha^{-1}$ ) which was found statistically different than all forest types under investigation. While, in dry blue pine forest ( $26.00\ t\ ha^{-1}$ ), tree below ground biomass was found statistically identical with dry broad-leaved and coniferous forests ( $25.00\ t\ ha^{-1}$ ), sub alpine fir forest ( $24.03\ t\ ha^{-1}$ ) and neoza pine forest ( $16.75\ t\ ha^{-1}$ ). However, minimum values were observed in birch-rhododendron scrub forest ( $10.31\ t\ ha^{-1}$ ) followed by sub alpine birch forest ( $8.25\ t\ ha^{-1}$ ) whereas, nil for alpine pasture and dry alpine scrub.

#### **4.4.3 Tree biomass (above + below) (t ha<sup>-1</sup>)**

Tree biomass data in Table 25 reveals that total tree biomass varies significantly among different forest types. The maximum tree above ground biomass was observed in dry deodar forest (250.56 t ha<sup>-1</sup>) which was found statistically different than all forest types under study. While, dry blue pine forest (149.83 t ha<sup>-1</sup>) total tree biomass was found statistically at par with sub alpine fir forest (128.99 t ha<sup>-1</sup>), dry broad-leaved and coniferous forests (128.11 t ha<sup>-1</sup>) and neoza pine forest (96.58 t ha<sup>-1</sup>). However, minimum values were found in birch-rhododendron scrub forest (59.31 t ha<sup>-1</sup>), sub alpine birch forest (47.75 ha<sup>-1</sup>) whereas, nil for alpine pasture and dry alpine scrub, respectively.

#### **4.4.4 Shrub biomass (t ha<sup>-1</sup>)**

Data in the Table 25 demonstrates that shrub biomass varies significantly among different forest types. The maximum shrub total biomass was observed in birch-rhododendron scrub forest (19.24 t ha<sup>-1</sup>), which was found statistically different than all forest types under study. While, other forest types viz., dry deodar forest (1.23 t ha<sup>-1</sup>), dry broad-leaved and coniferous forests (1.05 t ha<sup>-1</sup>), dry alpine scrub (0.94 t ha<sup>-1</sup>), neoza pine forest (0.94 t ha<sup>-1</sup>), dry blue pine forest (0.78 t ha<sup>-1</sup>), sub alpine fir forest (0.63 t ha<sup>-1</sup>) and sub alpine birch forest (0.58 ha<sup>-1</sup>) were found statistically similar to each other and there was no critical difference among them.

#### **4.4.5 Herb biomass (t ha<sup>-1</sup>)**

Results pertaining to total herb biomass are presented in Table 25. It shows that herb biomass varies significantly among different forest types. Maximum herb biomass was observed in alpine pasture (0.58 t ha<sup>-1</sup>) which remained at par with sub alpine birch forest (0.53 t ha<sup>-1</sup>). Sub alpine birch forest remains statistically at par with alpine pasture and there was no critical difference among them. Whereas, minimum value was recorded for dry alpine scrub (0.36 t ha<sup>-1</sup>).

#### **4.4.6 Total vegetation biomass (t ha<sup>-1</sup>)**

A perusal of the data presented in the Table 25 reveal that total vegetation biomass varies significantly among different forest types. Maximum total vegetation biomass was observed in dry deodar forest (252.24 t ha<sup>-1</sup>) which was found statistically different than all other different forest types. Dry blue pine forest (151 t ha<sup>-1</sup>), sub alpine fir forest (130.09 t ha<sup>-1</sup>) dry broad-leaved and coniferous forests (129.63 t ha<sup>-1</sup>) and neoza pine forest (97.92 t ha<sup>-1</sup>)

were statistically at par and there were no critical difference among them. Sub alpine birch forest ( $48.86 \text{ t ha}^{-1}$ ), dry alpine scrub ( $1.30 \text{ t ha}^{-1}$ ) and alpine pasture ( $0.58 \text{ t ha}^{-1}$ ) reported minimum values and found at par with each other for vegetation biomass.

Vegetation biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a larger global store of carbon than the atmosphere, and changes in the amount of vegetation biomass already affect the global atmosphere by being a net source of carbon and having the potential either to sequester carbon in future or to become an even larger source. Depending on the quantity of biomass the vegetation cover can have a direct influence on local, regional and even global climate, particularly on air temperature and humidity. Therefore, a global assessment of biomass and its dynamics is an essential input to climate change forecasting models and mitigation and adaptation strategies. Total biomass (above ground + below ground) of trees among different forest types ranged from  $0.00 - 250.56 \text{ t ha}^{-1}$  with highest biomass in dry deodar forest followed by dry blue pine forest, sub alpine fir forest, dry broad-leaved and coniferous forests, neoza pine forest, birch-rhododendron scrub forest, sub alpine birch forest and nil for alpine pasture and dry alpine scrub. These differences in tree biomass in forest are a manifestation of inherent growth characteristics of trees besides the differences in density of trees. The nil values for tree biomass in alpine pasture and dry alpine scrub were due to the absence of trees in those vegetation-systems. Highest trees biomass in dry deodar forest can be related to higher basal area of this forest ecosystem. Differences in tree biomass are the manifestation of inherent growth characteristics of constituent species, their specific ecological niche, climate difference and density of trees. Biomass is also related to human or natural disturbances (Lugo and Brown 1992). A cross-section of above-ground biomass, below ground biomass and total biomass values of trees for certain related forest ecosystem is given in Table 26. It is observed from the Table that the values of tree biomass recorded in present investigation is lower than those reported in other Himalayan forest type ecosystem by Sharma *et al.* 2010; Gairola *et al.* 2011; Bhat 2012 and Dar and Sundarapandian 2015. This can be attributed low temperature and rainfall / precipitation of this climatic zone, which limits the growth of the trees in this region.

The shrub total biomass varies significantly among different forest type with the maximum shrub biomass being in birch-rhododendron scrub forest ( $19.24 \text{ t ha}^{-1}$ ) followed by dry deodar forest ( $1.23 \text{ t ha}^{-1}$ ), dry broad-leaved and coniferous forests ( $1.05 \text{ t ha}^{-1}$ ), dry

alpine scrub (0.94 t ha<sup>-1</sup>) and neoza pine forest (0.94 t ha<sup>-1</sup>), dry blue pine forest (0.78 t ha<sup>-1</sup>), sub alpine fir forest (0.63 t ha<sup>-1</sup>), sub alpine birch forest (0.58 ha<sup>-1</sup>) and nil for alpine pasture. The difference in biomass of shrubs in different forest is related to species composition and their inherent growth capability. Ross and Walstad (1986) opined that biomass of shrub may be attributed to factors like age, size, origin, condition and habit of the species. In birch-rhododendron scrub forest, dominant shrub was *Rhododendron campanulatum* that resulted in higher biomass due to its hefty habit.

The total herbaceous biomass also varied significantly among different forest type. The maximum herb total biomass was observed in alpine pasture (0.58 t ha<sup>-1</sup>) followed by sub alpine birch forest (0.53 t ha<sup>-1</sup>), dry blue pine forest (0.48 t ha<sup>-1</sup>), sub-alpine fir forest (0.47 t ha<sup>-1</sup>), dry broad leaved and coniferous forests (0.47t ha<sup>-1</sup>), birch-rhododendron scrub forest (0.42 t ha<sup>-1</sup>), neoza pine forest (0.40 t ha<sup>-1</sup>) and least in dry alpine scrubs (0.36 t ha<sup>-1</sup>). The higher values of herbaceous biomass in alpine pasture can be attributed to sufficient sunlight due to absence of overstorey canopy as also reported by Grelen and Whrey 1978; Singh and Singh 1980; Ramakrishna 1984; Hazra and Patil 1986; Heinrichs and Schmidt 2010.

**Table 25. Vegetation biomass (t ha<sup>-1</sup>) and vegetation carbon density (t C ha<sup>-1</sup>) under different forest types**

Treatments (Forest Types)	Parameters						
	AGB (t ha <sup>-1</sup> )	BGB (t ha <sup>-1</sup> )	Tree biomass (t ha <sup>-1</sup> )	Shrub biomass (t ha <sup>-1</sup> )	Herb biomass (t ha <sup>-1</sup> )	Total vegetation biomass (t ha <sup>-1</sup> )	Total Vegetation carbon density (t C ha <sup>-1</sup> )
T <sub>1</sub> -Dry broad-leaved and coniferous forests	103.11 <sup>b</sup>	25.00 <sup>b</sup>	128.11 <sup>b</sup>	1.05 <sup>b</sup>	0.47 <sup>bc</sup>	129.63 <sup>bc</sup>	64.82 <sup>bc</sup>
T <sub>2</sub> -Neoza pine forest	79.83 <sup>b</sup>	16.75 <sup>bc</sup>	96.58 <sup>bc</sup>	0.94 <sup>b</sup>	0.40 <sup>b</sup>	97.92 <sup>bcd</sup>	48.96 <sup>bcd</sup>
T <sub>3</sub> -Dry deodar forest	207.06 <sup>a</sup>	43.50 <sup>a</sup>	250.56 <sup>a</sup>	1.23 <sup>b</sup>	0.45 <sup>bc</sup>	252.24 <sup>a</sup>	126.12 <sup>a</sup>
T <sub>4</sub> -Dry blue pine forest	123.83 <sup>b</sup>	26.00 <sup>b</sup>	149.83 <sup>b</sup>	0.78 <sup>b</sup>	0.48 <sup>bc</sup>	151.09 <sup>b</sup>	75.55 <sup>b</sup>
T <sub>5</sub> -Sub alpine birch forest	39.50 <sup>c</sup>	8.25 <sup>c</sup>	47.75 <sup>c</sup>	0.58 <sup>b</sup>	0.53 <sup>ab</sup>	48.86 <sup>de</sup>	24.43 <sup>de</sup>
T <sub>6</sub> -Sub alpine fir forest	104.96 <sup>b</sup>	24.03 <sup>b</sup>	128.99 <sup>b</sup>	0.63 <sup>b</sup>	0.47 <sup>bc</sup>	130.09 <sup>bc</sup>	65.05 <sup>bc</sup>
T <sub>7</sub> -Birch-rhododendron scrub forest	49.00 <sup>c</sup>	10.31 <sup>c</sup>	59.31 <sup>c</sup>	19.24 <sup>a</sup>	0.42 <sup>cd</sup>	78.97 <sup>cd</sup>	39.49 <sup>cd</sup>
T <sub>8</sub> -Alpine Pasture	-	-	-	-	0.58 <sup>a</sup>	0.58 <sup>e</sup>	0.29 <sup>e</sup>
T <sub>9</sub> -Dry Alpine scrub	-	-	-	0.94 <sup>b</sup>	0.36 <sup>d</sup>	1.30 <sup>e</sup>	0.65 <sup>e</sup>
CD <sub>0.05</sub>	<b>48.13</b>	<b>10.37</b>	<b>58.37</b>	<b>1.02</b>	<b>0.08</b>	<b>58.64</b>	<b>29.32</b>

#### 4.4.7 Total vegetation carbon density (t C ha<sup>-1</sup>)

Results pertaining to total vegetation carbon density vary significantly among different forest types. Maximum value was reported in dry deodar forest (126.12 t C ha<sup>-1</sup>), which was found statistically different than all forest types under study. Total vegetation carbon density in dry blue pine forest (75.55 t C ha<sup>-1</sup>), sub alpine fir forest (65.05 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (64.82 t C ha<sup>-1</sup>) and neoza pine forest (48.96 t C ha<sup>-1</sup>)

were statistically at par with each other. Whereas, total vegetation carbon density of birch-rhododendron scrub forest (39.49 t C ha<sup>-1</sup>) and sub alpine birch forest (24.43 t C ha<sup>-1</sup>) are also statistically at par with each other. The minimum total vegetation carbon density was found in dry alpine scrub (0.65 C t ha<sup>-1</sup>) and alpine pasture *i.e.* 0.29 t C ha<sup>-1</sup> (Table 25). The carbon stock in forest vegetation varies according to geographical location, plant species and age of the stand. Vegetation carbon density ranges as reported in our case is more or less in line as reported by Dar and Sundarapandian (2015) for Central Himalayan forest ranges. The maximum values of total vegetation carbon density in dry deodar forest can be attributed to higher biomass due to presence of higher proportion large size tree in the forest community.

**Table 26. Comparison between estimates of tree above-ground biomass, below ground biomass and total biomass under different forest ecosystems reported in earlier studies**

Sr. No.	Forest types/ Location	Tree above ground biomass (t ha <sup>-1</sup> )	Tree below ground biomass (t ha <sup>-1</sup> )	Tree total biomass (t ha <sup>-1</sup> )	Total tree Carbon density (t C ha <sup>-1</sup> )	References
1.	Upper west Himalayan <i>Abies pindrow</i> Spach.	305.33 ± 31.96	-	377.65 ± 38.64	173.72 ± 17.77	Sharma <i>et al.</i> 2010
2.	Upper West Himalayan <i>Quercus semicarpifolia</i> Sm.	224.25 ± 21.66	-	279.31 ± 26.33	128.48 ± 12.11	Sharma <i>et al.</i> 2010
3.	<i>Abies pindrow</i> forest, Chamoli Garhwal	237.9	-	296.0	148.0	Gairola <i>et al.</i> 2011
4.	Mixed broadleaved conifer forest, Chamoli Garhwal	240.1	-	298.6	149.3	Gairola <i>et al.</i> 2011
5.	Fir –Spruce forest , Sirmour (HP)	-	-	334.70	164.07	Bhat, 2012
6.	<i>Populus deltoids</i> forest Anantnag district (J& K)	204±23	50.3 ± 4.9	254.3 ± 28	114.4±12.6	Dar and Sundarapandian, 2015
7.	<i>Cedrus deodara</i> forest Anantnag district (J& K)	228.3±4.4	55.9±3.1	284.2 ± 7.5	130.7±8.1	Dar and Sundarapandian 2015
8.	<i>Pinus wallichiana</i> forest Anantnag district (J& K)	218.3±9.3	53.8±2	272.1±1.3	125.2±5.2	Dar and Sundarapandian, 2015
9.	Mixed coniferous forests Anantnag district (J& K)	222.3±3.2	54.6±2.9	276.9±6.1	127.4±7.4	Dar and Sundarapandian, 2015
10.	<i>Abies pindrow</i> forest Anantnag district (J& K)	237.0±9.8	57.8±2.2	294.8±12	135.6±5.5	Dar and Sundarapandian, 2015
11.	Himalayan dry temperate and alpine forest types (T <sub>1</sub> -T <sub>9</sub> )	0.00-207.06	0.00-43.50	0.00-250.56	0.00-125.28	Present study

#### 4.4.8 Soil and detritus carbon density (t C ha<sup>-1</sup>)

Humus depth of different forest types is tabulated in Table 27. Birch-rhododendron scrub forest showed the maximum of humus depth (4.41 cm) which was found significantly

higher than all forest types under investigation, followed by sub alpine fir forest (3.35), dry broad-leaved and coniferous forests (1.28cm), sub alpine birch forest (0.99cm), dry blue pine forest (0.74cm), dry deodar forest (0.61cm), neoza pine forest (0.27cm) and nil was recorded for alpine pasture and dry alpine scrub, respectively. Higher humus depth in birch rhododendron scrub may be due to a dense cover provided by *Rhododendron campanulatum* thereby preventing sun light to reach soil surface and thus hindering its decomposition. The green foliage forming the irregular to regular spherical crown has immense power to enrich the thickness of humus layer over the soil. Whereas, nil value of humus in alpine pasture and dry alpine scrub may be due to low litter production in these ecosystem along with the high wind velocity and overgrazing.

Data in the Table 27 demonstrate that soil carbon density ( $\text{t C ha}^{-1}$ ) of soil *viz.*, humus, 0-20 cm and 21-40 cm varied significantly among different forest types. In the humus layer, significantly maximum carbon density was recorded in birch-rhododendron scrub forest ( $11.30 \text{ t C ha}^{-1}$ ) which was found significantly higher than all forest types under investigation, followed by sub alpine fir forest ( $8.30 \text{ t C ha}^{-1}$ ), dry broad-leaved and coniferous forests ( $4.79 \text{ t C ha}^{-1}$ ), sub alpine birch forest ( $2.90 \text{ t C ha}^{-1}$ ), dry blue pine forest ( $0.63 \text{ t C ha}^{-1}$ ), dry deodar forest ( $0.54 \text{ t C ha}^{-1}$ ), neoza pine forest ( $0.36 \text{ t C ha}^{-1}$ ), and nil for both alpine pasture and dry alpine scrub, respectively. In the soil depth of 0-20 cm as well as 21-40 cm soil layer the carbon density varied significantly. Carbon density value for depth 0-20 cm was found significantly different among different forest types. Maximum carbon density in the depth of 0-20 cm was reported in birch-rhododendron scrub forest ( $71.55 \text{ t C ha}^{-1}$ ) followed by dry broad-leaved and coniferous forests ( $59.37 \text{ t C ha}^{-1}$ ), dry deodar forest ( $52.52 \text{ t C ha}^{-1}$ ), sub alpine birch forest ( $44.50 \text{ t C ha}^{-1}$ ), sub alpine fir forest ( $41.18 \text{ t C ha}^{-1}$ ), dry blue pine forest ( $35.43 \text{ t C ha}^{-1}$ ), alpine pasture ( $33.66 \text{ t C ha}^{-1}$ ), neoza pine forest ( $28.42 \text{ t C ha}^{-1}$ ) and dry alpine scrub ( $23.70 \text{ t C ha}^{-1}$ ) in descending order. In the depth of 21-40 cm, maximum carbon density was observed in birch-rhododendron scrub forest ( $47.54 \text{ t C ha}^{-1}$ ) which was found statistically similar with dry broad-leaved and coniferous forests ( $47.02 \text{ t C ha}^{-1}$ ). While, carbon density (depth 21-40 cm) of dry deodar forest ( $31.74 \text{ t C ha}^{-1}$ ), sub alpine birch forest ( $27.36 \text{ t C ha}^{-1}$ ) was found statistically different with each other. Minimum carbon density for depth 21-40 cm was found in dry alpine scrub ( $14.02 \text{ t C ha}^{-1}$ ).

Total soil carbon density (humus + soil (0-40 cm layer) varied significantly among different forest types. Birch-rhododendron scrub forest ( $130.39 \text{ t C ha}^{-1}$ ) showed maximum

carbon density followed by dry broad-leaved and coniferous forests (111.18 t C ha<sup>-1</sup>), dry deodar forest (84.81 t C ha<sup>-1</sup>), sub alpine birch forest (74.76 t C ha<sup>-1</sup>), sub alpine fir forest (73.56 t C ha<sup>-1</sup>), dry blue pine forest (56.55 t C ha<sup>-1</sup>), alpine pasture (51.06 t C ha<sup>-1</sup>), neoza pine forest (45.62 t C ha<sup>-1</sup>) and dry alpine scrub (37.73 t C ha<sup>-1</sup>) in descending order, respectively.

Worldwide, SOC stocks up to 1m average at 12.2 Kg m<sup>-2</sup> in temperate forest (Prentice *et al.* 2001 and Lal 2005), 13.9 Kg m<sup>-2</sup> in cool temperate wet forest (Post *et al.* 1982), and 11.3 Kg m<sup>-2</sup> among all forests (Sombroek *et al.* 1993). Soil carbon density of 161.9 t ha<sup>-1</sup> for the soil layer of 1 m was reported by Chhabra *et al.* (2003) for montane temperate forest. The soil carbon stock (SOC) exhibits considerable spatial variability, both horizontally according to land use and vertically within the soil profile. The SOC diminishes with depth regardless of vegetation type (Trujillo *et al.* 1997). Data presented in Table 27 showed that soil organic carbon density was significantly influenced due to humus, 0-20 cm as well as in 21-40 cm soil layer by the vegetation effect. In all the forest types, the carbon density declined with the increasing soil layer as we move from 0-20 cm to 21-40 cm. Soil organic carbon (SOC) depends on various biotic and abiotic factors such as microclimate, faunal diversity, land use and management. Leaf litter and root litter input play an important role in forest soil carbon. The upper soil layer remains in dynamic equilibrium with biological and anthropological activities and is generally richer in C than the lower layers. Similar results are also reported earlier by Shrestha *et al.* (2004) for mountain watershed of Nepal. The growth and functions of vegetation depends on the availability of plant nutrients in the soil, whilst, SOC dynamics depends on the input reported from the vegetation growth. Thus there is an inter-relationship between vegetation and soil carbon dynamics in an ecosystem. The input can be from above ground leaf litter and or below ground fine roots (Bloomfield *et al.* 1996) and their decomposition rates are governed by microbial activity. The soil carbon pools in different forest types in our study are on the lower side to the SOC reported for Garhwal region Uttarakhand (Raina and Gupta 2013) but are comparable to that reported by other workers (Wani *et al.* 2013) in Kashmir Himalayas and (Panwar and Gupta 2013) in Himachal Pradesh. It is also evidently clear from the data in Table 27 that soil carbon density in soil (humus, 0-20 cm and 21-40 cm) was highest in birch-rhododendron scrub forest. Hence, birch-rhododendron scrub forest have more capacity to store the carbon in soil layer and thus more carbon mitigation potential.

