

**ASSESSMENT OF FLORAL DIVERSITY AND CARBON  
STOCKS OF HIMALAYAN MOIST TEMPERATE  
FOREST IN HIMACHAL PRADESH**

*Thesis*

by

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(F-2012-28-D)**

**Submitted to**



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This is to certify that the thesis entitled, “**Assessment of floral diversity and carbon stocks of Himalayan moist temperate forest in Himachal Pradesh**” submitted in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY (FORESTRY) SILVICULTURE** of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP)-173230 is a record of bonafide research work carried out by **Mr. Milkuri Chiranjeeva Reddy (F-2012-28-D)** son of Shri. Narayana Reddy under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

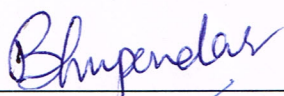
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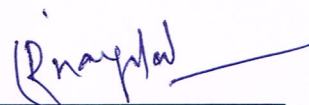
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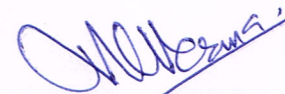


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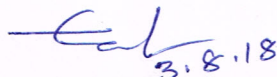
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## CONTENTS

| Chapter | Title                  | Pages   |
|---------|------------------------|---------|
| 1.      | INTRODUCTION           | 1-5     |
| 2.      | REVIEW OF LITERATURE   | 6-49    |
| 3.      | MATERIALS AND METHODS  | 50-64   |
| 4.      | RESULTS AND DISCUSSION | 65-294  |
| 5.      | SUMMARY AND CONCLUSION | 295-303 |
|         | LITERATURE CITED       | 304-343 |
|         | APPENDICES             | i-ii    |
|         | ABSTRACT               | 344     |
|         | BRIEF BIO-DATA         |         |

## ABBREVIATIONS

|               |   |                                           |
|---------------|---|-------------------------------------------|
| %             | : | Per cent                                  |
| &             | : | And                                       |
| °C            | : | Degree celcius                            |
| ABG           | : | Above ground biomass                      |
| Alt           | : | Altitude                                  |
| amsl          | : | Above mean sea level                      |
| Approx.       | : | Approximately                             |
| BA            | : | Basal Area                                |
| BD            | : | Bulk Density                              |
| BEF           | : | Biomass Expansion Factor                  |
| BGB           | : | Below Ground Biomass                      |
| C             | : | Carbon                                    |
| CD            | : | Critical difference                       |
| cm            | : | Centimetre                                |
| D             | : | Depth                                     |
| dbh           | : | Diameter at breast height                 |
| ed.           | : | Edition                                   |
| <i>et al.</i> | : | Co- workers                               |
| FRI           | : | Forest Research Institute                 |
| FSI           | : | Forest Survey of India                    |
| g             | : | Grams                                     |
| ha            | : | Hectare                                   |
| HP            | : | Himachal Pradesh                          |
| i. e.         | : | That is                                   |
| IPCC          | : | Intergovernmental Panel on Climate Change |
| IVI           | : | Importance value index                    |
| Kg            | : | Kilogram                                  |
| m             | : | metre                                     |
| Mt            | : | Metric ton                                |
| OC            | : | Organic carbon                            |
| RBA           | : | Relative basal area                       |
| RD            | : | Relative density                          |
| RF            | : | Relative Frequency                        |
| SI            | : | Similarility index                        |
| SOC           | : | Soil organic carbon                       |
| t             | : | Tonnes                                    |
| t/ha          | : | Tones/ha                                  |
| TB            | : | Tree biomass                              |
| TC            | : | Total carbon                              |
| yr            | : | Year                                      |