**Table 27. Soil carbon stock (t C ha<sup>-1</sup>) under different forest types**

Treatments (Forest Types)	Humus depth (cm)	Carbon density (t C ha <sup>-1</sup> )			
		Humus	0-20 cm	21-40 cm	Total Carbon density {Humus+Soil (0-40 cm)}
T <sub>1</sub> -Dry broad-leaved and coniferous forests	1.28 <sup>c</sup>	4.79 <sup>c</sup>	59.37 <sup>b</sup>	47.02 <sup>a</sup>	111.18 <sup>b</sup>
T <sub>2</sub> -Neoza pine forest	0.27 <sup>g</sup>	0.36 <sup>g</sup>	28.42 <sup>h</sup>	16.84 <sup>f</sup>	45.62 <sup>g</sup>
T <sub>3</sub> -Dry deodar forest	0.61 <sup>f</sup>	0.54 <sup>f</sup>	52.52 <sup>c</sup>	31.74 <sup>b</sup>	84.81 <sup>c</sup>
T <sub>4</sub> -Dry blue pine forest	0.74 <sup>e</sup>	0.63 <sup>e</sup>	35.43 <sup>f</sup>	20.49 <sup>e</sup>	56.55 <sup>e</sup>
T <sub>5</sub> -Sub alpine birch forest	0.99 <sup>d</sup>	2.90 <sup>d</sup>	44.50 <sup>d</sup>	27.36 <sup>c</sup>	74.76 <sup>d</sup>
T <sub>6</sub> -Sub alpine fir forest	3.35 <sup>b</sup>	8.30 <sup>b</sup>	41.18 <sup>e</sup>	24.09 <sup>d</sup>	73.56 <sup>d</sup>
T <sub>7</sub> -Birch-rhododendron scrub forest	4.41 <sup>a</sup>	11.30 <sup>a</sup>	71.55 <sup>a</sup>	47.54 <sup>a</sup>	130.39 <sup>a</sup>
T <sub>8</sub> -Alpine Pasture	0.00 <sup>h</sup>	0.00 <sup>h</sup>	33.66 <sup>g</sup>	17.40 <sup>f</sup>	51.06 <sup>f</sup>
T <sub>9</sub> -Dry Alpine scrub	0.00 <sup>h</sup>	0.00 <sup>h</sup>	23.70 <sup>i</sup>	14.02 <sup>g</sup>	37.73 <sup>h</sup>
<b>CD<sub>0.05</sub></b>	<b>0.08</b>	<b>0.04</b>	<b>1.61</b>	<b>1.23</b>	<b>2.65</b>

A perusal of data in the Table 28 reveals that litter biomass (t ha<sup>-1</sup>), dead twig biomass (t ha<sup>-1</sup>), total detritus biomass (t ha<sup>-1</sup>) and total detritus carbon (t C ha<sup>-1</sup>) varied significantly under different forest types. Leaf or surface litter biomass is found to be maximum in birch-rhododendron scrub forest (3.15 t ha<sup>-1</sup>) which was found significantly higher than all forest types under investigation followed by sub alpine fir forest (2.83 t ha<sup>-1</sup>), dry broad-leaved and coniferous forests (2.35 t ha<sup>-1</sup>), sub alpine birch forest (1.80 t ha<sup>-1</sup>), dry deodar forest (1.39 t ha<sup>-1</sup>), dry blue pine forest (1.35 t ha<sup>-1</sup>), neoza pine forest (1.35 t ha<sup>-1</sup>), alpine pasture (0.15 t C ha<sup>-1</sup>) and dry alpine scrub (0.11 t ha<sup>-1</sup>). Result pertaining to dead twig biomass varied significantly among different forest types. It was found to be maximum in birch-rhododendron scrub forest (2.84 t ha<sup>-1</sup>), which was found significantly higher than all forest types under investigation followed by sub alpine fir forest (2.40 t ha<sup>-1</sup>), dry broad-leaved and coniferous forests (1.70 t ha<sup>-1</sup>), sub alpine birch forest (1.27 t ha<sup>-1</sup>), dry deodar forest (1.18 t ha<sup>-1</sup>), dry blue pine forest (1.04 t ha<sup>-1</sup>), neoza pine forest (0.85 t ha<sup>-1</sup>) and nil on both alpine pasture as well as dry alpine scrub.

Data in the Table 28 demonstrates that total detritus biomass varied significantly among different forest types. It was found to be maximum in birch-rhododendron scrub forest (5.99 t ha<sup>-1</sup>) followed by sub alpine fir forest (5.23 t ha<sup>-1</sup>), dry broad-leaved and coniferous forests (4.05 t ha<sup>-1</sup>), sub alpine birch forest (3.07 t ha<sup>-1</sup>), dry deodar forest (2.57 t ha<sup>-1</sup>), dry

blue pine forest (2.39 t ha<sup>-1</sup>), neoza pine forest (1.64 t ha<sup>-1</sup>), alpine pasture (0.15 t ha<sup>-1</sup>), and dry alpine scrub (0.11 t ha<sup>-1</sup>) in descending order, respectively.

**Table 28. Litter, dead branches biomass, total detritus biomass (t ha<sup>-1</sup>) and total detritus carbon density under different forest types**

Treatments (Forest Types)	Parameters			
	Litter biomass (t ha <sup>-1</sup> )	Dead twig biomass (t ha <sup>-1</sup> )	Total detritus biomass (t ha <sup>-1</sup> )	Total detritus carbon (t C ha <sup>-1</sup> )
<b>T<sub>1</sub>-Dry broad-leaved and coniferous forests</b>	2.35 <sup>c</sup>	1.70 <sup>c</sup>	4.05 <sup>c</sup>	2.03 <sup>c</sup>
<b>T<sub>2</sub>-Neoza pine forest</b>	0.79 <sup>f</sup>	0.85 <sup>g</sup>	1.64 <sup>f</sup>	0.82 <sup>g</sup>
<b>T<sub>3</sub>-Dry deodar forest</b>	1.39 <sup>e</sup>	1.18 <sup>e</sup>	2.57 <sup>e</sup>	1.29 <sup>e</sup>
<b>T<sub>4</sub>-Dry blue pine forest</b>	1.35 <sup>e</sup>	1.04 <sup>f</sup>	2.39 <sup>e</sup>	1.20 <sup>f</sup>
<b>T<sub>5</sub>-Sub alpine birch forest</b>	1.80 <sup>d</sup>	1.27 <sup>d</sup>	3.07 <sup>d</sup>	1.54 <sup>d</sup>
<b>T<sub>6</sub>-Sub alpine fir forest</b>	2.83 <sup>b</sup>	2.40 <sup>b</sup>	5.23 <sup>b</sup>	2.62 <sup>b</sup>
<b>T<sub>7</sub>-Birch-rhododendron scrub forest</b>	3.15 <sup>a</sup>	2.84 <sup>a</sup>	5.99 <sup>a</sup>	3.00 <sup>a</sup>
<b>T<sub>8</sub>-Alpine Pasture</b>	0.15 <sup>f</sup>	0.00 <sup>h</sup>	0.15 <sup>g</sup>	0.08 <sup>h</sup>
<b>T<sub>9</sub>-Dry Alpine scrub</b>	0.11 <sup>g</sup>	0.00 <sup>h</sup>	0.11 <sup>g</sup>	0.06 <sup>h</sup>
<b>CD<sub>0.05</sub></b>	<b>0.29</b>	<b>0.04</b>	<b>0.31</b>	<b>0.15</b>

Total detritus carbon density also varied significantly among different forest types. The maximum detritus carbon is found in birch-rhododendron scrub forest (3.00 t C ha<sup>-1</sup>), which is significantly different than other forest types followed by sub alpine fir forest (2.62 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (2.03 t C ha<sup>-1</sup>), sub alpine birch forest (1.54 t C ha<sup>-1</sup>), dry deodar forest (1.29 t C ha<sup>-1</sup>), dry blue pine forest (1.20 t C ha<sup>-1</sup>), neoza pine forest (0.82 t C ha<sup>-1</sup>), alpine pasture (0.08 t C ha<sup>-1</sup>), and dry alpine scrub (0.06 t C ha<sup>-1</sup>) in descending order, respectively.

Detritus C stock variation among the forest types may be due to disturbances and variations in stand age structure, litter input and decomposition rate, and elevation (Pregitzer and Euskirchen 2004; Peichul and Arain 2006; Taylor *et al.* 2007). This difference probably may be due to the result of environmentally controlled decomposition rates and management history, in addition to differences induced by detritus inputs associated with vegetation status.

#### **4.4.9 Ecosystem carbon density (t C ha<sup>-1</sup>)**

Data presented in Table 29 reveals that the ecosystem carbon density under different forest type varied significantly.

**Table 29. Soil and ecosystem carbon density (t C ha<sup>-1</sup>) under different forest types**

Treatments (Forest Types)	Parameters			
	Vegetation (t C ha <sup>-1</sup> )	Soil (t C ha <sup>-1</sup> )	Detritus (t C ha <sup>-1</sup> )	Ecosystem (t C ha <sup>-1</sup> )
T <sub>1</sub> -Dry broad-leaved and coniferous forests	64.82 <sup>b</sup>	111.18 <sup>b</sup>	2.03 <sup>c</sup>	178.02 <sup>b</sup>
T <sub>2</sub> -Neoza pine forest	48.96 <sup>b</sup>	45.62 <sup>g</sup>	0.82 <sup>f</sup>	95.40 <sup>e</sup>
T <sub>3</sub> -Dry deodar forest	126.12 <sup>a</sup>	84.81 <sup>c</sup>	1.29 <sup>e</sup>	212.21 <sup>a</sup>
T <sub>4</sub> -Dry blue pine forest	75.55 <sup>b</sup>	56.55 <sup>e</sup>	1.20 <sup>e</sup>	133.29 <sup>c</sup>
T <sub>5</sub> -Sub alpine birch forest	24.43 <sup>c</sup>	74.76 <sup>d</sup>	1.54 <sup>d</sup>	100.72 <sup>d</sup>
T <sub>6</sub> -Sub alpine fir forest	65.05 <sup>b</sup>	73.56 <sup>d</sup>	2.62 <sup>b</sup>	141.22 <sup>c</sup>
T <sub>7</sub> -Birch-rhododendron scrub forest	39.49 <sup>c</sup>	130.39 <sup>a</sup>	3.00 <sup>a</sup>	172.87 <sup>b</sup>
T <sub>8</sub> -Alpine pasture	0.29 <sup>d</sup>	51.06 <sup>f</sup>	0.08 <sup>g</sup>	51.42 <sup>f</sup>
T <sub>9</sub> -Dry alpine scrub	0.65 <sup>d</sup>	37.73 <sup>h</sup>	0.06 <sup>g</sup>	38.43 <sup>f</sup>
CD <sub>0.05</sub>	<b>29.32</b>	<b>2.65</b>	<b>0.15</b>	<b>29.61</b>

Results pertaining to total vegetation carbon density vary significantly among different forest types. Maximum value was reported in dry deodar forest (126.12 t C ha<sup>-1</sup>), which was found statistically different than all forest types under study. Total vegetation carbon density in dry blue pine forest (75.55 t C ha<sup>-1</sup>), sub alpine fir forest (65.05 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (64.82 t C ha<sup>-1</sup>) and neoza pine forest (48.96 t C ha<sup>-1</sup>) were statistically at par with each other. Whereas, total vegetation carbon density of birch-rhododendron scrub forest (39.49 t C ha<sup>-1</sup>) and sub alpine birch forest (24.43 t C ha<sup>-1</sup>) are also statistically at par with each other. Minimum total vegetation carbon density was found in dry alpine scrub (0.65 t C ha<sup>-1</sup>) and alpine pasture *i.e.* 0.29 t C ha<sup>-1</sup> values being statistically at par with each other.

Total soil carbon density (humus + soil 0-40 cm layer) varied significantly in different forest type. Birch-rhododendron scrub forest (130.39 t C ha<sup>-1</sup>) (Table 29) showed maximum carbon density followed by dry broad-leaved and coniferous forests (111.18 t C ha<sup>-1</sup>), dry deodar forest (84.81 t C ha<sup>-1</sup>), sub alpine birch forest (74.76 t C ha<sup>-1</sup>), sub alpine fir forest (73.56 t C ha<sup>-1</sup>), dry blue pine forest (56.55 t C ha<sup>-1</sup>), alpine pasture (51.06 t C ha<sup>-1</sup>) neoza pine forest (45.62 t C ha<sup>-1</sup>) and dry alpine scrub (37.73 t C ha<sup>-1</sup>) in descending order, respectively.

Total detritus carbon also varied significantly among different forest types. The detritus carbon was found maximum in birch-rhododendron scrub forest (3.00 t C ha<sup>-1</sup>) followed by sub alpine fir forest (2.62 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (2.03 t C ha<sup>-1</sup>), sub alpine birch forest (1.54 t C ha<sup>-1</sup>), dry deodar forest (1.29 t C ha<sup>-1</sup>), dry

blue pine forest (1.20 t C ha<sup>-1</sup>), neoza pine forest (0.82 t C ha<sup>-1</sup>), alpine pasture (0.08 t C ha<sup>-1</sup>), and dry alpine scrub (0.06 t C ha<sup>-1</sup>) in descending order, respectively.

Data presented in Table 29 reveals that total ecosystem carbon density (vegetation + soil + detritus) of different forest types. Highest ecosystem carbon density was displayed by dry deodar forest (212.21 t C ha<sup>-1</sup>) followed by broad-leaved and coniferous forests (178.02 t C ha<sup>-1</sup>), birch-rhododendron scrub forest (172.87 t C ha<sup>-1</sup>), dry sub alpine fir forest (141.22 t C ha<sup>-1</sup>), dry blue pine forest (133.29 t C ha<sup>-1</sup>), sub alpine birch forest (100.72 t C ha<sup>-1</sup>), neoza pine forest (95.40 t C ha<sup>-1</sup>), alpine pasture (51.42 t C ha<sup>-1</sup>), and dry alpine scrub (38.43 t C ha<sup>-1</sup>) in descending order, respectively.

Forest vegetation and soil contain about 1240 Pg of C (Dixon *et al.* 1994), and the carbon stocks varies widely among latitudes. Total terrestrial C stock varied widely among latitudes. Of the total terrestrial C stock in forest biomass, 37 per cent is in low latitude forest, 14 per cent in mid latitude and 49 per cent in high latitudes. The above ground plant C density increases with decreasing latitudes from tundra to tropical rainforest (Fisher 1995). Typical plant C density ranges from 40-60 Mg C ha<sup>-1</sup> in boreal forest, 60-130 Mg C ha<sup>-1</sup> in temperate forest and 120-194 Mg C ha<sup>-1</sup> in tropical forest, with the C of an undisturbed TRF (Tropical rain forest) as high as 250 Mg C ha<sup>-1</sup>. Nonetheless as much as two-thirds of the terrestrial C in forest ecosystem is contained in soils (Dixon *et al.* 1994). Data presented in Table 29 reveals that carbon density varied significantly in all the components of all the ecosystems *viz.*, vegetation, soil, detritus and ecosystem as a whole, with different forest types. Highest ecosystem carbon density was recorded in dry deodar forest. The relative high values of vegetation carbon density as well as soil carbon density in this forest types resulted in the high ecosystem carbon density.

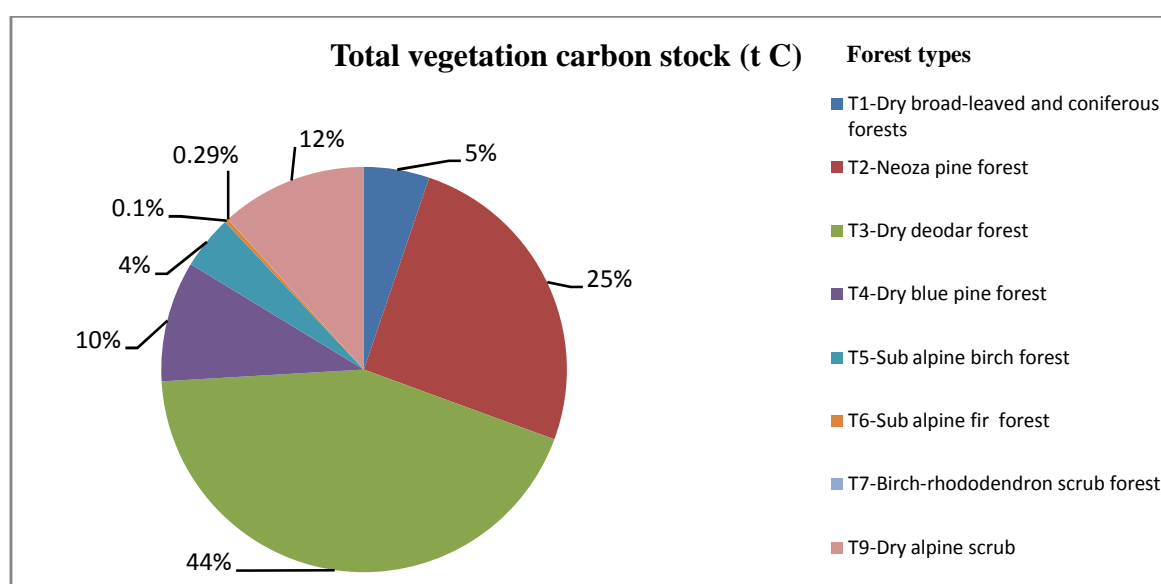
#### **4.4.10 Total vegetation carbon pool under different forest types in Kinnaur district of Himachal Pradesh**

A perusal of the data in the Table 30 and Figure 3 indicates that maximum vegetation carbon pool was found in dry deodar forest (1083118.56 t C) followed by neoza pine forest (546393.60 t C), dry blue pine forest (228916.50 t C), dry broad-leaved and coniferous forests (79534.14 t C ha<sup>-1</sup>), sub alpine birch forest (43509.83 t C), dry alpine scrub (8296.60 C t) sub alpine fir forest (5842.14 t C) and birch-rhododendron scrub forest (157.96 t C) in descending order, respectively.

**Table 30. Total vegetation carbon stock (t C) under different forest type in Kinnaur district of Himachal Pradesh**

Treatments (Forest Types)	Vegetation (t C ha <sup>-1</sup> )	Area (ha)*	Total vegetation carbon stock (t C)
T <sub>1</sub> -Dry broad-leaved and coniferous forests	64.82 ± 14.52	1227	79534.14
T <sub>2</sub> -Neoza pine forest	48.96 ± 5.89	11160	546393.60
T <sub>3</sub> -Dry deodar forest	126.12 ± 35.65	8588	1083118.56
T <sub>4</sub> -Dry blue pine forest	75.55 ± 19.02	3030	228916.50
T <sub>5</sub> -Sub alpine birch forest	24.43 ± 2.26	1781	43509.83
T <sub>6</sub> -Sub alpine fir forest	65.05 ± 18.45	89.81	5842.14
T <sub>7</sub> -Birch-rhododendron scrub forest	39.49 ± 9.23	4.00	157.96
T <sub>9</sub> -Dry alpine scrub	0.65 ± 0.17	12764	8296.60

\*Source: Working plan of Kinnaur Forest Division (1999-2015)



**Figure 3. Total vegetation carbon stock (t C) under different forest type in Kinnaur district of Himachal Pradesh**

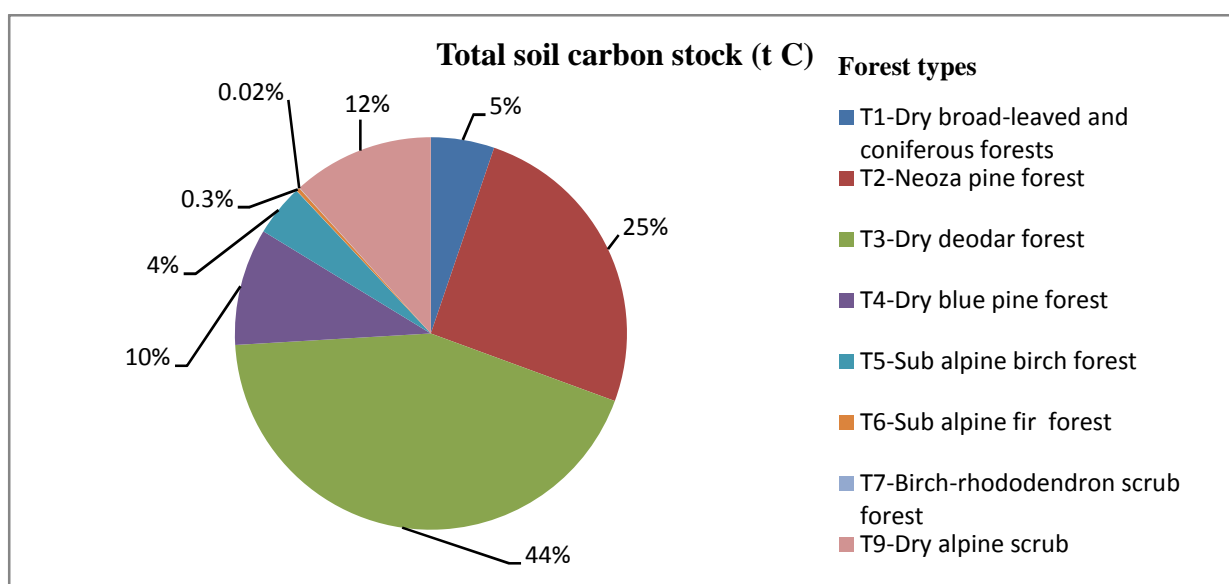
#### 4.4.11 Total soil carbon pool under different land uses in Kinnaur district of Himachal Pradesh

Result pertaining to total soil carbon pool (Table 31 and Figure 4) was found maximum in dry deodar forest (728348.28 t C ha<sup>-1</sup>) followed by neoza pine forest (509119.20 t C), dry alpine scrub (481585.72 C t), dry blue pine forest (171346.50 t C), dry broad-leaved and coniferous forests (136417.86 t C), sub alpine birch forest (133147.56 t C), sub alpine fir forest (6606.42 t C) and birch-rhododendron scrub forest (521.56 t C) in descending order, respectively.

**Table 31. Total soil carbon stock (t C) under different forest type in Kinnaur district of Himachal Pradesh**

Treatments (Forest Types)	Soil (t C ha <sup>-1</sup> )	Area* (ha)	Total soil carbon stock (t C)
T <sub>1</sub> -Dry broad-leaved and coniferous forests	111.18 ± 7.76	1227	136417.86
T <sub>2</sub> -Neoza pine forest	45.62 ± 4.18	11160	509119.20
T <sub>3</sub> -Dry deodar forest	84.81 ± 5.63	8588	728348.28
T <sub>4</sub> -Dry blue pine forest	56.55 ± 3.60	3030	171346.50
T <sub>5</sub> -Sub alpine birch forest	74.76 ± 4.05	1781	133147.56
T <sub>6</sub> -Sub alpine fir forest	73.56 ± 3.65	89.81	6606.42
T <sub>7</sub> -Birch-rhododendron scrub forest	130.39 ± 6.14	4.00	521.56
T <sub>9</sub> -Dry Alpine scrub	37.73 ± 3.42	12764	481585.72

\*Source: Working plan of Kinnaur Forest Division (1999-2015)



**Figure 4. Total soil carbon stock (t C) under different forest type in Kinnaur district of Himachal Pradesh**

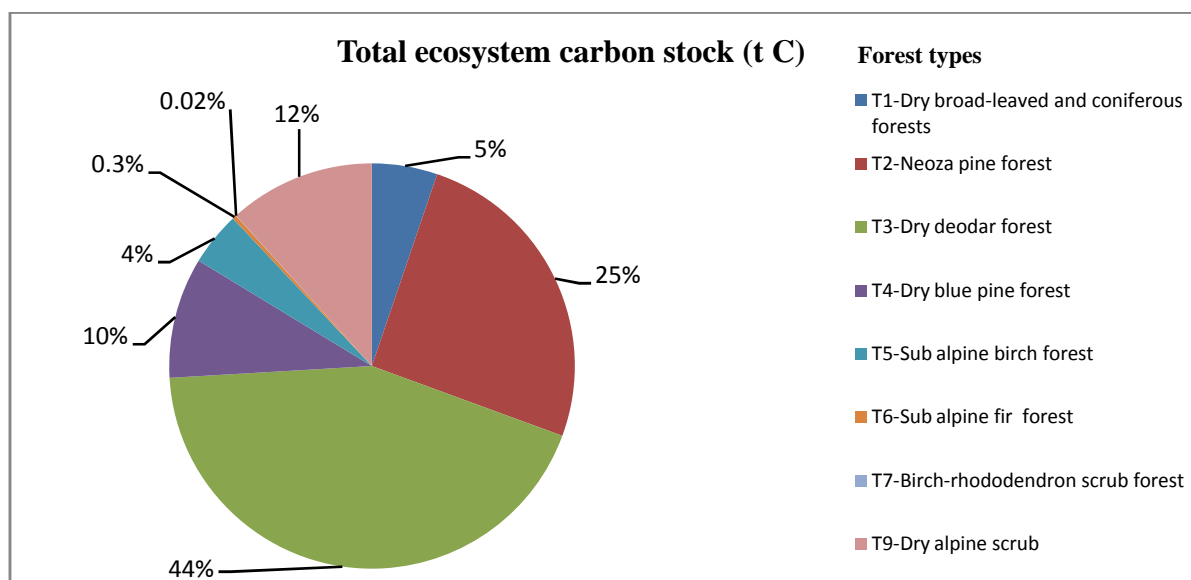
#### 4.4.12 Total ecosystem carbon pool under different land uses in Kinnaur district of Himachal Pradesh

Data presented in Table 32 and Figure 5 reveals that total ecosystem carbon pool was recorded maximum in dry deodar forest (1822459.48 t C) followed by neoza pine forest (1064664.00 t C), dry alpine scrub (490520.52 t C), dry blue pine forest (403868.70 t C), dry broad-leaved and coniferous forests (218430.54 t C ha<sup>-1</sup>), sub alpine birch forest (179382.32 t C), sub alpine fir forest (12682.97 t C) and birch-rhododendron scrub forest (691.48 t C) in descending order, respectively.

**Table 32. Total ecosystem carbon stock (t C) under different forest type in Kinnaur district of Himachal Pradesh**

Treatments (Forest Types)	Ecosystem (t C ha <sup>-1</sup> )	Area (ha)*	Total ecosystem carbon stock (t C)
T <sub>1</sub> -Dry broad-leaved and coniferous forests	178.02 ± 21.60	1227	218430.54
T <sub>2</sub> -Neoza pine forest	95.40 ± 9.96	11160	1064664.00
T <sub>3</sub> -Dry deodar forest	212.21 ± 30.01	8588	1822459.48
T <sub>4</sub> -Dry blue pine forest	133.29 ± 20.01	3030	403868.70
T <sub>5</sub> -Sub alpine birch forest	100.72 ± 5.92	1781	179382.32
T <sub>6</sub> -Sub alpine fir forest	141.22 ± 20.21	89.81	12682.97
T <sub>7</sub> -Birch-rhododendron scrub forest	172.87 ± 15.29	4.00	691.48
T <sub>9</sub> -Dry Alpine scrub	38.43 ± 3.40	12764	490520.52

\*Source: Working plan of Kinnaur Forest Division (1999-2015)



**Figure 5. Total ecosystem carbon stock (t C) under different forest type in Kinnaur district of Himachal Pradesh**

#### 4.5 SOIL PHYSICO-CHEMICAL PROPERTIES

Soil physico-chemical properties viz., bulk density (g cm<sup>-3</sup>), organic carbon (%), pH, EC (ds m<sup>-1</sup>), available macro-nutrients N P and K (kg ha<sup>-1</sup>) and micro-nutrient (mg ha<sup>-1</sup>) as observed in 0-20 cm and 21-40 cm soil layers under different forest types have been depicted in the following sections.

##### 4.5.1 Soil organic carbon (%)

##### 4.5.2 Bulk density (g cm<sup>-3</sup>)

##### 4.5.3 Soil pH

##### 4.5.4 Soil EC (dsm<sup>-1</sup>)

**4.5.5** Available N ( $\text{kg ha}^{-1}$ )

**4.5.6** Available P ( $\text{kg ha}^{-1}$ )

**4.5.7** Available K ( $\text{kg ha}^{-1}$ )

**4.5.8** Available Cu ( $\text{mg kg}^{-1}$ )

**4.5.9** Available Fe ( $\text{mg kg}^{-1}$ )

**4.5.10** Available Mn ( $\text{mg kg}^{-1}$ )

**4.5.11** Available Zn ( $\text{mg kg}^{-1}$ )

#### **4.5.1 Soil organic carbon (%)**

Data in Table 33 demonstrate that soil organic carbon (%) varied significantly under different forest types and soil layers. Maximum value (2.56%) was depicted under birch-rhododendron scrub forest which was found statistically different than all forest types under study. Soil organic carbon in different forest types followed the trend: birch-rhododendron scrub forest (2.56%) > dry broad-leaved and coniferous forests (2.24%) > dry deodar forest (1.75%) > sub alpine birch forest (1.48%) > sub alpine fir forest (1.29%) > dry blue pine forest (1.08%) > alpine pasture (0.97 %) > neoza pine forest (0.71%) > dry alpine scrub (0.56%). Irrespective of forest types, L<sub>1</sub> (0-20 cm) soil layer displayed significantly higher soil organic carbon (1.74%) than L<sub>2</sub> (21-40 cm) soil layer. The interaction between forest types and soil layers was found to be non-significant

Soil organic matter is responsible for building a major portion of the soil organic carbon pool, which regulates the soil properties *viz.*, physical, chemical and biological properties (Woomer *et al.* 1994). It was found that the birch-rhododendron scrub forest soil holds the highest carbon percentage in both the soil layers which, may be attributed to high addition of leaf litter and slow decomposition rates of organic residues under low light penetration to the soil surface (Dimri *et al.* 1997). However, low litter production in addition with high wind velocity and lack of overstorey vegetation results in faster decomposition of litter may be the reason for lower values of soil organic carbon in dry alpine scrub.

The results of organic carbon in different soil layers revealed that organic carbon percentage decreases with increase in soil depth in various forest types. Similar results were also reported by several workers (Senneh 2007; Kaushal 1992; Sharma 1991 and Maurya *et al.* 2014). Higher organic carbon accumulation in surface soil than sub-surface could be attributed to higher amount of litter accumulation on surface. Gradual decline in the availability towards lower soil layers could be due to more accumulation and mineralization

and reduced root biomass in deeper soil layers. The other reason may be cycling of nutrients *i.e.* deep tap root system may be extracting elements from lower layers and depositing on surface soils. These results are well supported by the findings of Malik (1992), Sharma (1991) and Soni (1991) for chir pine forests of Himachal Pradesh and Sharma *et al.*, (2012) for cold desert.

#### 4.5.2 Bulk density ( $\text{g cm}^{-3}$ )

It is evident from the Table 33 that bulk density was observed maximum in dry alpine scrub ( $1.68 \text{ g cm}^{-3}$ ) which was found to be significantly at par with other forest types under investigation *viz.*, neoza pine forest, alpine pasture, dry blue pine forest, sub alpine fir forest, sub alpine birch forest, dry broad-leaved and coniferous forests, sub alpine birch forest and dry deodar forest whereas, minimum value for bulk density ( $1.17 \text{ g cm}^{-3}$ ) was recorded under birch-rhododendron scrub forest.

**Table 33. Soil organic carbon % and bulk density ( $\text{g cm}^{-3}$ ) under different forest types of Himalayan dry temperate and alpine forest of Kinnaur district (H.P.)**

Treatments (Forest Types)	Organic carbon (%)			Bulk density ( $\text{g cm}^{-3}$ )		
	0-20cm	21-40 cm	Mean	0-20 cm	21-40 cm	Mean
T <sub>1</sub> -Dry broad-leaved and coniferous forests	2.51	1.96	2.24 <sup>b</sup>	1.18	1.20	1.19 <sup>e</sup>
T <sub>2</sub> -Neoza pine forest	0.91	0.52	0.71 <sup>h</sup>	1.56	1.62	1.59 <sup>b</sup>
T <sub>3</sub> -Dry deodar forest	2.19	1.30	1.75 <sup>c</sup>	1.20	1.22	1.21 <sup>f</sup>
T <sub>4</sub> -Dry blue pine forest	1.38	0.78	1.08 <sup>f</sup>	1.28	1.31	1.29 <sup>d</sup>
T <sub>5</sub> -Sub alpine birch forest	1.85	1.10	1.48 <sup>d</sup>	1.20	1.25	1.22 <sup>f</sup>
T <sub>6</sub> -Sub alpine fir forest	1.65	0.94	1.29 <sup>e</sup>	1.25	1.28	1.27 <sup>e</sup>
T <sub>7</sub> -Birch-rhododendron scrub forest	3.11	2.01	2.56 <sup>a</sup>	1.15	1.18	1.17 <sup>h</sup>
T <sub>8</sub> -Alpine pasture	1.30	0.64	0.97 <sup>g</sup>	1.29	1.35	1.32 <sup>c</sup>
T <sub>9</sub> -Dry alpine scrub	0.71	0.41	0.56 <sup>i</sup>	1.66	1.71	1.68 <sup>a</sup>
Mean	1.74 <sup>a</sup>	1.07 <sup>b</sup>		1.31 <sup>b</sup>	1.34 <sup>a</sup>	
CD at 5%						
T: Forest types			0.01	0.02		
L: Soil layers			0.004	0.01		
T × L: Forest types × Soil layer			NS	NS		

Irrespective of forest types, L<sub>1</sub> soil layer displayed significantly at par value with L<sub>2</sub>. The interaction between forest types and soil layers were found non-significant. Thus the findings clearly indicated that the value of bulk density varies with forest types and soil depth. The increase in bulk density with increasing soil depth can be owed to decrease in the

organic carbon with the increasing soil depth (Table 27). The variation in bulk density under different forest types can be owed to their varying rate of leaf litter decomposition and deposition. Similar decrease in bulk density with depth was reported by Zeng *et al.* 2014.

#### **4.5.3 Available Nitrogen (kg ha<sup>-1</sup>)**

The result pertaining to available nitrogen is presented in Table 34. Available nitrogen of soil was significantly influenced due to forest types and soil layers. Significantly maximum available nitrogen (407.11 kg ha<sup>-1</sup>) was recorded under birch-rhododendron scrub forest followed by dry broad-leaved and coniferous forests (333.23kg ha<sup>-1</sup>), sub alpine birch forest (246.71 kg ha<sup>-1</sup>), dry deodar forest (163.05 kg ha<sup>-1</sup>), sub alpine fir forest (156.15 kg ha<sup>-1</sup>), dry blue pine forest (141.83 kg ha<sup>-1</sup>), alpine pasture (134.12 kg ha<sup>-1</sup>), neoza pine forest (112.32 kg ha<sup>-1</sup>), dry alpine scrub (102.09 kg ha<sup>-1</sup>) in descending order, respectively. Among soil depths, the higher available nitrogen (232.42 kg ha<sup>-1</sup>) was observed in upper layer of soil (0-20cm) L<sub>1</sub> as compared to lower one (21-40 cm) L<sub>2</sub>, respectively. However, the interaction between different forest types and soil layers was found non significant.

#### **4.5.4 Available phosphorus (kg ha<sup>-1</sup>)**

Significant differences were observed on analyzing available phosphorus content under different forest types and soil layers (Table 34). Available phosphorus content was recorded maximum (30.37 kg ha<sup>-1</sup>) in birch-rhododendron scrub forest whereas, dry broad-leaved and coniferous forests showed values which were significantly at par with the values of sub alpine birch forest. The minimum available phosphorus (13.80 kg ha<sup>-1</sup>) was recorded under dry alpine scrub. Among two different soil depths, L<sub>1</sub> *i.e.* 0-20 cm layer recorded significantly higher available phosphorus content (24.33 kg ha<sup>-1</sup>) than L<sub>2</sub> *i.e.* 21-40 cm soil layer. On the other hand, interaction between different forest types and soil layers were found non significant.

#### **4.5.5 Available potassium (kg ha<sup>-1</sup>)**

Available potassium varies significantly under different forest types and soil layers (Table 34). Maximum available potassium content (873.60 Kg ha<sup>-1</sup>) was recorded under birch-rhododendron scrub forest followed by dry deodar forest (786.80 kg ha<sup>-1</sup>), sub alpine fir forest (594.41kg ha<sup>-1</sup>), sub alpine birch forest (563.70 kg ha<sup>-1</sup>), dry broad-leaved and coniferous forests (450.43 kg ha<sup>-1</sup>), dry blue pine forest (432.30 kg ha<sup>-1</sup>), alpine pasture (400.25 kg ha<sup>-1</sup>), neoza pine forest (317.78 kg ha<sup>-1</sup>) and dry alpine scrub (245.05 kg ha<sup>-1</sup>) in

descending order, respectively. Among two different soil depths, L<sub>1</sub> *i.e.* 0-20 cm layer recorded significantly higher available phosphorus content (549.87 Kg ha<sup>-1</sup>) than L<sub>2</sub> *i.e.* 21-40 cm soil layer. In contrast, interaction between different forest types and soil layers were found to be non significant.

#### **4.5.6 Available copper (mg kg<sup>-1</sup>)**

A scrutiny of data presented in (Table 34) reveals that available copper varies significantly under different forest types and soil layers. Birch-rhododendron scrub forest displayed significantly higher available copper (3.09 mg kg<sup>-1</sup>) than other forest types under investigation. Minimum available copper (0.63 mg kg<sup>-1</sup>) was recorded in dry alpine scrub. Available copper was found to be maximum in L<sub>1</sub> soil layer than L<sub>2</sub> layer while, interaction between different forest types and soil layers were found to be non significant.

#### **4.5.7 Available iron (mg kg<sup>-1</sup>)**

The available iron in the soil varied significantly with the different forest types and soil layers (Table 34). Maximum available iron (72.71 mg kg<sup>-1</sup>) was recorded in birch-rhododendron scrub forest followed by sub alpine fir forest (53.07 mg kg<sup>-1</sup>), sub alpine birch forest (49.99 mg Kg<sup>-1</sup>), blue pine forest (43.63 mg kg<sup>-1</sup>), blue deodar forest (38.65 mg kg<sup>-1</sup>), dry broad-leaved and coniferous forests (26.54 mg kg<sup>-1</sup>), neoza pine forest (24.04 mg kg<sup>-1</sup>), alpine pasture (23.63 mg kg<sup>-1</sup>) and dry alpine scrub (22.41 mg kg<sup>-1</sup>) in descending order, respectively. Available iron was found to be maximum (41.86 mg kg<sup>-1</sup>) in L<sub>1</sub> soil layer than L<sub>2</sub> layer, while, interaction between different forest types and soil layers were found to be non significant.

#### **4.5.8 Available manganese (mg kg<sup>-1</sup>)**

Analysis of data on available manganese is presented in Table 34. The results indicate that the effect of different forest types and soil layers have significant variation in values. Maximum available manganese (17.64 mg kg<sup>-1</sup>) was recorded under birch-rhododendron scrub forest, which was found to be statistically identical to sub alpine fir forest (17.40 mg kg<sup>-1</sup>).

**Table 34. Soil nutrients under different forest types of dry temperate and alpine forest in Kinnaur district of Himachal Pradesh**

Treatments (Forest Types)	Available N (kg ha <sup>-1</sup> )			Available P (kg ha <sup>-1</sup> )			Available K (kg ha <sup>-1</sup> )			Available Cu (mg kg <sup>-1</sup> )			Available Mn (mg kg <sup>-1</sup> )			Available Fe (mg kg <sup>-1</sup> )			Available Zn (mg kg <sup>-1</sup> )		
	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean	L <sub>1</sub> (0-20 cm)	L <sub>2</sub> (21-40 cm)	Mean
T <sub>1</sub> -Dry broad-leaved and coniferous forests	376.30	290.17	333.23 <sup>b</sup>	28.10	20.86	24.48 <sup>c</sup>	480.50	420.35	450.43 <sup>e</sup>	1.30	1.20	1.25 <sup>e</sup>	17.10	14.20	15.65 <sup>d</sup>	28.58	24.51	26.54 <sup>f</sup>	0.69	0.58	0.64 <sup>b</sup>
T <sub>2</sub> -Neozoa pine forest	139.20	85.43	112.32 <sup>b</sup>	19.20	16.20	17.70 <sup>g</sup>	345.21	290.35	317.78 <sup>b</sup>	1.03	0.85	0.94 <sup>h</sup>	13.63	11.23	12.43 <sup>e</sup>	26.64	21.40	24.02 <sup>g</sup>	0.35	0.31	0.33 <sup>g</sup>
T <sub>3</sub> -Dry deodar forest	196.58	129.52	163.05 <sup>d</sup>	25.80	20.16	22.98 <sup>c</sup>	833.30	740.30	786.80 <sup>b</sup>	1.48	1.32	1.40 <sup>d</sup>	18.28	14.80	16.54 <sup>e</sup>	40.78	36.52	38.65 <sup>e</sup>	0.64	0.54	0.59 <sup>c</sup>
T <sub>4</sub> -Dry blue pine forest	175.60	108.06	141.83 <sup>f</sup>	22.57	18.10	20.34 <sup>f</sup>	460.30	404.30	432.30 <sup>f</sup>	1.06	0.90	0.98 <sup>g</sup>	18.37	14.43	16.40 <sup>e</sup>	46.23	41.02	43.63 <sup>d</sup>	0.55	0.48	0.52 <sup>d</sup>
T <sub>5</sub> -Sub alpine birch forest	282.20	211.21	246.71 <sup>c</sup>	27.52	20.10	23.81 <sup>d</sup>	594.19	533.20	563.70 <sup>d</sup>	1.47	1.40	1.44 <sup>c</sup>	19.56	15.00	17.28 <sup>b</sup>	52.62	47.36	49.99 <sup>e</sup>	0.32	0.26	0.29 <sup>b</sup>
T <sub>6</sub> -Sub alpine fir forest	188.20	124.10	156.15 <sup>e</sup>	29.90	21.48	25.69 <sup>b</sup>	628.30	560.52	594.41 <sup>c</sup>	1.51	1.42	1.46 <sup>b</sup>	19.69	15.10	17.40 <sup>ab</sup>	55.04	51.10	53.07 <sup>b</sup>	0.45	0.37	0.41 <sup>c</sup>
T <sub>7</sub> -Birch-rhododendron scrub forest	439.01	375.21	407.11 <sup>a</sup>	33.51	27.23	30.37 <sup>a</sup>	937.00	810.20	873.60 <sup>a</sup>	3.19	2.99	3.09 <sup>a</sup>	19.79	15.49	17.64 <sup>a</sup>	76.30	69.12	72.71 <sup>a</sup>	1.07	0.90	0.99 <sup>a</sup>
T <sub>8</sub> -Alpine pasture	169.63	98.60	134.12 <sup>g</sup>	17.20	15.20	16.20 <sup>h</sup>	410.40	390.10	400.25 <sup>g</sup>	1.09	0.94	1.02 <sup>f</sup>	11.75	8.70	10.23 <sup>f</sup>	25.90	21.36	23.63 <sup>h</sup>	0.44	0.35	0.39 <sup>f</sup>
T <sub>9</sub> -Dry alpine scrub	125.07	79.10	102.09 <sup>i</sup>	15.20	12.40	13.80 <sup>i</sup>	259.59	230.50	245.05 <sup>i</sup>	0.65	0.61	0.63 <sup>i</sup>	10.90	7.20	9.05 <sup>g</sup>	24.70	20.12	22.41 <sup>i</sup>	0.29	0.21	0.25 <sup>i</sup>
Mean	232.42 <sup>a</sup>	166.82 <sup>b</sup>		24.33 <sup>a</sup>	19.08 <sup>b</sup>		549.87 <sup>a</sup>	486.65 <sup>b</sup>		1.42 <sup>a</sup>	1.29 <sup>b</sup>		16.56 <sup>a</sup>	12.91 <sup>b</sup>		41.86 <sup>a</sup>	36.95 <sup>b</sup>		0.53 <sup>a</sup>	0.44 <sup>b</sup>	
CD at 5%																					
T: Forest types			1.62			1.16			0.56			0.03			1.08			1.53			0.01
L: Soil layers			0.79			0.55			0.27			0.01			0.51			0.72			0.002
T × L: Forest types × Soil layer			NS			NS			NS			NS			NS			NS			NS

Dry blue pine forest also recorded statistically at par with dry deodar forest while, minimum available manganese ( $9.05 \text{ mg kg}^{-1}$ ) was to be recorded in dry alpine scrub. In the effect of soil depth, higher available manganese content ( $16.56 \text{ mg kg}^{-1}$ ) was observed at 0-20 cm layer than 21-40 cm layer. However, interaction between different forest types and soil layers were found non significant.

#### **4.5.9 Available Zinc ( $\text{mg kg}^{-1}$ )**

The available zinc in a soil varied significantly with the different forest type and soil depth. Data revealed that maximum available zinc ( $0.99 \text{ mg kg}^{-1}$ ) is recorded in birch-rhododendron scrub forest followed by dry broad-leaved and coniferous forests ( $0.64 \text{ mg kg}^{-1}$ ), dry deodar forest ( $0.59 \text{ mg kg}^{-1}$ ), dry blue pine forest ( $0.52 \text{ mg kg}^{-1}$ ), sub alpine fir forest ( $0.41 \text{ mg kg}^{-1}$ ), alpine pasture ( $0.39 \text{ mg kg}^{-1}$ ), neoza pine forest ( $0.33 \text{ mg kg}^{-1}$ ), sub alpine birch forest ( $0.29 \text{ mg kg}^{-1}$ ), and dry alpine scrub ( $0.25 \text{ mg kg}^{-1}$ ) in descending order, respectively (Table 34). In the effect of soil depth, higher available manganese content ( $0.53 \text{ mg kg}^{-1}$ ) was observed at 0-20cm layer than 21-40 cm layer. In contrary, interaction between different forest types and soil layers were found non significant.