## LIST OF TABLES

| Table | Title                                                                                                                                                                                                                 | Page(s) |
|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 1     | Types of Himalayan moist temperate forest in Shimla district of Himachal Pradesh, their elevation ranges and delineation of E <sub>1</sub> E <sub>2</sub> and E <sub>3</sub> in each of them for their detailed study | 53      |
| 2.    | Experimental sites with their coordinates of the study                                                                                                                                                                | 57      |
| 3.    | NDVI change matrix for the years 2008 and 2013                                                                                                                                                                        | 74      |
| 4.    | Trees species under different forest types in Himalayan moist temperate forest in Shimla district (H.P)                                                                                                               | 77      |
| 5.    | Shrubs species under different forest types in Himalayan moist temperate forest in Shimla district (H.P)                                                                                                              | 78-80   |
| 6.    | Forb species under different forest types in Himalayan moist temperate forest in Shimla district (H.P)                                                                                                                | 81-85   |
| 7.    | Vegetation diversity indices for trees, shrubs and forbs in different forests under Himalayan moist temperate forest in Shimla district HP                                                                            | 88      |
| 8.    | Density, basal area, and importance value index (IVI) of trees in Ban Oak ( <i>Q. leuchotrichophora</i> ) forests at different elevations                                                                             | 93      |
| 9.    | Density, basal area, and importance value index (IVI) of trees in Moru Oak ( <i>Q. floribunda</i> ) forests at different elevations                                                                                   | 94      |
| 10.   | Density, basal area, and importance value index (IVI) of trees in Deodar ( <i>Cedrus deodara</i> ) forests at different elevations                                                                                    | 96      |
| 11.   | Density, basal area, and importance value index (IVI) of trees in western mixed coniferous forests at different elevations                                                                                            | 97      |
| 12.   | Density, basal area, and importance value index (IVI) of trees in moist temperate lower deciduous forests at different elevations                                                                                     | 99      |
| 13.   | Density, basal area, and importance value index (IVI) of trees in Kail ( <i>Pinus wallichiana</i> ) forests at different elevations                                                                                   | 101     |
| 14.   | Density, basal area, and importance value index (IVI) of trees in Kharsu Oak ( <i>Q. semecarpifolia</i> ) forests at different elevations                                                                             | 102     |
| 15.   | Density, basal area, and importance value index (IVI) of trees in upper Oak-Fir forests at different elevations                                                                                                       | 104     |
| 16.   | Density, basal area, and importance value index (IVI) of trees in upper moist temperate deciduous forests at different elevations                                                                                     | 105     |
| 17.   | Change in density and basal area of trees among forests (F) and elevations (E)                                                                                                                                        | 107     |
| 18.   | Density, basal area, and importance value index (IVI) of shrubs in Ban Oak ( <i>Q. leuchotrichophora</i> ) forests at different elevations                                                                            | 110-112 |
| 19.   | Density, basal area, and importance value index (IVI) of shrubs in Moru Oak ( <i>Q. floribunda</i> ) forests at different elevations                                                                                  | 113-115 |

| Table | Title                                                                                                                                      | Page(s) |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 20.   | Density, basal area, and importance value index of shrubs in Deodar ( <i>Cedrus deodara</i> ) forests at different elevations              | 117-119 |
| 21.   | Density, basal area, and Importance value index (IVI) of shrubs in western mixed coniferous forests at different elevations                | 120-122 |
| 22.   | Density, basal area, and importance value index (IVI) of shrubs in moist temperate lower deciduous forests at different elevations         | 123-125 |
| 23.   | Density, basal area, and importance value index (IVI) of shrubs in Kail ( <i>Pinus wallichiana</i> ) forests at different elevations       | 127-129 |
| 24.   | Density, basal area, and importance value index (IVI) of shrubs in Kharsu Oak ( <i>Q. semecarpifolia</i> ) forests at different elevations | 130-132 |
| 25.   | Density, basal area, and importance value index (IVI) of shrubs in upper Oak-Fir forests at different elevations                           | 133-134 |
| 26.   | Density, basal area, and importance value index (IVI) of shrubs in upper moist temperate deciduous forests at different elevations         | 135-137 |
| 27.   | Change in density (plants/ha) and basal area (m <sup>2</sup> /ha) of shrubs among forests (F) and elevations (E)                           | 138     |
| 28.   | Density, basal area, and importance value index (IVI) of forbs in Ban Oak ( <i>Q. leucotrichophora</i> ) forests at different elevations   | 141-144 |
| 29.   | Density, basal area, and importance value index (IVI) of forbs in Moru Oak ( <i>Q. floribunda</i> ) forests at different elevations        | 145-148 |
| 30.   | Density, basal area, and importance value index (IVI) of forbs in Deodar ( <i>Cedrus deodara</i> ) forests at different elevations         | 149-152 |
| 31.   | Density, basal area, and importance value index (IVI) of forbs in western mixed coniferous forests at different elevations                 | 154-158 |
| 32.   | Density, basal area, and importance value index (IVI) of forbs in moist temperate lower deciduous forests at different elevations          | 159-162 |
| 33.   | Density, basal area, and importance value index (IVI) of forbs in Kail ( <i>Pinus wallichiana</i> ) forests at different elevations        | 164-167 |
| 34.   | Density, basal area, and importance value index (IVI) of forbs in Kharsu Oak ( <i>Q. semecarpifolia</i> ) forests at different elevations  | 169-173 |
| 35.   | Density, basal area, and importance value index (IVI) of forbs in upper Oak-Fir forests at different elevations                            | 174-176 |
| 36.   | Density, basal area, and importance value index (IVI) of forbs in upper moist temperate deciduous forests at different elevations          | 177-180 |
| 37.   | Change in density (plants/ha) and basal area (cm <sup>2</sup> /m <sup>2</sup> ) of forbs among forests (F) and elevations (E)              | 181     |
| 38.   | Regeneration status of different forests types (F) at three different elevations (E)                                                       | 183     |