The values of soil nutrients (N, P, K, Cu, Fe, Mn and Zn) decreased with increase in soil depth in all the forest types. This could be attributed to higher water holding capacity and the presence of heavy litter and humus contents in the upper layers of the studied forest types. The availability of soil nutrients depends to a larger extent on the amount and properties of organic matter (De Hann 1977). Therefore the high amount of organic matter in different forest types in the upper layers may also be the reason for the richness of plant nutrients in the upper layers as compared to lower layers. Availability of soil nutrients (N, P, K, Cu, Fe, Mn and Zn) was recorded slightly higher in birch-rhododendron scrub forest which could be due to differential leaf litter deposition and decomposition rates, nodulation behaviour, availability of water and nutrient status of the site. Similar findings were also reported by Russel (1975) and Mishra *et al.* 1994.

#### **4.5.10 Soil pH**

Soil pH varied significantly with the different forest type and different layers. The highest pH value (6.82) was noted for dry broad-leaved and coniferous forests whereas, lowest pH was recorded for sub alpine birch forest (4.81). pH under different forest types followed the trend dry broad-leaved and coniferous forests > Dry deodar forest > Sub alpine

fir forest > Neoza pine forest > Alpine pasture > Dry blue pine forest > Dry alpine scrub > Birch-rhododendron scrub forest > Sub alpine birch forest (Table 35). In the effect of soil depth, higher soil pH (5.96) was observed at 21-40 cm layer than (5.88) in 0-20 cm layer. In contrary, interaction between different forest types and soil layers were found to be non significant.

**Table 35. Soil physical parameters (pH and EC) under different forest types of dry temperate and alpine forest of Kinnaur district (H.P.)**

Treatments (Forest Types)	Physical parameters					
	pH			EC		
	0-20cm	21-40 cm	Mean	0-20cm	21-40 cm	Mean
T <sub>1</sub> -Dry broad-leaved and coniferous forests	6.79	6.84	6.82 <sup>a</sup>	0.13	0.12	0.13b
T <sub>2</sub> -Neoza pine forest	6.24	6.45	6.35 <sup>d</sup>	0.06	0.05	0.06
T <sub>3</sub> -Dry deodar forest	6.63	6.71	6.67 <sup>b</sup>	0.12	0.11	0.11b
T <sub>4</sub> -Dry blue pine forest	5.56	5.67	5.62 <sup>f</sup>	0.10	0.08	0.09d
T <sub>5</sub> -Sub alpine birch forest	4.80	4.82	4.81 <sup>i</sup>	0.11	0.10	0.11b
T <sub>6</sub> -Sub alpine fir forest	6.41	6.33	6.37 <sup>c</sup>	0.14	0.11	0.13b
T <sub>7</sub> -Birch-rhododendron scrub forest	5.09	5.20	5.15 <sup>h</sup>	0.19	0.17	0.18a
T <sub>8</sub> -Alpine pasture	6.12	6.18	6.15 <sup>e</sup>	0.10	0.09	0.10c
T <sub>9</sub> -Dry alpine scrub	5.29	5.40	5.35 <sup>g</sup>	0.07	0.06	0.07d
Mean	5.88 <sup>b</sup>	5.96 <sup>a</sup>		0.11 <sup>a</sup>	0.09 <sup>b</sup>	
<b>CD at 5%</b>						
<b>T: Forest types</b>			<b>0.01</b>	<b>0.02</b>		
<b>L: Soil layers</b>			<b>0.004</b>	<b>0.01</b>		
<b>T × L: Forest types × Soil layer</b>			<b>NS</b>	<b>NS</b>		

It has been reported that forest soils should be slightly acidic for nutrient supply to be balanced (Leskiw 1998). A fertile soil generally has a pH range between 5.5 and 7.2, which makes the essential elements and nutrients available to the flora. Values of pH in the study area varied between 4.80 (Sub alpine birch forest) and 6.79 (Dry broad-leaved and coniferous forests) (Table 35). Soil pH varied significantly with the average affect of forest types and increased with increasing depth. It has been observed from the data that pH level in all forest types was acidic to neutral and could be ascribed to accumulateion and decomposition of organic matter and release of organic acids during the decomposition of leaf litter resulting more acidity in soil.

#### 4.5.11 Soil EC (dsm<sup>-1</sup>)

Analysis of data on soil EC is presented in Table 35. The results indicate that the effect of different forest types and soil layers have significant values. Maximum soil EC (0.18 dsm<sup>-1</sup>) was recorded under birch-rhododendron scrub forest. Dry broad-leaved and coniferous

forests, sub alpine fir forest and sub alpine birch forest which was found to be statistically identical and their values were statistically at par with each other. While, minimum soil EC was to be recorded in dry alpine scrub which was statistically at par with neoza pine forest. In the effect of soil depth, soil EC showed not significant deviation at 0-20 cm layer to 21-40 cm layer. However, interaction between different forest types and soil layers were found to be non significant. It was further found that soil EC decreased significantly with increase in soil depth in all the forest types. Similar, findings have been reported by Srikanth *et al.* (2002) and Jayabaskaran *et al.* (2001).

#### 4.6 PRINCIPAL COMPONENT ANALYSIS (PCA) AND FACTOR ANALYSIS

##### 4.6.1 Principal Component Analysis

Principal component analysis was performed for vegetation carbon and soil physico-chemical property in different forest types. Out of 15 only 7 PC (Principal component) exhibited more than 1 eigen value and and showed about 100% total variability among the characters. The per cent variability in PC-1 was 79.143 while, in rest it varied from 0.002-13.884 for parameter under study (Table 36).

**Table 36. Principal component analysis of vegetation carbon and soil physico-chemical properties of different forest types of Kinnaur district (H.P.)**

	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
<b>Eigen value</b>	52163.940	9150.908	4410.309	100.602	76.953	6.998	1.099
<b>Variability (%)</b>	79.143	13.884	6.691	.153	.117	.011	.002
<b>Cumulative (%)</b>	79.143	93.027	99.718	99.871	99.987	99.998	100.000
<b>Vegetation biomass</b>	0.1960	-0.6315	0.4376	0.1838	-0.2581	-0.0212	0.0042
<b>Vegetation Carbon</b>	0.0980	-0.3158	0.2188	0.0919	-0.1290	-0.0106	0.0021
<b>Soil carbon density</b>	0.1045	0.1157	0.1947	-0.3703	0.5666	0.0555	0.0335
<b>Detritus carbon</b>	0.0027	0.0020	0.0062	0.0196	0.0529	-0.0543	-0.0291
<b>Ecosystem carbon</b>	0.2052	-0.1981	0.4197	-0.2587	0.4904	-0.0093	0.0064
<b>pH</b>	0.0000	-0.0038	0.0041	-0.0213	-0.0170	0.1026	0.0921
<b>EC</b>	0.0001	0.0001	0.0001	0.0007	0.0001	-0.0019	0.0107
<b>OC (%)</b>	0.0024	0.0024	0.0039	-0.0076	0.0062	0.0221	-0.0054
<b>N</b>	0.3113	0.6679	0.5902	0.1486	-0.2915	-0.0366	-0.0144
<b>P</b>	0.0210	0.0121	0.0142	0.1810	0.0413	0.8493	0.4697
<b>K</b>	0.8933	-0.0306	-0.4424	-0.0592	-0.0419	0.0036	-0.0065
<b>Cu</b>	0.0025	0.0030	-0.0006	0.0100	0.0048	-0.0266	0.1104
<b>Fe</b>	0.0583	0.0410	-0.0462	0.8196	0.5050	-0.2314	0.0751
<b>Mn</b>	0.0117	-0.0016	0.0107	0.1507	0.0931	0.4532	-0.8639
<b>Zn</b>	0.0007	0.0006	0.0008	-0.0035	0.0073	-0.0013	0.0627

Hence, these eigen principal component can replace the 15 variable significantly. Scree plot (Figure 6) explained the percentage of variance associated with each principle component obtained by drawing a graph between eigen values and PC number. PC-1 showed 79.143% variability with eigen value 52163.940 which then decline markedly and after two PC tends to become straight with little variation. The maximum variation was observed in PC-1 as compare to other six.

#### 4.6.2 Factor Analysis

The data presented in Table 37 and Figure 7 showed that out of 15 variable only 3 factors exhibited more than 1 eigen value and showed about 84.416 % total variability. The per cent variability of F-1 was 59.130 while, in rest it varied from 0.15-18.29. From the

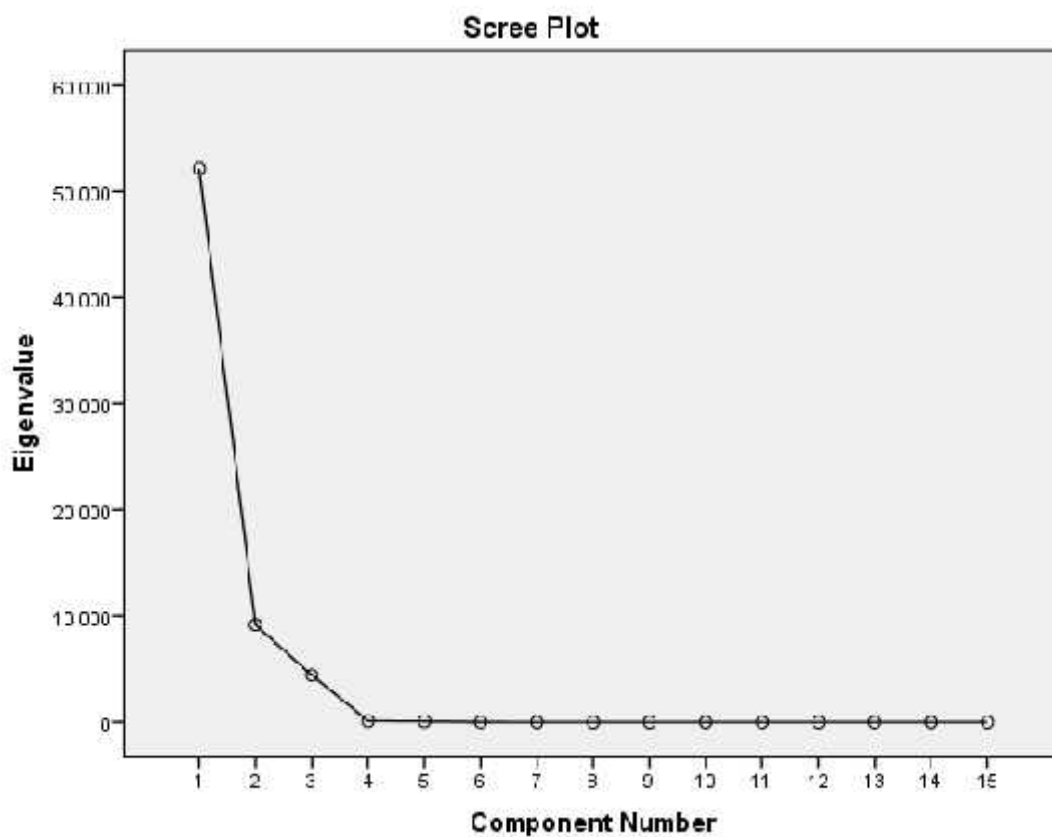
**Table 37. Factor analysis showing Eigen value, Extraction value, Variability per cent and cumulative per cent**

Component	Total Variance Explained					
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.870	59.130	59.130	8.870	59.130	59.130
2	2.744	18.292	77.422	2.744	18.292	77.422
3	1.049	6.994	84.416	1.049	6.994	84.416
4	.859	5.729	90.146			
5	.553	3.685	93.831			
6	.483	3.217	97.048			
7	.236	1.570	98.618			
8	.081	.542	99.160			
9	.061	.408	99.569			
10	.033	.219	99.788			
11	.021	.142	99.930			
12	.008	.055	99.985			
13	.002	.015	100.000			
14	1.801E-09	1.201E-08	100.000			
15	8.567E-10	5.711E-09	100.000			

Table 38, It is clear that Soil carbon density, Detritious carbon, Ecosystem carbon, EC, OC (%), N, P, K, Cu, Fe, Mn and Zn define factor -1 (high loading on factor-1, small or negligible on factor 2 and 3).Vegetation biomass, Vegetation carbon and pH define factor-2 (high loading on factor-2, small or negligible on factor 1 and 3).

**Table 38. Rotation component matrix**

	Component Matrix		
	1	2	3
Vegetation biomass	0.502	0.834	-0.160
Vegetation carbon	0.502	0.834	-0.160
Soil carbon density	0.923	-0.130	0.315
Detritious carbon	0.833	-0.110	-0.042
Ecosystem carbon	0.841	0.511	0.051
pH	-0.008	0.790	0.444
EC	0.400	-0.137	0.060
OC (%)	0.919	-0.094	0.314
N	0.829	-0.374	0.327
P	0.902	-0.064	-0.124
K	0.878	0.037	-0.202
Cu	0.863	-0.369	-0.035
Fe	0.804	-0.320	-0.465
Mn	0.829	0.121	-0.349
Zn	0.870	-0.112	0.305



**Figure 6. Scree plot of Principle component analysis**

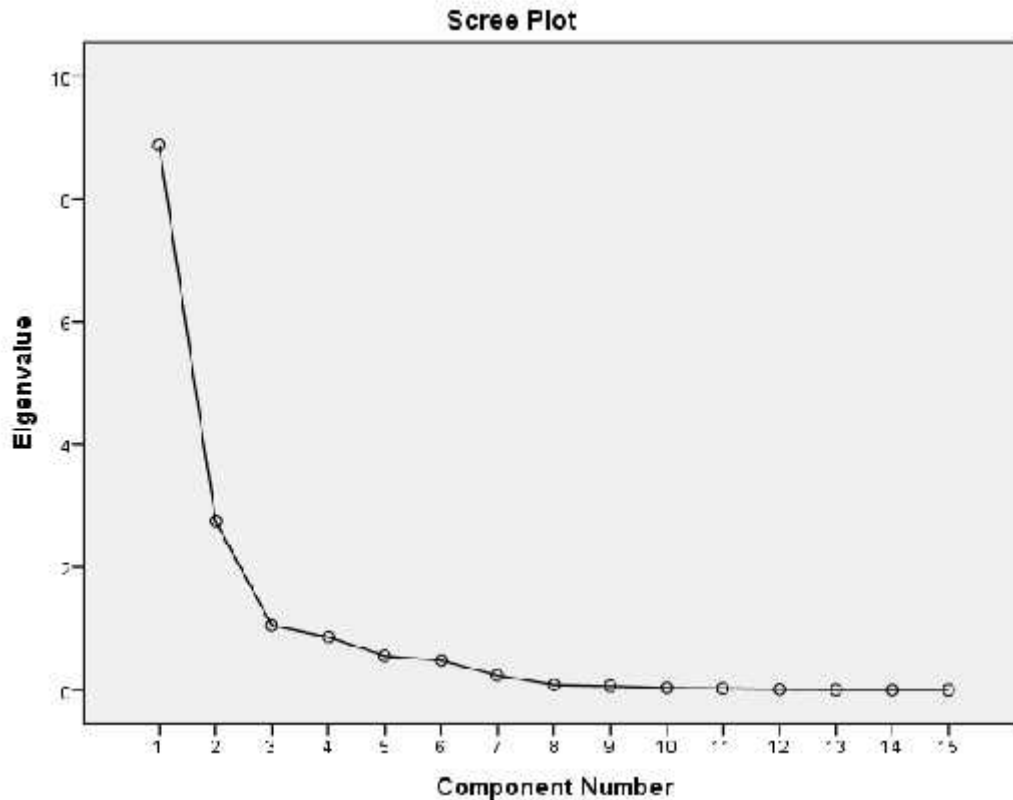


Figure 7. Scree plot of Factor analysis

#### 4.7 CORRELATION (PEARSON'S) MATRIX AND REGRESSION EQUATION FOR DIFFERENT PARAMETER OF DIFFERENT FOREST COMMUNITY TYPE

##### a) Correlation studies

**Correlation (Pearson's) matrix of vegetation biomass with different parameter of soil under various forest types (Table 39).**

**Vegetation biomass:** Vegetation biomass was showing no significant correlation with soil parameter.

**Soil pH:** Soil pH was showing no correlation with soil parameter.

**EC:** - Soil EC was showing no correlation with soil parameter.

**OC %:** Soil OC % was showing no correlation with other soil parameter.

**N:** Soil N was showing postive correlation with OC%, N, P, K, Cu, Fe, Mn and Zn.

**P:** Soil P was showing postive correlation with OC%, N, P, K, Cu, Fe and Zn.

**K:** Soil k was showing postive correlation with OC%, N, P, K, Cu, Fe, Mn and Zn.

**Cu:** Soil Cu was showing postive correlation with OC%, N, P, K, Fe, Mn and Zn.

**Fe:** Soil Fe was showing postive correlation with OC%, N, P, K, Mn and Zn.

**Mn:** - Soil Mn was showing postive correlation with OC%, P, K, Cu and Fe.

**Zn:** - Soil Mn was showing postive correlation with OC%, P, K, Cu and Fe.

The availability of soil nitrogen depends to a larger extent on the amount and properties of organic matter (De Hann 1977) which is confirmed by the positive correlation shown between nitrogen and soil organic carbon ( $r=0.93$ ). It is observed that P is found in all terrestrial systems in the form of organic and inorganic matter, while organic P forms are the major available source of phosphorus. Soil organic matter has the inorganic form of P transformed into insoluble form in many soils. The carbon–phosphorus and nitrogen–phosphorus ratios vary according to the parent material, which depends upon degree of weathering and by other means (Paul and Clark, 1996). Available P was positively correlated with organic C (0.86). Gupta and Sharma (2008) also showed that organic C and P were positively correlated chiefly because all these attributes were intimately linked with soil humus. Although Gupta and Sharma (2008) argued that the K is not much influenced by soil organic matter because it is not the direct supplier of K, in our study area, available K showed a significant positive correlation with organic carbon (0.79) (Table 36). This was supported by the findings of Basumatary and Bordoloi (1992) and Boruah and Nath (1992), who reasoned that a layer of organic matter significantly improves the retention of K in the soils. Available K showed a positive correlation with total N (0.62). Gupta and Sharma (2008) also showed that N and organic C were positively correlated chiefly because all these attributes are intimately linked with soil humus. There is a strong interaction between these two nutrients in plant growth. It was observed that the plant response to applied nitrogen fertilizers decreases when the available potassium content of a soil is below the optimal level. The reading of the genetic code in plant cells to produce proteins and enzymes would be impossible without adequate potassium. Although, nitrogen is fundamental in production of proteins, plants deficient in potassium will not produce proteins despite an abundance of available nitrogen. Instead, incomplete protein such as amino acids, amides and nitrate accumulate in the cell. This is because; the enzyme nitrate reductase which catalyzes the formation of proteins is activated by potassium. Potassium has direct synergistic relationships with two micronutrients (Malvi, 2010) namely: iron ( $r=81$ ) and manganese ( $r=74$ ) which is shown by the positive correlation between these nutrients.

Manganese is a very important component of photosynthesis, nitrogen metabolism and nitrogen assimilation; it activates decarboxylase, dehydrogenase and oxidase enzymes. Iron plays a very important part in chlorophyll formation. It is a component of ferredoxin which is responsible for oxidation/reduction reactions in the plant system like - nitrate and sulphate reduction and nitrogen fixation. Iron is also a constituent of peroxidase and catalase, which are defense enzymes of the plant.

**Table 39. Correlation (Pearson's) matrix of vegetation biomass with different parameters of soil under various forest types in dry temperate and alpine forest of Kinnaur district (H.P.)**

	<b>Vegetation biomass</b>	<b>pH (0-40cm)</b>	<b>EC (0-40 cm)</b>	<b>OC % (0-40 cm)</b>	<b>N (0-40 cm)</b>	<b>P (0-40cm)</b>	<b>K (0-40cm)</b>	<b>Cu (0-40cm)</b>	<b>Fe (0-40cm)</b>	<b>Mn (0-40cm)</b>	<b>Zn (0-40cm)</b>
<b>Vegetation biomass</b>	1										
<b>pH (0-40cm)</b>	0.51	1									
<b>EC (0-40cm)</b>	0.18	-0.11	1								
<b>OC % (0-40cm)</b>	0.35	0.04	0.85*	1							
<b>N (0-40cm)</b>	0.05	-0.20	0.80*	0.93*	1						
<b>P (0-40cm)</b>	0.37	-0.05	0.84*	0.86*	0.79*	1					
<b>K (0-40cm)</b>	0.47	-0.07	0.79*	0.79*	0.62*	0.82*	1				
<b>Cu (0-40cm)</b>	0.11	-0.29	0.85*	0.81*	0.82*	0.82*	0.85*	1			
<b>Fe (0-40cm)</b>	0.19	-0.46	0.76*	0.61*	0.61*	0.82*	0.81*	0.86*	1		
<b>Mn (0-40cm)</b>	0.57	-0.05	0.65*	0.69*	0.57	0.88*	0.74*	0.60*	0.77*	1	
<b>Zn (0-40cm)</b>	0.34	0.04	0.80*	0.87*	0.79*	0.74*	0.75*	0.84*	0.62*	0.54	1

**Note: \* Level of significance 0.05=0.58**

**b) Regression studies**  
**Simple regression equation**

Various linear functions have been tried on primary data by taking vegetation, soil and ecosystem carbon density as a dependent variable and other parameters studied as independent variable. Different generalised equations have been made with the help of SPSS. The fitted equations for biomass and carbon with their respective  $r^2$  values have been presented as below:

The data regressed for the relationship of vegetation carbon and other parameters are shown in Table 40. The relationship between vegetation carbon density and tree biomass showed highest adjusted  $r^2$  (0.995) in quadratic function followed by average basal area ( $r^2 = 0.877$ ) function.

**Table 40. Generalise non-linear regression for vegetation carbon density with other parameters studied**

(Y)	Independent variable(X)	Regression type	Best fitted regression equation	S.E.	$r^2$
Vegetation carbon density	Average basal area	Cubic	$Y = -2.13 + 0.023X + 1.28X^2 - 0.042X^3$	15.041	0.877
	Tree biomass	Quadratic	$Y = 1.73 + 0.51X - 3.586E - 0.05X^2$	3.045	0.995
	Shrub biomass	Cubic	$Y = -1.175 + 74.36X - 7.615X^2 + 0.199X^3$	34.432	0.355
	Herb biomass	Quadratic	$Y = -445.72 + 2223.77X - 2422.74X^2$	37.775	0.190
	Soil carbon density	Cubic	$Y = -127.92 + 4.59X - 0.27X^2 + 1.678E - 005X^3$	35.128	0.329
	Total no. of species	Power	$Y = .002 X^{3.64}$	1.642	0.424
	Total density	Cubic	$Y = -37.66 + .00X + 4.974E - 009X^2 - 1.159E - 013X^3$	36.449	0.277
	Tree basal area	Cubic	$Y = 3.80 + 1.996X + .077X^2 - .001X^3$	14.396	0.887
	Shrub basal area	Cubic	$Y = 58.64 - 14.70X - .307X^2 + .227X^3$	41.167	0.078
	Herb basal area	Cubic	$Y = -34.98 + 51.38X - 8.14X^2 + .35X^3$	38.818	0.180

Table 41 was shows various non linear regressions to find out soil carbon density with other parameters as independent variable of dry temperate and alpine forest of kinnaur district of Himachal Pradesh. The relationship between soil carbon and other parameters was derived through different functions simultaneously, where cubic and powe function showed highest  $r^2$ .

**Table 41. Generalise non-linear regression for soil carbon density with other parameters studied**

(Y)	Independent variable(X)	Regression type	Best fitted regression equation	S.E.	r2
Soil carbon density	Average basal area	Power	$Y = 41.03 X^{0.299}$	0.334	0.331
	Tree biomass	Cubic	$Y = 49.66 + 10.853X - 0.006X^2 + 1.177E - 005X^3$	28.131	0.220
	Shrub biomass	Cubic	$Y = 50.39 + 23.20X - 1.92X^2 + 0.48X^3$	21.888	0.528
	Herb biomass	Quadratic	$Y = -250.63 + 1404.29X - 1475.82X^2$	29.212	0.122
	Total no. of species	Power	$Y = 37.14X^{0.243}$	0.397	0.053
	Total density	Power	$Y = 0.362X^{0.433}$	0.381	0.125
	Tree basal area	Cubic	$Y = 53.30 + 7.17X - 0.412X^2 + 0.006X^3$	28.130	0.220
	Shrub basal area	Cubic	$Y = 77.68 - 31.16X + 9.50X^2 - 0.591X^3$	22.502	0.501
	Herb basal area	Power	$Y = 47.69X^{0.258}$	0.379	0.138
	vegetation carbon	Power	$Y = 49.84X^{0.108}$	0.334	0.328
	Ecosystem carbon	Cubic	$Y = 81.10 - 1.58X + 0.018X^2 - 4.863E - 005X^3$	18.067	0.678

Table 42 is showing various generalised non linear functions for vegetation biomass with other parameters studied of soil. The relationship is shown with different parameters simultaneously, where the cubic function showed highest  $r^2$  in most case followed by power function. The best relationship as ( $r^2 = 0.706$ ) observed between vegetation biomass with Mn content.

**Table 42. Generalise non-linear regression for vegetation biomass with other soil parameters studied**

(Y)	Independent variable(X)	Regression type	Best fitted regression equation	S.E.	$r^2$
Vegetation biomass	pH	Cubic	$Y = 437.85 - 42.09X + 5.36X^2$	69.658	0.312
	EC	Cubic	$Y = -37.43 - 801.46X - 24967.80X^2 - 101997.29X^3$	80.274	0.124
	OC %	Cubic	$Y = -36.69 - 131.94X + 246.06X^2 - 73.34X^3$	69.516	0.343
	N	Cubic	$Y = -554.18 + 8.80X - 0.034X^2 + 4.127E-005X^3$	75.646	0.222
	P	Power	$Y = 7.648 \times 10^7 X^{5.81}$	1.548	0.489
	K	Power	$Y = 2.761 \times 10^7 X^{3.034}$	1.784	0.321
	Cu	Cubic	$Y = -320.12 + 701.32X - 336.54X^2 + 48.98X^3$	72.922	0.277
	Fe	Cubic	$Y = -1729.93 + 132.24X - 2.86X^2 + 0.019X^3$	55.237	0.585
	Mn	Power	$Y = 1.927 \times 10^7 X^{7.171}$	1.175	0.706
	Zn	Cubic	$Y = -202.82 + 960.46X - 372.46X^2 - 314.43X^3$	60.609	0.501

The regression equations given in the Table 43 is showing the relationship between ecosystem carbons with other parameters studied. The relationship with vegetation carbon showed highest adjusted  $r^2$  (0.827) in power function with basal area.

**Table 43. Generalise non-linear regression for ecosystem carbon density with other parameters studied**

(Y)	Independent variable (X)	Regression type	Best fitted regression equation	S.E.	$r^2$
Ecosystem Carbon density	Average basal area	Power	$Y = 35.30X^{0.660}$	0.245	0.817
	Tree biomass	Cubic	$Y = 50.88 + 1.46X - 0.007X^2 + 1.373E-005X^3$	30.939	0.748
	Shrub biomass	Cubic	$Y = 49.96 + 98.22X - 9.59X^2 + 0.249X^3$	48.164	0.389
	Herb biomass	Quadratic	$Y = -706.12 + 3678.01X - 3952.67X^2$	52.808	0.233
	vegetation carbon	Power	$Y = 53.88X^{0.241}$	0.239	0.827
	Soil carbon density	Cubic	$Y = -132.34 + 5.76X - 0.029X^2$	35.176	0.674
	Total no. of species	Power	$Y = 13.09X^{0.844}$	0.471	0.325
	Total density	Cubic	$Y = -54.45 + 0.001X + 1.85E-009X^2 - 1.14E-013X^3$	52.764	0.267
	Tree basal area	Cubic	$Y = 57.46 + 9.46X - 0.35X^2 + 0.005X^3$	39.006	0.599
	Shrub basal area	Cubic	$Y = 137.90 + 46.88X + 4.49X^2 - 0.384X^3$	56.336	0.164
	Herb basal area	Cubic	$Y = -11.84 + 78.06X - 11.71X^2 + 0.48X^3$	54.503	0.217

The regression equations given in the Table 44 is showing the relationship between soil carbon density with other soil parameters. Soil carbon density showed highest  $r^2$  value (0.987) with organic carbon per cent in cubic function.

**Table 44. Generalise non-linear regression for soil carbon density with other soil parameters studied**

(Y)	Independent variable(X)	Regression type	Best fitted regression equation	S.E.	r <sup>2</sup>
Soil carbon density	pH	Cubic	$Y=630.15 -50.60X^2+5.756X^3$	25.157	0.349
	EC	Cubic	$Y= 77.05-1600.65X+20376.27X^2-55296.64X^3$	15.16	0.774
	OC %	Cubic	$Y= 8.017+59.57X-16.63X^2+4.71X^3$	3.655	0.987
	N	Cubic	$Y = -85.78+1.78X-0.006X^2+7.964E-006X^3$	9.295	0.915
	P	Exponential	$Y =14.84 e^{.070X}$	0.16	0.847
	K	Power	$Y = 0.384X^{0.839}$	0.226	0.693
	Cu	Power	$Y = 57.40X^{0.826}$	0.749	0.204
	Fe	Cubic	$Y = -359.52+32.07X-0.74X^2+0.005X^3$	19.176	0.638
	Mn	Exponential	$Y = 16.704 e^{0.096X}$	0.256	0.606
	Zn	Cubic	$Y =92.94-360.04X+881.03X^2 -482.31X^3$	14.962	0.779

In the present study, among all regression types, power and cubic functions showed maximum adjusted r<sup>2</sup> value for most of the variables studied making these two functions as the best fitted function. The results of the study are supported by the results of Chave *et al.*(2005) who have reported power function as the best fit for dry tropical forests with strong relationship (R<sup>2</sup> >= 90%) between aboveground biomass and DBH, tree height and wood density when analyzed separately. The present value of R<sup>2</sup> are more or less similar to values as reported by Ali *et al.* (2016) who have reported power and log linear function as the best fit for estimation of aboveground biomass for *Cedrus deodara*. However, Ahmad *et al.* (2014) have noted 96 percent variation in biomass of forests when basal area was taken as a variable in quadratic linear regression equation for *Abies pindrow*. Sharma (2016) also reported power, cubic and quadratic functions as the best suited functions for different variables studied in temperate forests of Himachal Pradesh.

## Chapter-5

# SUMMARY AND CONCLUSION

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The work done on “**Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh**” is summarized as below:

The present investigation entitled “Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh” was carried out during the year of 2015-16 to know the status of floral diversity, regeneration status, carbon stock and soil physico-chemical properties in dry temperate and alpine forests area of Kinnaur district in Himachal Pradesh. There were nine forest types viz., 13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex* – *Pinus gerardiana*), 13C<sub>2a</sub>- Neoza pine forest (*Pinus gerardiana*), 13C<sub>2b</sub>- Dry deodar forest (*Cedrus deodara*), 13 C<sub>3</sub>- West Himalayan high level dry blue pine forest (*Pinus wallichiana*), 14C<sub>1a</sub>- West Himalayan sub- alpine birch forest, 14C<sub>1b</sub>- West Himalayan sub- alpine fir forests, 15C<sub>1</sub>- Birch-rhododendron scrub forest, 15C<sub>3</sub>- Alpine pasture, 16C<sub>1</sub>-Dry alpine scrub (Champion and Seth, 1968) in dry temperate and alpine forest ecosystem of Kinnaur district of Himachal Pradesh. Each forest type was considered as a treatment.

To study the status of plant diversity, community analysis was carried out during rainy season when majority of the plants were at the peak of their growth. In each nine forest type, 9 quadrates of size 20 m × 20 m for trees were laid out randomly across the slope distributed along the elevation gradient (lower, medium and high). Within each quadrate (20 m × 20 m), three sub-quadrates of the size of 5 m × 5 m for shrubs and 1 m × 1 m for herbs were laid out. Density of trees was calculated by counting trees in each sample plot. Diameter of each tree in the sample plot was determined by tree calliper or tap. Density of shrubs was calculated by counted plants of different species in each sub-plot. The diameter of shrub was calculated by using digital calliper. While in case of herbaceous vegetation, each quadrate was segregated species wise and each species was analyzed quantitatively for various parameters viz., basal area, density and IVI, etc. To study the regeneration status of dominant forest species, 9 sub-quadrate of 2 m x 2 m within each quadrate of size 20 m × 20 m were laid out. To estimate the biomass, the entire trees falling in the plot (20 m × 20 m) were enumerated. The diameter at breast height (DBH) was measured with meter tape. Stem volume of trees

was determined by number of stem in different diameter class multiply by respective volume factor given in working plan of Kinnaur Forest Division (Government of Himachal Pradesh Forest Department, 1999-2015). Shrub biomass was estimated using 5 m × 5 m 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 calliper 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. Herb biomass was estimated using 1 m × 1 m quadrates. The total herb biomass occurring within the borders of the quadrate were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 + 5°C to a constant weight. The herb biomass converted into carbon by multiplying with a factor of 0.5 (IPCC default value). Surface litter was collected in nine quadrates of 1 m × 1 m. Samples were weighed, sub-sampled and oven dried at 65 + 5°C to a constant weight, grounded and ashes. Corrected dry ash was assumed to contain 50 per cent of carbon.

Soil samples were collected in the month of Oct – Nov 2016, within each clustered plot. Composite soil samples were collected from two different depths *viz.*, (i) “upper” (0–20 cm), (ii) “lower” (21–40 cm) for assessing the physical and chemical properties of the soil in all the selected forest types. Humus samples were also collected and humus depth was recorded using measuring scale. The soil tests were conducted at the laboratory of Department of Silviculture and Agroforestry of the university. Soil attributes *viz.*, bulk density, organic carbon and soil nutrients (N, P, K, Cu, Fe, Mn and Zn), pH, EC were also determined. The same was used in preparing the carbon pool inventory and soil organic carbon density. The salient findings of the experiments are summarized as follows:

## **5.1 FLORISTIC DIVERSITY**

In all nine forest types, 139 plant species were recorded of which 7 tree species, 26 shrub species and 106 herbs species were belonging to 102 genera and 44 families. Maximum floristic diversity was found under dry deodar forest followed by dry broad-leaved and coniferous forests, dry blue pine forest, sub alpine fir forest, neoza pine forest, alpine pasture, sub-alpine birch forest, birch-rhododendron scrub forest and dry alpine scrub in descending order, respectively.

The study of various floristic diversity attributes of different forest types reveals that the maximum trees species (4) were recorded in Sub alpine fir forest, whereas, no tree species were recorded in alpine pasture and dry alpine scrub. The maximum number of shrubs were recorded in dry deodar forest (12) followed by dry broad-leaved and coniferous forests (9), neoza pine forest (9), dry blue pine forest (6) and sub alpine fir forest (5), sub-alpine birch forest (4), birch-rhododendron scrub forest (3) and dry alpine scrub (3). In case of herbaceous vegetation the number of herb species were recorded maximum (25) in dry deodar forest followed by dry blue pine forest (24), sub alpine fir forest (23) and alpine pasture (23), dry broad-leaved and coniferous forests (22) and neoza pine forest (20), and, sub-alpine birch forest (15), dry alpine scrub (12) and birch-rhododendron scrub forest (11).

Alpine pasture and dry alpine scrub did not show any richness in their forest types whereas, maximum tree species richness (0.56) was showed for sub-alpine fir forest. Shrubs species richness ranged from 0.00-1.76. Alpine pasture did not show any richness in their forest type whereas, maximum species richness (1.76) was showed for dry deodar forest. However, herbaceous vegetation richness ranged from 0.84-1.97. The maximum herb species richness (1.97) was observed in dry deodar forest and minimum richness (0.84) was recorded in birch-rhododendron scrub.

The species diversity for trees ranged from 0.00-1.12. Alpine pasture and dry alpine scrub did not show any diversity in their forest community types whereas, maximum species diversity (1.12) was observed in sub-alpine fir forest. The shrubs species diversity ranged from 0-2.36. Alpine pasture did not show any diversity in their forest communities types whereas, maximum species diversity (2.36) was showed by dry deodar forest. However, herbaceous vegetation diversity ranged from 2.08-3.04. Maximum species diversity (3.04) was observed in dry deodar forest and minimum diversity (2.08) was recorded in birch-rhododendron scrub forest.

The species dominance for trees ranged from 0.00-0.91. Alpine pasture and dry alpine scrub did not show any species dominance in their forest communities type whereas, maximum species dominance (0.91) was shown by birch-rhododendron scrub forest. The shrubs species dominance ranged from 0-0.84. Alpine pasture did not showed any dominance in their forest communities type whereas, maximum species dominance (0.84) were shown by birch-rhododendron scrub forest. Herbaceous vegetation dominance ranged from 0.06-0.16.

Maximum species dominance (0.16) was observed in birch-rhododendron scrub forest and minimum dominance (0.06) was recorded in dry deodar forest.

## 5.2 PHYTOSOCIOLOGY

In phytosociology growth parameters *viz.*, density and basal area of trees, shrubs and herbs were computed in nine forest types. Based on these growth characters, importance value index (IVI) of constituent species of trees, shrubs and herbs in different forest types suggested various plants associations. The summary of the findings is as follow:

The study of various phytosociological attributes of different forest types revealed that tree density was recorded maximum in dry broad-leaved and coniferous forests (275 N ha<sup>-1</sup>) followed by dry blue pine forest (233 N ha<sup>-1</sup>), sub alpine fir forest (222 N ha<sup>-1</sup>), sub-alpine birch forest (211 N ha<sup>-1</sup>), dry deodar forest (197 N ha<sup>-1</sup>), neoza pine forest (189 N ha<sup>-1</sup>), birch-rhododendron scrub forest (178 N ha<sup>-1</sup>) and nil in alpine pasture and dry alpine scrub. While, basal area was recorded maximum in dry deodar forest (34.94 m<sup>2</sup> ha<sup>-1</sup>) followed by sub alpine fir forest (21.07 m<sup>2</sup> ha<sup>-1</sup>), dry blue pine forest (19.80 m<sup>2</sup> ha<sup>-1</sup>), neoza pine forest (18.45 m<sup>2</sup> ha<sup>-1</sup>), dry broad-leaved and coniferous forests (17.03 m<sup>2</sup> ha<sup>-1</sup>), sub-alpine birch forest (13.93 m<sup>2</sup> ha<sup>-1</sup>), birch-rhododendron scrub forest (6.66 m<sup>2</sup> ha<sup>-1</sup>) and nil in alpine pasture and dry alpine scrub.

In case of shrubs, maximum density was recorded in dry broad-leaved and coniferous forests (592 N ha<sup>-1</sup>) followed by dry deodar forest (518 N ha<sup>-1</sup>), birch-rhododendron scrub forest (489 N ha<sup>-1</sup>), dry blue pine forest (459 N ha<sup>-1</sup>), neoza pine forest (385 N ha<sup>-1</sup>), sub-alpine birch forest (355 N ha<sup>-1</sup>), sub alpine fir forest (296 N ha<sup>-1</sup>), dry alpine scrub (222 N ha<sup>-1</sup>) and nil in alpine pasture. While, basal area was recorded maximum in birch-rhododendron scrub forest (7.74 m<sup>2</sup> ha<sup>-1</sup>) followed by dry alpine scrub (2.05 m<sup>2</sup> ha<sup>-1</sup>), deodar forest (0.39 m<sup>2</sup> ha<sup>-1</sup>), dry blue pine forest (0.37 m<sup>2</sup> ha<sup>-1</sup>), neoza pine forest (0.36 m<sup>2</sup> ha<sup>-1</sup>) and dry broad-leaved and coniferous forests (0.36 m<sup>2</sup> ha<sup>-1</sup>), sub-alpine birch forest (0.27 m<sup>2</sup> ha<sup>-1</sup>), sub alpine fir forest (0.22 m<sup>2</sup> ha<sup>-1</sup>), and nil in alpine pasture.

Herbaceous vegetation showed maximum density in alpine pasture (258890 N ha<sup>-1</sup>) followed by dry broad-leaved and coniferous forests (245185 N ha<sup>-1</sup>), dry blue pine forest (210772 N ha<sup>-1</sup>), sub alpine fir forest (207778 N ha<sup>-1</sup>), dry deodar forest (194444 N ha<sup>-1</sup>), sub-alpine birch forest (179259 N ha<sup>-1</sup>), neoza pine forest (152223 N ha<sup>-1</sup>), birch-rhododendron scrub forest (143333 N ha<sup>-1</sup>) and dry alpine scrub (99259 N ha<sup>-1</sup>). While, basal area was

recorded maximum in alpine pasture ( $6.82 \text{ m}^2 \text{ ha}^{-1}$ ) followed by sub-alpine birch forest ( $6.41 \text{ m}^2 \text{ ha}^{-1}$ ), sub alpine fir forest ( $5.69 \text{ m}^2 \text{ ha}^{-1}$ ), dry blue pine forest ( $5.53 \text{ m}^2 \text{ ha}^{-1}$ ), dry broad-leaved and coniferous forests ( $5.50 \text{ m}^2 \text{ ha}^{-1}$ ), dry deodar forest ( $3.65 \text{ m}^2 \text{ ha}^{-1}$ ), neoza pine forest ( $3.46 \text{ m}^2 \text{ ha}^{-1}$ ), birch-rhododendron scrub forest ( $3.45 \text{ m}^2 \text{ ha}^{-1}$ ) and dry alpine scrub ( $1.25 \text{ m}^2 \text{ ha}^{-1}$ ).

### 5.3 REGENERATION STATUS

The main objective of regeneration survey is to assess whether or not there is adequate regeneration in the forest area. The adequacy of regeneration is judged on the basis of number of established plants in a unit area.

The result related to regeneration status of major forest types revealed that maximum number of recruits were observed for dry deodar forest ( $25278 \text{ N ha}^{-1}$ ) and minimum in dry broad-leaved and coniferous forests [ $1574 \text{ N ha}^{-1}$  (*Quercus ilex*),  $1759 \text{ N ha}^{-1}$  (*Pinus gerardiana*)]. Whereas, un-established regeneration was maximum in dry blue pine forest ( $2778 \text{ N ha}^{-1}$ ) and minimum in dry broad-leaved and coniferous forests [ $1018 \text{ N ha}^{-1}$  (*Quercus ilex*),  $370 \text{ N ha}^{-1}$  (*Pinus gerardiana*)]. However, established regeneration was maximum in dry deodar forest ( $833 \text{ N ha}^{-1}$ ) and minimum in sub alpine fir forest ( $277 \text{ N ha}^{-1}$  *Abies pindrow*), ( $0 \text{ N ha}^{-1}$  *Abies spectabilis*). The height of un-established regeneration was recorded maximum dry deodar forest ( $386.67 \text{ cm}$ ) whereas, minimum was observed in neoza pine forest ( $116.67 \text{ cm}$ ). The Regeneration success was recorded maximum in dry deodar forest ( $58.33 \%$ ) whereas, it was minimum for neoza pine forest ( $27.78 \%$ ).

### 5.4 CARBON STOCK

The results of the experiment in the forest ecosystem have revealed that different forest types have significant influence on the production of above, below as well as on total biomass and carbon stock. The maximum total vegetation biomass is observed in dry deodar forest ( $252.24 \text{ t ha}^{-1}$ ) followed by dry blue pine forest ( $151 \text{ t ha}^{-1}$ ), sub alpine fir forest ( $130.09 \text{ t ha}^{-1}$ ) dry broad-leaved and coniferous forests ( $129.63 \text{ t ha}^{-1}$ ), neoza pine forest ( $97.92 \text{ t ha}^{-1}$ ), birch-rhododendron scrub forest ( $78.97 \text{ t ha}^{-1}$ ), sub alpine birch forest ( $48.86 \text{ t ha}^{-1}$ ), dry alpine scrub ( $1.30 \text{ t ha}^{-1}$ ) and alpine pasture ( $0.58 \text{ t ha}^{-1}$ ) in descending order, respectively. Total vegetation carbon density varies significantly among different forest type. The maximum value is reported in dry deodar forest ( $126.12 \text{ t C ha}^{-1}$ ) followed by dry blue pine forest ( $75.55 \text{ t C ha}^{-1}$ ), sub alpine fir forest ( $65.05 \text{ t C ha}^{-1}$ ), dry broad-leaved and

coniferous forests (64.82 t C ha<sup>-1</sup>), neoza pine forest (48.96 t C ha<sup>-1</sup>), birch-rhododendron scrub forest (39.49 t C ha<sup>-1</sup>), sub alpine birch forest (24.43 t C ha<sup>-1</sup>), dry alpine scrub (0.65 t C ha<sup>-1</sup>) and alpine pasture (0.29 t C ha<sup>-1</sup>).

In case of total detritus biomass varies significantly among different forest types. It was found to be maximum in birch-rhododendron scrub (5.99 t ha<sup>-1</sup>) followed by sub alpine fir forest (5.23 t ha<sup>-1</sup>), dry broad-leaved and coniferous forests (4.05 t ha<sup>-1</sup>), sub alpine birch forest (3.07 t ha<sup>-1</sup>), dry deodar forest (2.57 t ha<sup>-1</sup>), dry blue pine forest (2.39 t ha<sup>-1</sup>), neoza pine forest (1.64 t ha<sup>-1</sup>), alpine pasture (0.15 t ha<sup>-1</sup>), and dry alpine scrub (0.11 t ha<sup>-1</sup>) in descending order, respectively. However, total detritus carbon density was found maximum in birch-rhododendron scrub forest (3.00 t C ha<sup>-1</sup>) followed by sub alpine fir forest (2.62 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (2.03 t C ha<sup>-1</sup>), sub alpine birch forest (1.54 t C ha<sup>-1</sup>), dry deodar forest (1.29 t C ha<sup>-1</sup>), dry blue pine forest (1.20 t C ha<sup>-1</sup>), neoza pine forest (0.82 t C ha<sup>-1</sup>), alpine pasture (0.08 t C ha<sup>-1</sup>), and dry alpine scrub (0.06 t C ha<sup>-1</sup>) in descending order, respectively.

## 5.5 SOIL STUDIES

The maximum value of bulk density (g cm<sup>-3</sup>) was recorded in dry alpine scrub (1.68 g cm<sup>-3</sup>) which was significantly at par to all forest types under investigation *viz.*, neoza pine forest, alpine pasture, dry blue pine forest, sub alpine fir forest, sub alpine birch forest, dry broad-leaved and coniferous forests and Birch-rhododendron scrub forest. Minimum bulk density (1.17 g cm<sup>-3</sup>) was recorded under Birch-rhododendron scrub forest. Irrespective of forest types, L<sub>1</sub> soil layer displayed significantly at par value with L<sub>2</sub>.

Soil organic carbon (%) was significantly varied under different forest types and soil layers. Maximum value (2.56%) was depicted under birch-rhododendron scrub forest followed by dry broad-leaved and coniferous forests (2.24%), dry deodar forest (1.75%), sub alpine birch forest (1.48%), sub alpine fir forest (1.29%), dry blue pine forest (1.08%), alpine pasture (0.97%), neoza pine forest (0.71%), and dry alpine scrub (0.56%) in descending order, respectively. Irrespective of forest types, L<sub>1</sub> soil layer displayed significantly higher soil organic carbon (1.74%) than L<sub>2</sub> soil layer.

Total ecosystem carbon density varied significantly among different forest type. The highest ecosystem carbon density was displayed by dry deodar forest (212.21 t C ha<sup>-1</sup>) followed by broad-leaved and coniferous forests (178.02 t C ha<sup>-1</sup>), birch-rhododendron scrub

forest (172.87 t C ha<sup>-1</sup>), dry sub alpine fir forest (141.22 t C ha<sup>-1</sup>), dry blue pine forest (133.29 t C ha<sup>-1</sup>), sub alpine birch forest (100.72 t C ha<sup>-1</sup>), neoza pine forest (95.40 t C ha<sup>-1</sup>), alpine pasture (51.42 t C ha<sup>-1</sup>), and dry alpine scrub (38.43 t C ha<sup>-1</sup>) in descending order, respectively.

The study of various physico-chemical properties of soil in different forest types reveal that birch-rhododendron scrub forest soil had maximum concentration of soil nutrients like available nitrogen (407.11 kg/ha), available phosphorous (30.37 kg/ha), available potassium (873.60 kg/ha) and available copper (3.09 mg kg<sup>-1</sup>), available iron (72.71 mg kg<sup>-1</sup>), available manganese (17.64 mg kg<sup>-1</sup>) and available zinc (0.99 mg kg<sup>-1</sup>). pH in different forest type followed the trend dry broad-leaved and coniferous forests > dry deodar forest > Sub alpine fir forest > neoza pine forest > alpine pasture > dry blue pine forest > dry alpine scrub > birch-rhododendron scrub forest > sub alpine birch forest. All the soil nutrients decreased with the depth of the soil layers depth, pH was found to increase with an increase in the soil depth excepting K.

## 5.6 CORELATION AND REGRESSION STUDIES

In the correlation study of various soil parameters studied in different forest types, it was observed that the availability of soil nitrogen showed positive correlation to soil organic carbon. Available P was positively correlated with organic C. Available K showed a positive correlation with total N. Potassium has direct synergistic relationships with two micronutrients namely: iron and manganese which is shown by the positive correlation between these nutrients.

The data regressed for the relationship between vegetation carbon density and tree biomass showed highest adjusted  $r^2$  (0.995) in quadratic function followed by average basal area ( $r^2 = 0.877$ ) function, whereas, the relationship between soil carbon and other parameters was derived through different functions simultaneously, where cubic and power function showed highest  $r^2$ . The relationship of vegetation biomass with other parameters of soil was studied simultaneously, where the cubic function showed highest  $r^2$  in most case followed by power function. The best relationship as ( $r^2 = 0.706$ ) observed between vegetation biomass with Mn content. The relationship with vegetation carbon showed highest adjusted  $r^2$  (0.827) in power function with basal area. Soil carbon density showed highest  $r^2$  value (0.987) with organic carbon per cent in cubic function.

## CONCLUSIONS

- In the present study, a total of 139 plant species were recorded of which 7 were tree species, 26 shrub species and 106 herbs species belonging to 102 genera and 44 families. Maximum floristic diversity was found under dry deodar forest followed by dry broad-leaved and coniferous forests, dry blue pine forest, sub alpine fir forest, neoza pine forest, alpine pasture, sub-alpine birch forest, birch-rhododendron scrub forest and dry alpine scrub in descending order, respectively
- Species richness for trees was ranged from 0.00-0.56, whereas, shrubs species richness ranged from 0.00-1.76 while, herbaceous vegetation richness ranged from 0.84-1.97. Species diversity for tree was ranged from 0.00-1.12 while, shrubs species diversity ranged from 0.00-2.36 whereas, herbaceous vegetation diversity ranged from 2.08-3.04, respectively. Species dominance for tree ranged from 0.00-0.91 and shrubs species richness ranged from 0.00-0.84. However, herbaceous vegetation dominance ranged from 0.06-0.16.
- Tree density and basal area were recorded maximum in dry broad-leaved and coniferous forests ( $275 \text{ N ha}^{-1}$  and  $34.94 \text{ m}^2 \text{ ha}^{-1}$ ), respectively and nil in alpine pasture and dry alpine scrub. In case of shrubs, maximum density was recorded in dry broad-leaved and coniferous forests ( $592 \text{ N ha}^{-1}$ ) and nil in alpine pasture. While, basal area was recorded maximum in birch-rhododendron scrub forest ( $7.74 \text{ m}^2 \text{ ha}^{-1}$ ) and nil in alpine pasture. Herbaceous vegetation showed maximum density and basal area in alpine pasture ( $258890 \text{ N ha}^{-1}$  and  $6.82 \text{ m}^2 \text{ ha}^{-1}$ ) whereas, dry alpine scrub showed minimum herbaceous density ( $99259 \text{ N ha}^{-1}$ ) with basal area of ( $1.25 \text{ m}^2 \text{ ha}^{-1}$ ). Phytosociological parameters and biomass of herbage were better in alpine pasture as compared to other forest types.
- Regeneration status of major forest types showed that maximum number of recruits were found in dry deodar forest and minimum in dry broad-leaved and coniferous forests [(*Quercus ilex*), (*Pinus gerardiana*)]. Un-established regeneration was found maximum in dry blue pine forest and minimum in dry broad-leaved and coniferous forests. Established regeneration was maximum in dry deodar forest and minimum in sub alpine fir forest [(*Abies pindrow*), (*Abies spectabilis*)]. The Regeneration success was better in dry deodar forest while it was fair in neoza pine forest (*Pinus gerardiana*).

- Maximum total vegetation biomass was observed in dry deodar forest (252.24 t ha<sup>-1</sup>) and minimum was found in alpine pasture (0.58 t ha<sup>-1</sup>). The highest vegetation carbon density value was reported in dry deodar forest (126.12 t C ha<sup>-1</sup>) and lowest in alpine pasture (0.29 t C ha<sup>-1</sup>). The total detritus biomass was found to be maximum in birch-rhododendron and minimum in dry alpine scrub. However, total detritus carbon density was found maximum in birch-rhododendron scrub forest (3.00 t C ha<sup>-1</sup>) and minimum in dry alpine scrub (0.06 t C ha<sup>-1</sup>).
- The maximum ecosystem carbon density was displayed by dry deodar forest (212.21 t C ha<sup>-1</sup>).
- The highest value for bulk density at 0-40cm depth was recorded in dry alpine scrub. The maximum concentration of soil nutrients (N, P, K, Cu, Fe, Mn and Zn) are reported in birch-rhododendron scrub.

Present study provides relevant information regarding floral diversity, regeneration status, live tree biomass, live tree C stocks and total ecosystem carbon density stocks of a dry temperate and alpine forest ecosystem. The results of the present study will be helpful for understanding the patterns of regeneration and C storage in various forest types/species of dry temperate and alpine regions in other parts of the globe having similar species composition.

From the above study it can be concluded that among all the forest types of the dry temperate and alpine forest ecosystem, dry deodar forest are very important forest type from species diversity, species dominance and species richness point of view. In addition to this, this forest type is also conserving maximum ecosystem carbon density as well as carbon stock of the dry temperate and alpine forest ecosystem. There is no doubt that this forest type is showing good natural regeneration success rate which is essential for the sustenance of this forest types. But in future they can become susceptible because of the increasing threat of the climate change. Therefore, we should keep a close watch on this forest types so as to avoid degradation of this precious forest ecosystem of the dry temperate and alpine forest ecosystem. This type of ecological knowledge is fundamental for conservation and sustainable utilization, and may provide important information to the policy makers at both national and international level and also to find effective solutions to problems that are threatening the similar ecologically fragile regions.

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## APPENDIX-I

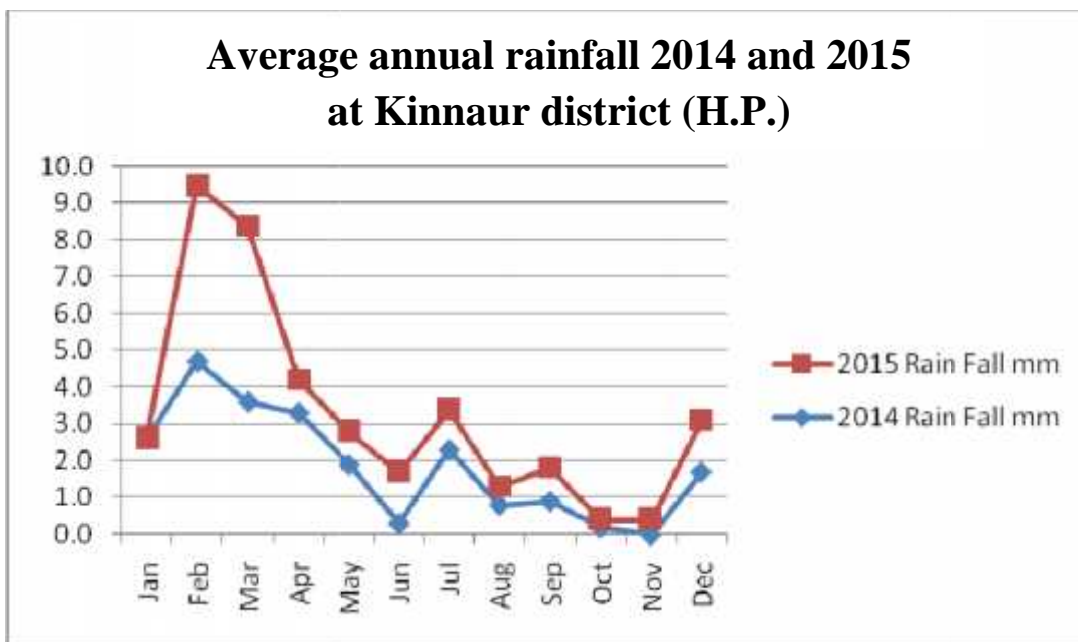
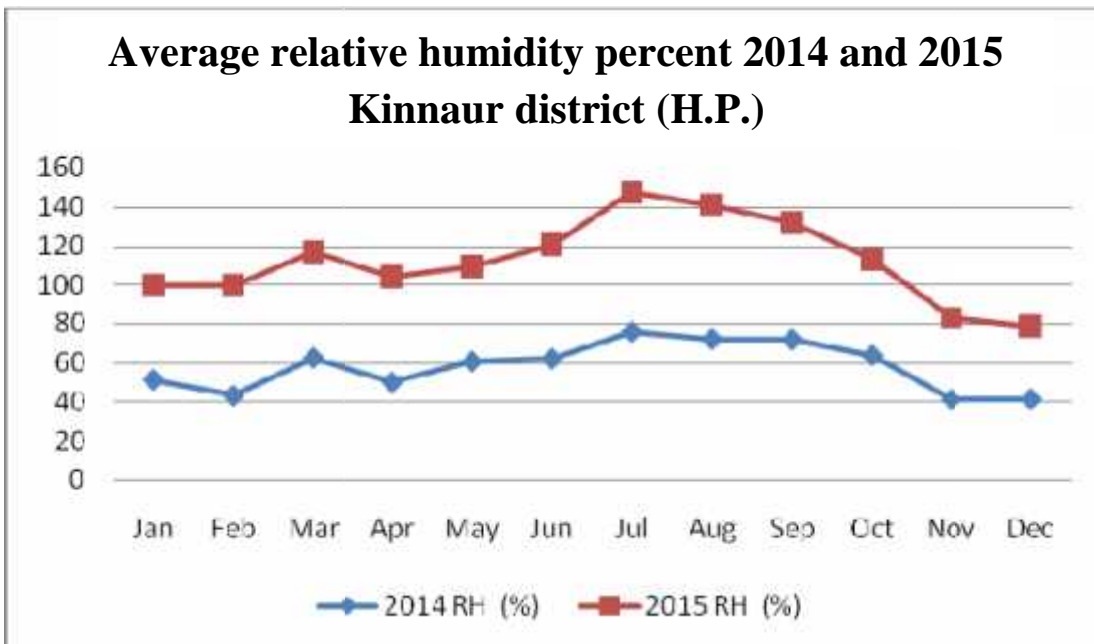
### Meteorological data of the study area on monthly basis for 2014 and 2015

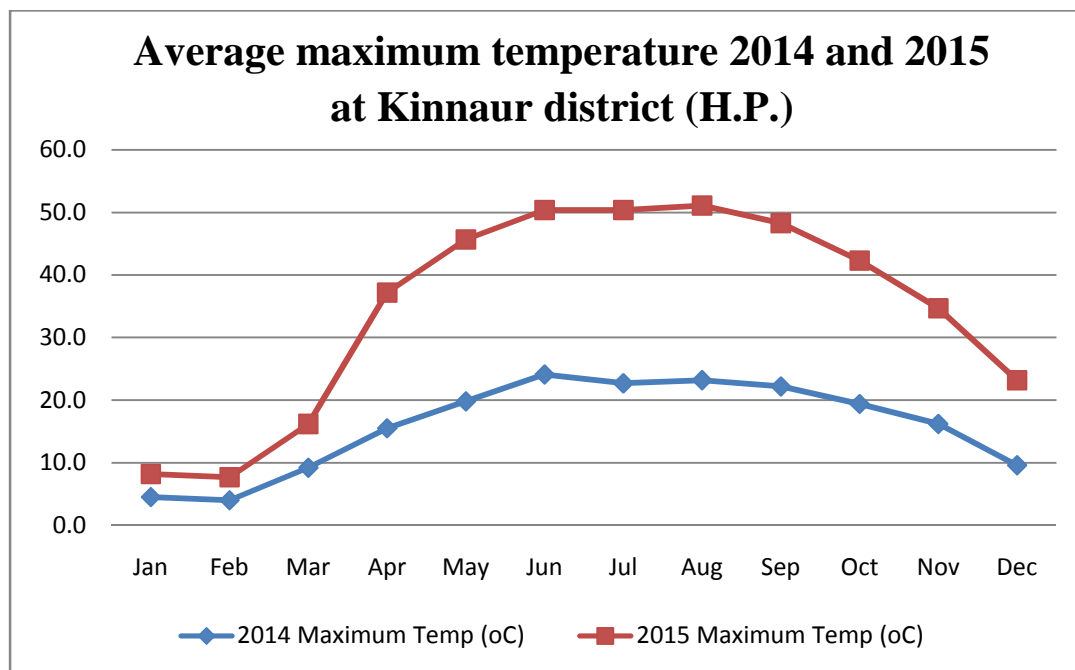
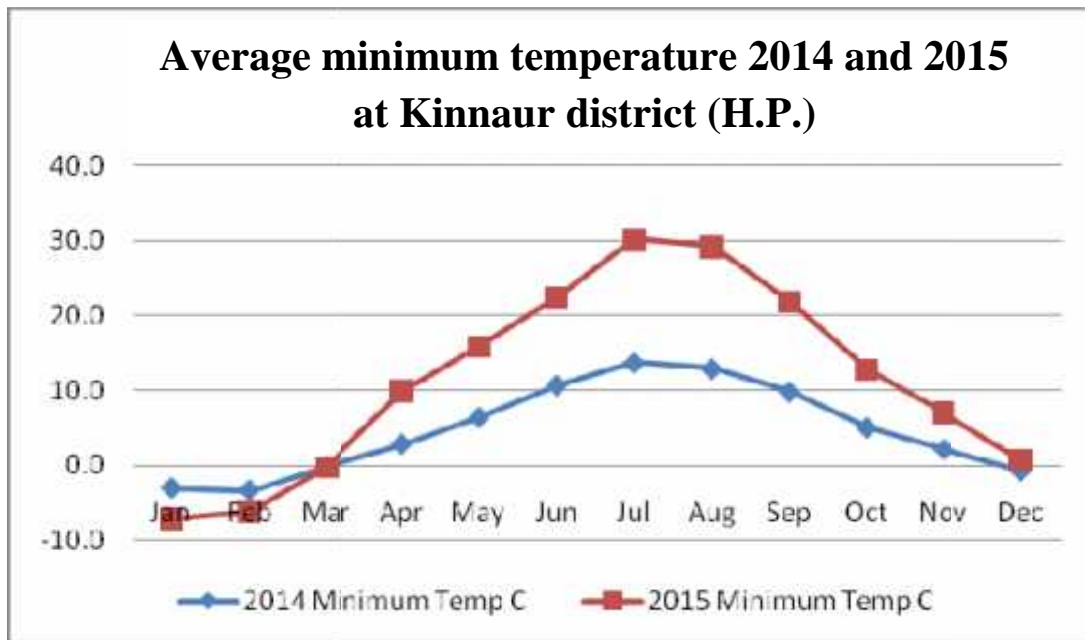
Sr. No	Month	Relative humidity (%)		Rain fall (mm)		Temperature ( <sup>0</sup> C)			
		2014	2015	2014	2015	2014 (Max.)	2015 (Max.)	2014 (Min.)	2015 (Min.)
1.	January	51.3	48.5	2.6	0.0	4.5	3.7	-3.1	-4.1
2.	February	43.2	56.7	4.7	4.8	4.0	3.7	-3.4	-2.9
3.	March	62.6	54.2	3.6	4.8	9.2	7.0	-0.2	-0.1
4.	April	49.9	54.2	3.3	0.9	15.5	21.7	2.8	7.1
5.	May	60.8	48.6	1.9	0.9	19.8	25.9	6.4	9.5
6.	June	62.2	58.3	0.3	1.4	24.1	26.3	10.7	11.8
7.	July	76.0	71.3	2.3	1.1	22.7	27.7	13.7	16.5
8.	August	72.2	68.3	0.8	0.5	23.2	27.9	12.9	16.3
9.	September	72.0	59.6	0.9	0.9	22.2	26.1	9.8	12.1
10.	October	63.9	48.8	0.2	0.2	19.4	22.9	5.0	7.8
11.	November	41.1	41.8	0.0	0.4	16.2	18.5	2.1	4.9
12.	December	41.4	37.4	1.7	1.4	9.6	13.6	-0.8	1.4

Source: Metrological department Kalpa, Kinnaur (H.P.).

## APPENDIX-II

Average data of relative humidity %,rain fall and minimum and maximum temperature of study Area for Year 2014 and 2015





**Source: Metrological department Kalpa, Kinnaur (H.P.).**

## APPENDIX-III

Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 13C<sub>1</sub>-Dry broad-leaved and coniferous forests (*Quercus ilex* – *Pinus gerardiana*) at different altitude

	Forest Type	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI		
		Species	A <sub>1</sub> (2000-2150m)	A <sub>2</sub> (2150-2300m)	A <sub>3</sub> (2300-2450m)	A <sub>1</sub> (2000-2150m)	A <sub>2</sub> (2150-2300m)	A <sub>3</sub> (2300-2450m)	A <sub>1</sub> (2000-2150m)	A <sub>2</sub> (2150-2300m)
Trees	<i>Quercus ilex</i>	225	175	142	14.27	8.04	8.46	189.45	168.64	164.86
	<i>Pinus gerardiana</i>	92	100	92	6.59	6.58	7.16	110.55	131.36	135.14
	<b>Total</b>	<b>317</b>	<b>275</b>	<b>234</b>	<b>20.86</b>	<b>14.62</b>	<b>15.62</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
Shrubs	<i>Abelia trifolora</i>	-	-	44	-	-	0.08	-	-	44.92
	<i>Berberis lycium</i>	-	89	89	-	0.04	0.05	-	35.23	47
	<i>Daphne oleoides</i>	44	-	-	0.03	-	-	24.00	-	-
	<i>Desmodium elegens</i>	133	-	-	0.11	-	-	66.00	-	-
	<i>Desmodium tiliaefolium</i>	-	133	-	-	0.15	-	-	92.34	-
	<i>Indigofera heterantha</i>	-	222	-	-	0.04	-	-	66.4	-
	<i>Lonicera quinquelocularis</i>	89	44	178	0.08	0.07	0.17	53.00	36.81	141.49
	<i>Plactranthus rugosus</i>	444	89	133	0.18	0.03	0.04	157.00	43.74	66.59
	<i>Rhamnus variegata</i>	-	44	-	-	0.03	-	-	25.48	-
	<b>Total</b>	<b>710</b>	<b>621</b>	<b>444</b>	<b>0.40</b>	<b>0.36</b>	<b>0.34</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
Herbs	<i>Artemisia parviflora</i>	-	43333	5556	-	1.48	0.05	-	62.83	8.99
	<i>Artemisia scoparia</i>	6667	-	-	0.66	-	-	22.33	-	-
	<i>Artemisia roxburghiana</i>	12222	-	-	0.38	-	-	20.58	-	-
	<i>Aster ablescens</i>	5556	-	-	0.46	-	-	13.68	-	-
	<i>Erigeron annuus</i>	13333	-	13333	0.01	-	0.01	10.45	-	11.82
	<i>Fragaria nubicola</i>	-	-	15556	-	-	0.44	-	-	29.75
	<i>Geum sikkimense</i>	-	4444	-	-	0.04	-	-	16.09	-
	<i>Impatiens sulcata</i>	-	40000	-	-	0.56	-	-	40.07	-
	<i>Lepedeza gerardiana</i>	-	5556	22222	-	0.06	0.28	-	7.89	43.64
	<i>Saussurea albescens</i>	8889	-	-	1.08	-	-	28.72	-	-
	<i>Silene edgeworthii</i>	-	-	13333	-	-	0.14	-	-	20.28
	<i>Stachys melissifolia</i>	-	23333	-	-	0.12	-	-	25.14	-
	<i>Trifolium pratense</i>	-	3333	-	-	0.24	-	-	10.3	-
	<i>Verbascum thapsus</i>	1111	-	-	0.01	-	-	6.11	-	-
	<i>Agropyron longearistatum</i>	-	-	57778	-	-	0.96	-	-	79.61
	<i>Agrostis alba</i>	-	-	51111	-	-	1.56	-	-	77.93
	<i>Arthraxon lancifolius</i>	22222	-	-	0.37	-	-	18.46	-	-
	<i>Oryzopsis aequiglumis</i>	-	27778	26667	-	0.35	0.18	-	26.72	27.98
	<i>Oryzopsis munrio</i>	-	68889	-	-	0.99	-	-	64.14	-
	<i>Pennisetum orientale</i>	-	-	-	-	-	-	-	-	-
<i>Piptatherum spp</i>	106667	-	-	2.83	-	-	92.55	-	-	
<i>Stipa sibirica</i>	104444	32222	-	1.66	1.59	-	87.12	46.82	-	
	<b>Total</b>	<b>281111</b>	<b>248888</b>	<b>205556</b>	<b>7.46</b>	<b>5.43</b>	<b>3.62</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>

## APPENDIX-IV

Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 13C<sub>2</sub>a- Neoza Pine forest (*Pinus gerardiana*) at different altitude

	Forest Type species	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI			
		A <sub>1</sub> (2300-2450m)	A <sub>2</sub> (2450-2600m)	A <sub>3</sub> (2600-2750m)	A <sub>1</sub> (2300-2450m)	A <sub>2</sub> (2450-2600m)	A <sub>3</sub> (2600-2750m)	A <sub>1</sub> (2300-2450m)	A <sub>2</sub> (2450-2600m)	A <sub>3</sub> (2600-2750m)	
Trees	<i>Pinus gerardiana</i>	175	150	125	14.75	16.15	10.65	187.42	212.94	199.98	
	<i>Cedrus deodara</i>	33	33	33	2.74	3.76	4.34	65.74	87.06	100.02	
	<i>Pinus wallichiana</i>	17	-	-	2.95	-	-	46.84	-	-	
	<b>Total</b>	<b>225</b>	<b>183</b>	<b>158</b>	<b>20.44</b>	<b>19.91</b>	<b>14.99</b>	<b>300</b>	<b>300.00</b>	<b>300.00</b>	
Shrub	<i>Abelia triflora</i>	44	-	-	0.06	-	-	36.58	-	-	
	<i>Berberis aristata</i>	89	-	-	0.07	-	-	59.68	-	-	
	<i>Berberis lycium</i>	44	-	-	0.02	-	-	25.91	-	-	
	<i>Desmodium tilaefolium</i>	44	-	-	0.04	-	-	30.12	-	-	
	<i>Ephedra gerardiana</i>	-	222	133	-	0.03	0.21	-	88.21	188.2	
	<i>Lonicera hypoleuca</i>	-	133	-	-	0.21	-	-	129.05	-	
	<i>Lonicera quinquelocularis</i>	133	-	-	0.15	-	-	89.59	-	-	
	<i>Plectranthus rugosus</i>	133	-	-	0.03	-	-	58.12	-	-	
	<i>Rosa webbiana</i>	-	89	89	-	0.17	0.1	-	82.74	111.8	
	<b>Total</b>	<b>487</b>	<b>444</b>	<b>222</b>	<b>0.37</b>	<b>0.41</b>	<b>0.31</b>	<b>300</b>	<b>300.00</b>	<b>300.00</b>	
	Herb	<i>Anemone polyanthes</i>	15558	-	-	0.07	-	-	20.84	-	-
		<i>Artemisia brevifolia</i>	12222	6667	8889	1.7	1.27	1.77	66.02	47.26	82.4
		<i>Artemisia maritima</i>	22222	-	-	0.28	-	-	30.21	-	-
		<i>Artemisia scorpioides</i>	-	28889	18889	-	0.36	0.23	-	50.2	34.36
<i>Astragalus candoleanus</i>		-	2222	-	-	0.62	-	-	22.58	-	
<i>Bunium persicum</i>		-	23333	5556	-	0.1	0.003	-	26.58	10.2	
<i>Chenopodium botrys</i>		-	-	36667	-	-	0.15	-	-	50.67	
<i>Dianthus angulatus</i>		4444	-	-	0.04	-	-	8.54	-	-	
<i>Galium aparine</i>		12222	-	-	0.31	-	-	20.1	-	-	
<i>Impatiens brachycentra</i>		21111	-	-	0.19	-	-	27.13	-	-	
<i>Lactuca bentharii</i>		14444	-	-	0.48	-	-	30.92	-	-	
<i>Origanum vulgare</i>		-	-	20000	-	-	0.06	-	-	40.82	
<i>Potentilla atrosanguinea</i>		10000	-	-	0.34	-	-	19.75	-	-	
<i>Salvia glutinosa</i>		23333	-	-	0.23	-	-	29.45	-	-	
<i>Scnecio chrysanthemoides</i>		13333	2222	-	0.12	0.03	-	17.44	6.65	-	
<i>Sopubia trifida</i>		-	47778	14444	-	0.3	0.09	-	52.11	26.08	
<i>Thymus serpyllum</i>		21111	5556	-	0.09	0.02	-	29.6	8.42	-	
<i>Verbascum Thapsus</i>		-	11111	-	-	0.78	-	-	54.26	-	
<i>Agropyron semicostatum</i>		-	-	27778	-	-	0.47	-	-	55.47	
<i>Agropyron longearistatum</i>		-	26667	-	-	0.22	-	-	31.94	-	
<b>Total</b>		<b>170000</b>	<b>154445</b>	<b>132223</b>	<b>3.85</b>	<b>3.70</b>	<b>2.773</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>	

## APPENDIX-V

Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 13C<sub>2</sub>b- Dry Deodar forest (*Cedrus deodara*) at different altitude

	Forest Type species	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI			
		A <sub>1</sub> (2450-2600m)	A <sub>2</sub> (2600-2750m)	A <sub>3</sub> (2750-2900m)	A <sub>1</sub> (2450-2600m)	A <sub>2</sub> (2600-2750m)	A <sub>3</sub> (2750-2900m)	A <sub>1</sub> (2450-2600m)	A <sub>2</sub> (2600-2750m)	A <sub>3</sub> (2750-2900m)	
<b>Tree</b>	<i>Cedrus deodara</i>	183	242	125	23.71	31.48	47.12	236.92	300	267.62	
	<i>Pinus wallichiana</i>	-	-	8	-	-	0.54	-	-	32.38	
	<i>Pinus geardiana</i>	33	-	-	1.98	-	-	63.08	-	-	
	<b>Total</b>	<b>216</b>	<b>242</b>	<b>133</b>	<b>25.69</b>	<b>31.48</b>	<b>47.66</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>	
<b>Shrub</b>	<i>Berberis aristata</i>	44	-	-	0.04	-	-	24.47	-	-	
	<i>Cotoneaster bacillaris</i>	-	-	89	-	-	0.17	-	-	110.18	
	<i>Daphne oleoides</i>	89	-	-	0.05	-	-	41.72	-	-	
	<i>Desmodium confertum</i>	44	133	-	0.05	0.13	-	26.59	82.35	-	
	<i>Ephedra gerardiana</i>	-	-	44	-	-	0.01	-	-	47.52	
	<i>Indigofera heterantha</i>	133	-	-	0.04	-	-	36.74	-	-	
	<i>Indigofera gerardiana</i>	-	222	-	-	0.12	-	-	93.26	-	
	<i>Lonicera hypoleuca</i>	-	133	44	-	0.1	0.04	-	87.43	42.15	
	<i>Lonicera quinquelocularis</i>	44	-	-	0.06	-	-	29.21	-	-	
	<i>Plectranthus rugosus</i>	267	89	-	0.12	0.04	-	-	36.96	-	
	<i>Rosa microphylla</i>	89	-	-	0.07	-	-	93.73	-	-	
	<i>Rosa webbiana</i>	-	-	89	-	-	0.14	47.54	-	100.15	
	<b>Total</b>	<b>710</b>	<b>577</b>	<b>266</b>	<b>0.43</b>	<b>0.39</b>	<b>0.36</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>	
	<b>Herb</b>	<i>Anaphalis busua</i>	5556	-	-	0.07	-	-	7.98	-	-
		<i>Arisaema flavum</i>	3333	-	-	0.1	-	-	11.15	-	-
		<i>Artemisia scoparia</i>	-	33333	12222	-	0.24	0.02	-	51.27	14.41
		<i>Asparagus filicinus</i>	10000	-	-	0.17	-	-	15.46	-	-
		<i>Aster indamellus</i>	-	22222	-	-	0.11	-	-	35.57	-
		<i>Astragalus candoleanus</i>	-	-	7778	-	-	1.34	-	-	57.8
		<i>Erigeron annuus</i>	-	21111	-	-	0.12	-	-	25.27	-
		<i>Fragaria vesca</i>	6667	6667	-	0.01	0.01	-	6.9	8.69	-
		<i>Impatiens sulcata</i>	36667	-	-	1.21	-	-	48.54	-	-
<i>Lactuca benthami</i>		8889	-	-	0.08	-	-	17.08	-	-	
<i>Nepeta ruderalis</i>		-	-	13333	-	-	0.3	-	-	23.42	
<i>Origanum vulgare</i>		-	-	20000	-	-	0.07	-	-	26.9	
<i>Salvia glutinosa</i>		10000	12222	-	0.2	0.5	-	12.21	29.42	-	
<i>Senecio cappa</i>		14444	-	-	0.18	-	-	21.62	-	-	
<i>Smilacina purpurea</i>		16667	-	-	1.03	-	-	32.23	-	-	
<i>Thymus serpyllum</i>		13333	-	-	0.08	-	-	11.31	-	-	
<i>Verbascum thapsus</i>		3333	8889	7778	0.04	0.09	0.16	6.1	12.95	28.25	
<i>Viola canasense</i>		8889	8889	-	0.01	0.04	-	7.89	11.06	-	
<i>Viola serpens</i>		6667	13333	-	0.01	0.14	-	7.01	21.98	-	
<i>Hemarthris altissima</i>		-	-	37778	-	-	0.45	-	-	55.39	
<i>Agropyron semicostum</i>		-	-	34444	-	-	0.6	-	-	51.74	
<i>Agropyron longearistatum</i>		-	64444	30000	-	1.51	0.37	-	103.79	42.09	
<i>Stipa Sibirica</i>		27778	-	-	0.49	-	-	29.8	-	-	
<i>Alopecurus arundinaceus</i>		50000	-	-	0.98	-	-	53.49	-	-	
<i>Pteridium aquilinum</i>		6667	-	-	0.23	-	-	11.46	-	-	
<b>Total</b>		<b>228890</b>	<b>191110</b>	<b>163333</b>	<b>4.89</b>	<b>2.76</b>	<b>3.31</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>	

## APPENDIX-VI

**Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 13 C<sub>3</sub>- West Himalayan high level dry Blue Pine forest (*Pinus wallichiana*) at different altitude**

	Forest Type	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI		
		A <sub>1</sub> (3000-3150m)	A <sub>2</sub> (3150-3300m)	A <sub>3</sub> (3300-3450m)	A <sub>1</sub> (3000-3150m)	A <sub>2</sub> (3150-3300m)	A <sub>3</sub> (3300-3450m)	A <sub>1</sub> (3000-3150m)	A <sub>2</sub> (3150-3300m)	A <sub>3</sub> (3300-3450m)
Tree	<i>Pinus wallichiana</i>	200	183	167	15.12	16.59	14.77	200.61	212.99	229.63
	<i>Cedrus ceodara</i>	67	50	-	4.88	5.7	-	99.39	87.01	-
	<i>Abies spectabilis</i>	-	-	33	-	-	2.35	-	-	70.37
	<b>Total</b>	<b>267</b>	<b>233</b>	<b>200</b>	<b>20.00</b>	<b>22.29</b>	<b>17.12</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
Shrub	<i>Berberis erythroclada</i>	-	222	222.22	-	0.13	0.07	-	122.34	133.48
	<i>Desmodium confertum</i>	133	-	-	0.17	-	-	100.2	-	-
	<i>Indigofera gerardiana</i>	222	-	-	0.11	-	-	101.98	-	-
	<i>Plectranthus rugosus</i>	89	-	-	0.05	-	-	40.82	-	-
	<i>Rosa microphylla</i>	89	-	-	0.07	-	-	57	-	-
	<i>Salix hastata</i>	-	222	177.78	-	0.33	0.19	-	177.66	166.52
	<b>Total</b>	<b>533</b>	<b>444</b>	<b>400</b>	<b>0.40</b>	<b>0.46</b>	<b>0.26</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
	Herb	<i>Aconitum heterophyllum</i>	5556	-	-	0.03	-	-	7.72	-
<i>Artemisia scoparia</i>		14444	22222	11111	0.07	0.48	0.14	21.89	28.91	23.12
<i>Astragalus frigidus</i>		-	28889	-	-	0.53	-	-	33.17	-
<i>Cynoglossum glochidiatum</i>		8889	-	-	0.33	-	-	12.9	-	-
<i>Fragaris nubicola</i>		-	-	14444	-	-	0.02	-	-	17.05
<i>Fragaris vesca</i>		-	17778	24444	-	0.09	0.04	-	18.93	22.94
<i>Geranium wallichianum</i>		13333	6667	-	0.46	0.03	-	16.42	12.14	-
<i>Impatiens sulcata</i>		6668	-	-	0.13	-	-	9.41	-	-
<i>Lamium album</i>		-	-	30000	-	-	0.05	-	-	39.71
<i>Pimpinella diversifolia</i>		20833	16667	-	0.45	0.4	-	33.14	28.83	-
<i>Rumex nepalensis</i>		-	1111	-	-	0.01	-	-	4.89	-
<i>salvia glutinosa</i>		23333	-	-	2.83	-	-	55.81	-	-
<i>salvia nubicola</i>		-	31111	32222	-	1.93	1.52	-	74.95	76.14
<i>Scencio chrysanthemoidas</i>		-	-	6667	-	-	0.09	-	-	10.31
<i>Thymus serphyllum</i>		-	8889	-	-	0.02	-	-	9.01	-
<i>Verbascum thapsus</i>		1111	-	-	0.01	-	-	5.6	-	-
<i>Viola serpens</i>		-	10000	-	-	0.01	-	-	9.36	-
<i>Brachypodium distachyon</i>		23333	-	-	0.53	-	-	21.46	-	-
<i>Chrysopogon gryllus</i>		-	21111	45556	-	0.54	0.65	-	25.38	59.21
<i>Dactylis glomerate</i>		23704	-	-	0.45	-	-	22.37	-	-
<i>Danthonia schneideri</i>		-	14444	27778	-	0.29	1.21	-	17.07	51.52
<i>Setaria viridis</i>		64444	-	-	1.89	-	-	61.05	-	-
<i>Stipa sibirica</i>		28889	14444	-	0.59	0.18	-	24.69	15.05	-
<i>Pteridium aquilinum</i>		3333	8889	-	0.09	0.48	-	7.54	22.31	-
<b>Total</b>		<b>237870</b>	<b>202222</b>	<b>192222</b>	<b>7.86</b>	<b>4.99</b>	<b>3.72</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>

## APPENDIX-VII

**Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 14C1a- West Himalayan sub- alpine birch forests at different altitude**

	Forest Type	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI		
		species	A <sub>1</sub> (3100-3250m)	A <sub>2</sub> (3250-3400m)	A <sub>3</sub> (3400-3550m)	A <sub>1</sub> (3100-3250m)	A <sub>2</sub> (3250-3400m)	A <sub>3</sub> (3400-3550m)	A <sub>1</sub> (3100-3250m)	A <sub>2</sub> (3250-3400m)
Tree	<i>Betula utilis</i>	175	175	158	13.97	9.74	8.26	238.18	189.07	187.55
	<i>Abies pindrow</i>	8	50	33	1.16	3.43	1.58	31.53	89.4	72.03
	<i>Pinus wallichiana</i>	8	8	17	0.96	0.5	2.18	30.29	21.53	40.42
	<b>Total</b>	<b>191</b>	<b>233</b>	<b>208</b>	<b>16.09</b>	<b>13.67</b>	<b>12.02</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
Shrub	<i>Berberis vulgaris</i>	267	178	178	0.15	0.13	0.09	183.67	144.97	153.94
	<i>Cotoneaster bacillaris</i>	44	44	44	0.06	0.05	0.06	47.51	41.61	52.12
	<i>Rhododendron anthropogon</i>	-	-	44	-	-	0.06	-	-	53.79
	<i>Rosa macrophylla</i>	89	133	44	0.06	0.11	0.03	68.82	113.43	40.15
	<b>Total</b>	<b>400</b>	<b>355</b>	<b>310</b>	<b>0.27</b>	<b>0.29</b>	<b>0.24</b>	<b>300.00</b>	<b>300.01</b>	<b>300.00</b>
Herb	<i>Aconitum molli</i>	14444	-	-	0.58	-	-	20.78	-	-
	<i>Ainsliae aptera</i>	6667	-	-	0.01	-	-	9.57	-	-
	<i>Aquilegia fragranus</i>	-	17778	11111	-	0.07	0.03	-	26.78	19.92
	<i>Bergenia stracheyi</i>	1111	-	32222	0.09	-	2.04	7.21	-	93.22
	<i>Bistorta affinis</i>	12222	-	-	0.21	-	-	15.13	-	-
	<i>Chenopodium opulifolium</i>	-	71111	44444	-	0.96	0.91	-	78.36	67.16
	<i>Impatiens sulcata</i>	38889	26667	36667	0.83	0.16	0.22	43.43	27.12	39.67
	<i>Primula macrophalla</i>	3333	-	-	0.02	-	-	7.74	-	-
	<i>Rumex nepalensis</i>	8889	-	-	0.24	-	-	24.62	-	-
	<i>Silene edgeworthii</i>	-	-	34444	-	-	0.92	-	-	55.13
	<i>Thalictrum javanicum</i>	10000	-	-	0.01	-	-	11.48	-	-
	<i>Urtica dioca</i>	18889	4444	8889	0.3	0.02	0.04	31.14	19.28	24.9
	<i>Deyeurcia pulchella</i>	-	45556	-	-	1.08	-	-	56.04	-
	<i>Danthonia cachemyriana</i>	25556	-	-	0.9	-	-	31.02	-	-
	<i>Danthonia schneideri</i>	33333	31111	-	5.22	4.37	-	97.88	92.42	-
<b>Total</b>	<b>173333</b>	<b>196667</b>	<b>167777</b>	<b>8.41</b>	<b>6.66</b>	<b>4.16</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>	

## APPENDIX-VIII

Density (Nha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 14c<sub>1</sub>b- West Himalayan sub- alpine fir forest at different altitude

	Forest Type	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI			
		A <sub>1</sub> (3150-3300m)	A <sub>2</sub> (3300-3450m)	A <sub>3</sub> (3400-3550m)	A <sub>1</sub> (3150-3300m)	A <sub>2</sub> (3300-3450m)	A <sub>3</sub> (3400-3550m)	A <sub>1</sub> (3150-3300m)	A <sub>2</sub> (3300-3450m)	A <sub>3</sub> (3400-3550m)	
Tree	<i>Abies pindrow</i>	217	158	-	21.69	14.14	-	236.58	180.49	-	
	<i>Abies spectabilis</i>	-	-	192	-	-	18.05	-	-	300.00	
	<i>Pinus wallichiana</i>	33	58	-	2.43	6.41	-	63.42	99.3	-	
	<i>Betula utilis</i>	-	8	-	-	0.47	-	-	20.22	-	
	<b>Total</b>	<b>250</b>	<b>224</b>	<b>192</b>	<b>24.12</b>	<b>21.02</b>	<b>18.05</b>	<b>300</b>	<b>300.01</b>	<b>300.00</b>	
Shrub	<i>Berberis erythroclada</i>	44	44	133	0.01	0.02	0.08	31.68	55.39	118.45	
	<i>Cotoneaster bacillaris</i>	44	89	-	0.05	0.08	-	47.39	127.54	-	
	<i>Rosa macrophylla</i>	222	89	-	0.09	0.06	-	154.6	117.07	-	
	<i>Salix hastata</i>	-	-	178	-	-	0.15	-	-	181.55	
	<i>Sorbus foliolosa</i>	44	-	-	0.11	-	-	66.33	-	-	
	<b>Total</b>	<b>354</b>	<b>222</b>	<b>311</b>	<b>0.26</b>	<b>0.16</b>	<b>0.23</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>	
Herb	<i>Ainsliaea aptera</i>	-	8889	-	-	0.02	-	-	13.57	-	
	<i>Anaphalis busua</i>	-	-	7778	-	-	0.07	-	-	11.93	
	<i>Astragalus chlorostachys</i>	13333	-	11111	0.34	-	0.34	14.73	-	19.86	
	<i>Equisetum arvense</i>	-	8889	-	-	0.01	-	-	8.98	-	
	<i>Fragaria nubicola</i>	-	31111	-	-	0.12	-	-	35.25	-	
	<i>Geranium wallichiana</i>	-	6667	28889	-	0.09	0.4	-	9.37	36.86	
	<i>Impatiens sulcata</i>	43333	13333	34444	1.48	0.45	1.01	51.93	19.2	60.02	
	<i>Jurinea dolomiaea</i>	-	3333	-	-	1.17	-	-	27.43	-	
	<i>Laminas album</i>	-	24444	-	-	0.33	-	-	22.66	-	
	<i>Ligularia fischeri</i>	36667	22222	13333	1.03	0.82	0.13	42.98	34.85	22.44	
	<i>Picrorhiza kurroa</i>	-	13333	-	-	0.26	-	-	15.77	-	
	<i>Potential atrosanguinea</i>	-	27778	-	-	0.76	-	-	45.34	-	
	<i>Rumex napalensis</i>	5556	-	-	0.03	-	-	15.83	-	-	
	<i>Salvia nubicola</i>	15556	-	10000	0.03	-	0.11	15.75	-	14.02	
	<i>Saussuria lappa</i>	-	2222	-	-	0.2	-	-	9.19	-	
	<i>Selinum tenuifolium</i>	-	3333	-	-	0.23	-	-	10.23	-	
	<i>Thalictrum alpinum</i>	-	-	7778	-	-	0.03	-	-	11.13	
	<i>Thymus serphyllum</i>	-	5556	-	-	0.07	-	-	8.4	-	
	<i>Viola canescens</i>	17778	11111	-	0.05	0.1	-	21.25	11.8	-	
	<i>Stachys melissaefilia</i>	35556	16667	23333	1.18	0.83	0.57	44.54	27.96	37.79	
	<i>Danthonia schneideri</i>	15556	-	36667	0.45	-	1.16	17.14	-	58.28	
	<i>Dactylis glomerata</i>	17778	-	-	0.65	-	-	20.99	-	-	
	<i>Dryopteris barbigera (F)</i>	34444	-	15556	1.96	-	0.58	54.86	-	27.67	
		<b>Total</b>	<b>235557</b>	<b>198888</b>	<b>188889</b>	<b>7.20</b>	<b>5.46</b>	<b>4.40</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>

**APPENDIX-IX**

**Density (nha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 15c<sub>1</sub>- birch-rhododendron scrub forests at different altitude**

	Forest Type species	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI		
		A <sub>1</sub> (3300-3400m)	A <sub>2</sub> (3400-3500m)	A <sub>3</sub> (3500-3600m)	A <sub>1</sub> (3300-3400m)	A <sub>2</sub> (3400-3500m)	A <sub>3</sub> (3500-3600m)	A <sub>1</sub> (3300-3400m)	A <sub>2</sub> (3400-3500m)	A <sub>3</sub> (3500-3600m)
Tree	<i>Betula utilis</i>	200	167	142	7.8	5.41	5.09	300	259.9	232.38
	<i>Abies pindrow</i>	-	8	17	-	0.62	1.05	-	40.1	67.62
	<b>Total</b>	<b>200</b>	<b>175</b>	<b>158</b>	<b>7.80</b>	<b>6.03</b>	<b>6.14</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
Shrub	<i>Rhododendron campanulatum</i>	400	400	444	8.05	8.41	6.46	300	254.95	271.46
	<i>Salix hastata</i>	-	133	-	-	0.16	-	-	45.05	-
	<i>Rhododendron anthropogon</i>	-	-	89	-	-	0.12	-	-	28.54
	<b>Total</b>	<b>400</b>	<b>533</b>	<b>533</b>	<b>8.05</b>	<b>8.57</b>	<b>6.58</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
Herb	<i>Aconogonum alpinum</i>	-	63333	-	-	2.16	-	-	137.51	-
	<i>Anemone tetrasepala</i>	12222	-	-	0.27	-	-	42.4	-	-
	<i>Bistorta affinis</i>	-	-	78889	-	-	2.57	-	-	162.54
	<i>Cassiope fastigata</i>	31111	-	-	0.17	-	-	62.79	-	-
	<i>Geum elatum</i>	-	6667	-	-	0.004	-	-	13.57	-
	<i>Iris hookeriana</i>	10000	-	-	0.01	-	-	18.38	-	-
	<i>Potentilla atosanguinea</i>	-	-	26667	-	-	0.19	-	-	52.99
	<i>Stachys sylvatica</i>	-	32222	-	-	0.48	-	-	50.63	-
	<i>Danthonia Jacquemonti</i>	-	-	15556	-	-	0.29	-	-	25.14
	<i>Deyaurcia pulchella</i>	13333	-	11111	0.16	-	0.73	27.95	-	33.39
	<i>Dryopteris barbigera</i>	58889	50000	20000	1.52	1.63	0.2	148.48	98.29	25.94
	<b>Total</b>	<b>125555</b>	<b>152222</b>	<b>152223</b>	<b>2.13</b>	<b>4.27</b>	<b>3.98</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>

**APPENDIX-X**  
**Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of 15C<sub>3</sub>- Alpine pasture at different altitude**

	Forest Type species	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI		
		A <sub>1</sub> (2900-3050m)	A <sub>2</sub> (3050-3200m)	A <sub>3</sub> (3200-3350m)	A <sub>1</sub> (2900-3050m)	A <sub>2</sub> (3050-3200m)	A <sub>3</sub> (3200-3350m)	A <sub>1</sub> (2900-3050m)	A <sub>2</sub> (3050-3200m)	A <sub>3</sub> (3200-3350m)
Herb	<i>Anaphalis busua</i>	-	-	16667	-	-	0.14	-	-	17.55
	<i>Artemisia brevifolia</i>	-	11111	13333	-	0.78	0.18	-	38.43	21.66
	<i>Artemisia parviflora</i>	-	-	6667	-	-	1.13	-	-	38.43
	<i>Carum carvi</i>	6667	-	4444	0.13	-	0.09	<b>7.42</b>	-	9.53
	<i>Chenopodium album</i>	-	-	3333	-	-	0.04	-	-	<b>7.76</b>
	<i>Cirsium falconeri</i>	-	10000	-	-	0.86	-	-	28.65	-
	<i>Cirsium verutum</i>	6667	-	-	0.5	-	-	19.11	-	-
	<i>Cynoglossum micranthum</i>	-	-	<b>1111</b>	-	-	0.01	-	-	5.78
	<i>Datura stramonium</i>	-	-	8889	-	-	0.16	-	-	23.5
	<i>Echinops cornigerus</i>	-	-	38889	-	-	<b>1.74</b>	-	-	<b>75.06</b>
	<i>Heracleum candicans</i>	4444	-	-	0.45	-	-	13.91	-	-
	<i>Medicago falcata</i>	15556	-	-	0.13	-	-	10.09	-	-
	<i>Mentha longifolia</i>	-	27778	-	-	0.21	-	-	20.6	-
	<i>Polygonum polygaloides</i>	13333	-	26667	0.02	-	0.32	12.36	-	32.27
	<i>Rumex nepalensis</i>	-	<b>6667</b>	-	-	0.15	-	-	15.66	-
	<i>Silene edgeworthii</i>	-	45556	-	-	0.96	-	-	46.56	-
	<i>Thalictrum javanicum</i>	-	10000	-	-	<b>0.04</b>	-	-	<b>14.94</b>	-
	<i>Trifolium repens</i>	-	-	16667	-	-	0.01	-	-	19.82
	<i>Verbascum thapsus</i>	<b>2222</b>	-	-	<b>0.004</b>	-	-	8.71	-	-
	<i>Agropyron semicostatum</i>	68889	<b>105556</b>	37778	2.35	<b>1.98</b>	0.78	53.11	<b>85.16</b>	48.64
<i>Agrostis canina</i>	<b>135556</b>	-	-	<b>5.05</b>	-	-	109.04	-	-	
<i>Alopecurus arundinaceus</i>	30000	61111	-	0.49	1.04	-	34.17	50	-	
<i>Elymus dasystachys</i>	41111	-	-	0.73	-	-	32.08	-	-	
<b>Total</b>		<b>324445</b>	<b>277779</b>	<b>174445</b>	<b>9.854</b>	<b>6.02</b>	<b>4.60</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>

**APPENDIX-XII**

**Density (N ha<sup>-1</sup>), basal area (m<sup>2</sup> ha<sup>-1</sup>) and IVI of at 16c<sub>1</sub>-dry alpine scrub different altitude**

	Forest Type	Density (N ha <sup>-1</sup> )			Basal area (m <sup>2</sup> ha <sup>-1</sup> )			IVI		
		A <sub>1</sub> (3300-3450m)	A <sub>2</sub> (3450-36000m)	A <sub>3</sub> (3600-3750m)	A <sub>1</sub> (3300-3450m)	A <sub>2</sub> (3450-36000m)	A <sub>3</sub> (3600-3750m)	A <sub>1</sub> (3300-3450m)	A <sub>2</sub> (3450-36000m)	A <sub>3</sub> (3600-3750m)
<b>Shrub</b>	<i>Ribes orientale</i>	133	-	-	0.32	-	-	117.52	-	-
	<i>Juniperus communis</i>	133	222.22	44	1.49	2.5	0.58	182.48	300	81.14
	<i>Juniperus indica</i>	-	-	133	-	-	1.28	-	-	218.86
	<b>Total</b>	266	222.22	177	1.81	2.5	1.86	300.00	300.00	300.00
<b>Herb</b>	<i>Artemisia brevifolia</i>	7778	-	-	0.16	-	-	39.48	-	-
	<i>Bergenia stracheyi</i>	-	11111	5556	-	0.45	0.13	-	52.91	38.95
	<i>Datura stramonium</i>	-	-	2222	-	-	0.02	-	-	19.08
	<i>Echinops cornigerus</i>	23333.33	-	-	0.73	-	-	99.87	-	-
	<i>Iris hookeriana</i>	-	30000	-	-	0.11	-	-	64.19	-
	<i>Mentha longifolia</i>	-	-	7778	-	-	0.06	-	-	32.97
	<i>Polygonum polygaloides</i>	36666.67	-	-	0.05	-	-	48.27	-	-
	<i>Potentilla atrosanguinea</i>	-	20000	17778	-	0.16	0.11	-	38.55	68.1
	<i>Sedum ewersii</i>	-	14444	-	-	0.09	-	-	28.79	-
	<i>Danthonia schneideri</i>	-	36667	35556	-	0.42	0.49	-	91.74	140.9
	<i>Agropyron semicostatum</i>	40000	-	-	0.68	-	-	112.38	-	-
<i>Deyaurcia pulchella</i>	-	8889	-	-	0.09	-	-	23.82	-	
		<b>107778</b>	<b>121111</b>	<b>68890</b>	<b>1.62</b>	<b>1.32</b>	<b>0.81</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>

APPENDIX-XIII

ANOVA OF BIOMASS

ANOVA TABLE OF TREE ABOVE GROUND BIOMASS

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	323.121			
Treatment	8	103,812.644	12,976.580	17.072	sig
Error	16	12,161.886	760.118		
Total	26	116,297.651			

ANOVA TABLE OF TREE BELOW GROUND BIOMASS

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	9.707			
Treatment	8	4,777.574	597.197	16.938	sig
Error	16	564.130	35.258		
Total	26	5,351.411			

ANOVA TABLE OF TOTAL BIOMASS OF TREE

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	9.707			
Treatment	8	4,777.574	597.197	16.938	sig
Error	16	564.130	35.258		
Total	26	5,351.411			

ANOVA TABLE OF TOTAL BIOMASS OF SHRUBS

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1.506			
Treatment	8	912.240	114.030	333.148	sig
Error	16	5.476	0.342		
Total	26	919.223			

ANOVA TABLE OF TOTAL BIOMASS OF HERBS

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.028			
Treatment	8	0.107	0.013	6.580	sig
Error	16	0.033	0.002		
Total	26	0.168			

### ANOVA TABLE OF TOTAL VEGETATION BIOMASS

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	422.640			
Treatment	8	150,693.347	18,836.668	16.698	sig
Error	16	18,048.791	1,128.049		
Total	26	169,164.778			

### ANOVA TABLE OF TOTAL VEGETATION CARBON

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	105.597			
Treatment	8	37,673.049	4,709.131	16.698	sig
Error	16	4,512.247	282.015		
Total	26	42,290.893			

### ANOVA TABLE OF TOTAL ECOSYSTEM CARBON

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	534.701			
Treatment	8	92,676.098	11,584.512	40.014	sig
Error	16	4,632.191	289.512		
Total	26	97,842.989			

### ANOVA TABLE OF BULK DENSITY

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	0.07	0.03	128.31	3.28	sig
Treatments	8	1.63	0.20	801.77	2.23	sig
Depth	1	0.02	0.02	73.06	4.13	sig
TXD	8	0.0	0.00	1.49	2.23	ns
Error	34	0.01	0.00			
Total	53	1.72				

### ANOVA TABLE OF OC (%)

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	0.00	0.00	0.01	3.28	ns
Treatments	8	21.83	2.73	193.12	2.23	sig
Depth	1	5.90	5.90	417.66	4.13	sig
TXD	8	0.23	0.03	2.04	2.23	ns
Error	34	0.48	0.01			
Total	53	28.44				

### ANOVA TABLE OF pH

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	0.00	0.00	0.14	3.28	ns
Treatments	8	24.31	3.04	1999.05	2.23	sig
Depth	1	0.08	0.08	50.19	4.13	sig
TXD	8	0.03	0.00	2.14	2.23	ns
Error	34	0.05	0.00			
Total	53	24.47				

### ANOVA TABLE OF ELECTRICAL CONDUCTIVITY

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	0.00	0.00	3.11	3.28	ns
Treatments	8	0.06	0.01	19.60	2.23	sig
Depth	1	0.00	0.00	5.89	4.13	sig
TXD	8	0.00	0.00	0.31	2.23	ns
Error	34	0.01	0.00			
Total	53	0.08				

### ANOVA TABLE OF AVAILABLE NITROGEN

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	8.99	4.50	0.15	3.28	ns
Treatments	8	546682.94	68335.37	2224.29	2.23	sig
Depth	1	58094.70	58094.70	1890.96	4.13	sig
TXD	8	545.45	68.18	2.22	2.23	ns
Error	34	1044.56	30.72			
Total	53	606376.65				

### ANOVA TABLE OF AVAILABLE PHOSPHORUS

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	6.25	3.13	1.65	3.28	ns
Treatments	8	1292.58	161.57	85.21	2.23	sig
Depth	1	372.41	372.41	196.40	4.13	sig
TXD	8	32.11	4.01	2.12	2.23	ns
Error	34	64.47	1.90			
Total	53	1767.83				

### ANOVA TABLE OF AVAILABLE POTASSIUM

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	1.47	0.73	0.00	3.28	ns
Treatments	8	2081994.87	260249.36	1099.95	2.23	sig
Depth	1	53954.48	53954.48	228.04	4.13	sig
TXD	8	4103.60	512.95	2.17	2.23	ns
Error	34	8044.41	236.60			
Total	53	2148098.82				

### ANOVA TABLE OF EXCHANGEABLE COPPER

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	0.00	0.00	1.25	3.28	ns
Treatments	8	23.97	3.00	3011.42	2.23	sig
Depth	1	0.22	0.22	221.58	4.13	sig
TXD	8	0.02	0.00	2.14	2.23	ns
Error	34	0.03	0.00			
Total	53	24.24				

### ANOVA TABLE OF AVAILABLE MANGANESE

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	4.54	2.27	2.70	3.28	ns
Treatments	8	520.99	65.12	77.34	2.23	sig
Depth	1	180.62	180.62	214.50	4.13	sig
TXD	8	7.10	0.89	1.05	2.23	ns
Error	34	28.63	0.84			
Total	53	741.89				

### ANOVA TABLE OF AVAILABLE IRON

Source of variation	DF	Sum of Squares	Mean Squares	F cal	F tab	Significance
Replication	2	10.62	5.31	3.11	3.28	ns
Treatments	8	14196.36	1774.55	1039.78	2.23	sig
Depth	1	326.69	326.69	191.42	4.13	sig
TXD	8	11.70	1.46	0.86	2.23	ns
Error	34	58.03	1.71			
Total	53	14603.39				

## ANOVA TABLE OF AVAILABLE ZINC

<b>Source of variation</b>	<b>DF</b>	<b>Sum of Squares</b>	<b>Mean Squares</b>	<b>F cal</b>	<b>F tab</b>	<b>Significance</b>
Replication	2	0.00	0.00	0.17	3.28	ns
Treatments	8	2.50	0.31	923.31	2.23	sig
Depth	1	0.10	0.10	299.31	4.13	sig
TXD	8	0.01	0.00	2.21	2.23	ns
Error	34	0.01	0.00			
Total	53	2.62				

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**Title of Thesis** : “Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh”  
**Name of the Student** : Rakesh Kumar  
**Admission Number** : F-2013-29-D  
**Major Advisor** : Dr. D. R. Bhardwaj  
**Major Field** : Forestry  
**Minor Field(s)** : Silviculture  
**Degree Awarded** : Ph.D. Forestry (Silviculture)  
**Year of Award of Degree** : 2013  
**No. of pages in Thesis** : 157+XVII  
**No. of words in Abstract** : 820

**ABSTRACT**

The present investigation entitled “Floral diversity and carbon stock assessment of Himalayan dry temperate and alpine forest of Himachal Pradesh” was carried out in Kinnaur district of Himachal Pradesh during the year 2015-16 with the aim to assess floristic diversity, regeneration status, carbon stock and soil physico-chemical properties in dry temperate and alpine forests area of Kinnaur (H.P.). Nine different forest types were selected viz., dry broad-leaved and coniferous forests (*Quercus ilex* – *Pinus gerardiana*), neoza pine forest (*Pinus gerardiana*), dry deodar forest (*Cedrus deodara*), west Himalayan high level dry blue pine forest (*Pinus wallichiana*), west Himalayan sub- alpine birch forests, west Himalayan sub- alpine fir forests, birch-rhododendron scrub forest, alpine pasture and dry alpine scrub. In every forest types 9 quadrates of size 20 m × 20 m for trees were laid out randomly across the slope distributed along the elevation gradient (lower, medium and high). Within each quadrat (20 m × 20 m), three sub-quadrates of size of 5 m × 5 m for shrubs and 1 x 1 m for herbs were laid out. To study the regeneration status of dominant forest species, 9 sub-quadrat of 2 m × 2 m within each quadrat of size 20 m x 20 m were laid out. To estimate the biomass, quadrat size was same as floristic diversity studied. To converted biomass into carbon it was multiplying with a factor of 0.5 (IPCC default value). Surface litter was collected in nine quadrates of 1 m × 1 m. Samples were weighed, sub-sampled and oven dried at 65 + 5°C to a constant weight, grounded and ashes. Corrected dry ash was assumed to contain 50 per cent of carbon. These forest types comprise of comprised of 139 species out of which 7 tree species, 26 shrub species and 106 herbs species were recorded that belong to 102 genera and 44 families. The plant species (Trees + shrubs + herbs) found under different types were recorded maximum in dry deodar forest (40) followed by dry broad-leaved and coniferous forests (34), dry blue pine forest (33), sub alpine fir forest and neoza pine forest (32), alpine pasture (23), sub-alpine birch forest (22), birch-rhododendron scrub (16) and dry alpine scrub (15). The Regeneration success was recorded maximum in dry deodar forest (58.33 %) whereas, it was minimum for neoza pine forest 27.78 per cent. Total vegetation carbon density varies significantly among different forest type. The maximum value is reported in dry deodar forest (126.12 t C ha<sup>-1</sup>) followed by dry blue pine forest (75.55 t C ha<sup>-1</sup>), sub alpine fir forest (65.05 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (64.82 t C ha<sup>-1</sup>), neoza pine forest (48.96 t C ha<sup>-1</sup>), birch-rhododendron scrub forest (39.49 t C ha<sup>-1</sup>), sub alpine birch forest (24.43 t C ha<sup>-1</sup>), dry alpine scrub (0.65 t C ha<sup>-1</sup>) and alpine pasture (0.29 t C ha<sup>-1</sup>). Total detritus carbon density varied significantly among different forest type. While, maximum detritus carbon is found in birch-rhododendron scrub forest (3.00 t C ha<sup>-1</sup>) followed by sub alpine fir forest (2.62 t C ha<sup>-1</sup>), dry broad-leaved and coniferous forests (2.03 t C ha<sup>-1</sup>), sub alpine birch forest (1.54 t C ha<sup>-1</sup>), dry deodar forest (1.29 t C ha<sup>-1</sup>), dry blue pine forest (1.20 t C ha<sup>-1</sup>), neoza pine forest (0.82 t C ha<sup>-1</sup>), alpine pasture (0.08 t C ha<sup>-1</sup>), and dry alpine scrub (0.06 t C ha<sup>-1</sup>). Total soil carbon density (humus+ soil (0-40 cm layer) varied significantly in different forest type. birch-rhododendron scrub (130.39 t C ha<sup>-1</sup>) showed maximum carbon density followed by dry broad-leaved and coniferous forests (111.18 t C ha<sup>-1</sup>), dry deodar forest (84.81 t C ha<sup>-1</sup>), sub alpine birch forest (74.76 t C ha<sup>-1</sup>), sub alpine fir forest (73.56 t C ha<sup>-1</sup>), dry blue pine forest (56.55 t C ha<sup>-1</sup>), alpine pasture (51.06 t C ha<sup>-1</sup>), neoza pine forest (45.62 t C ha<sup>-1</sup>) and dry alpine scrub (37.73 t C ha<sup>-1</sup>). However, total ecosystem carbon density varied significantly among different forest type. The highest ecosystem carbon density was displayed by dry deodar forest (212.21 t C ha<sup>-1</sup>) followed by broad-leaved and coniferous forests (178.02 t C ha<sup>-1</sup>), birch-rhododendron scrub forest (172.87 t C ha<sup>-1</sup>), dry sub alpine fir forest (141.22 t C ha<sup>-1</sup>), dry blue pine forest (133.29 t C ha<sup>-1</sup>), sub alpine birch forest (100.72 t C ha<sup>-1</sup>), neoza pine forest (95.40 t C ha<sup>-1</sup>), alpine pasture (51.42 t C ha<sup>-1</sup>), and dry alpine scrub (38.43 t C ha<sup>-1</sup>). pH in different forest type followed the trend dry broad-leaved and coniferous forests > dry deodar forest > sub alpine fir forest > neoza pine forest > alpine pasture > dry blue pine forest > dry alpine scrub > birch-rhododendron scrub forest > sub alpine birch forest. The maximum concentration of soil nutrient (N, P, K, Cu, Fe, Mn and Zn) was reported for birch-rhododendron scrub forest whereas, minimum was reported in dry alpine scrub.

**Signature of the Major Advisor**

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<b>M.Sc. (Forestry) Silviculture</b>	Dr. Y S Parmar, UHF, Nauni-173 230, Solan (HP)	2013	First
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**Research papers (in peered journals)** : 9  
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**Visits abroad along with duration** : Nil

**(Rakesh Kumar)**