| Table | Title                                                                                                                                                                           | Page(s) |
|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 39.   | Establishment stocking per cent and regeneration success of different forests at three different elevations                                                                     | 185     |
| 40.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in Ban Oak ( <i>Q. leuchotrichophora</i> ) forests at different elevations      | 190     |
| 41.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total tree carbon (TC) of trees in Moru Oak ( <i>Q. floribunda</i> ) forests at different elevations       | 192     |
| 42.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in Deodar ( <i>C. deodara</i> ) forests at different elevations                 | 193     |
| 43.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in western mixed coniferous forests at different elevations                     | 195     |
| 44.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total tree carbon (TC) of trees in moist temperate lower deciduous forests at different elevations         | 197     |
| 45.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in Kail ( <i>Pinus wallichiana</i> ) forests at different elevations            | 199     |
| 46.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total tree carbon (TC) of trees in Kharsu Oak ( <i>Q. semecarpifolia</i> ) forests at different elevations | 200     |
| 47.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in upper Oak-Fir forests at different elevations                                | 202     |
| 48.   | Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in upper moist temperate deciduous forests at different elevations              | 204     |
| 49.   | Change in total biomass (TB) and total carbon (TC) of trees among forests and elevations                                                                                        | 205     |
| 50.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in Ban Oak ( <i>Q. leuchotrichophora</i> ) forests at different elevations             | 210-212 |
| 51.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in Moru Oak ( <i>Q. floribunda</i> ) forests at different elevations                   | 214-216 |
| 52.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in Deodar ( <i>Cedrus deodara</i> ) forests at different elevations                    | 217-219 |

| Table | Title                                                                                                                                                               | Page(s) |
|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 53.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in western mixed coniferous forests at different elevations                | 220-222 |
| 54.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in moist temperate lower deciduous forest at different elevations          | 223-225 |
| 55.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrub species in Kail ( <i>Pinus wallichiana</i> ) forest at different elevations | 226-229 |
| 56.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in Kharsu Oak ( <i>Q. semecarpifolia</i> ) forests at different elevations | 230-231 |
| 57.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in upper Oak-Fir forest at different elevations                            | 232-234 |
| 58.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in upper moist temperate deciduous forests at different elevation          | 235-237 |
| 59.   | Change in total biomass (TB) and total carbon (TC) of shrubs among forests (F) and elevations (E)                                                                   | 238     |
| 60.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Ban Oak ( <i>Q. leuchotrichophora</i> ) forests at different elevations  | 241-245 |
| 61.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Moru Oak ( <i>Q. floribunda</i> ) forests at different elevations        | 246-249 |
| 62.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Deodar ( <i>Cedrus deodara</i> ) forests at different elevations         | 251-254 |
| 63.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Western mixed coniferous forests at different elevations                 | 255-259 |
| 64.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in moist temperate lower deciduous forests at different elevations          | 260-263 |
| 65.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forb species in Kail ( <i>Pinus wallichiana</i> ) forests at different elevations | 265-268 |
| 66.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Kharsu Oak ( <i>Q. semecarpifolia</i> ) forests at different elevations  | 269-273 |

| Table | Title                                                                                                                                                                                                | Page(s) |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 67.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Upper Oak-Fir forests at different elevations                                                             | 274-277 |
| 68.   | Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in upper moist temperate deciduous forests at different elevations                                           | 279-281 |
| 69.   | Change in total biomass (TB) and total carbon (TC) of forbs among forests (F) and elevations (E)                                                                                                     | 282     |
| 70.   | Change in Soil bulk density ( $\text{g/cm}^3$ ) among forests (F) and elevations (E)                                                                                                                 | 286     |
| 71.   | Change in soil organic carbon (SOC %) among forests (F) and elevations (E)                                                                                                                           | 288     |
| 72.   | Change in soil organic carbon stocks ( $\text{t/ha}$ ) among forests (F) and elevations (E)                                                                                                          | 290     |
| 73.   | Timber volume, aboveground biomass of vegetation, total biomass of vegetation, total carbon stock in vegetation and total carbon stock in Himalayan moist temperate forests of Shimla district (HP). | 293     |

## LIST OF FIGURES

| Figure | Title                                                                                                                              | Page(s) |
|--------|------------------------------------------------------------------------------------------------------------------------------------|---------|
| 1.     | Boundary of Himachal Pradesh along with Shimla district                                                                            | 51      |
| 2.     | Flow chart of preparing cartographic maps using remote sensing and GIS                                                             | 55      |
| 3.     | Data used in the study (A: SRTM-DEM, B: LISS III image of 2008, C: LISS III image of 2013 and D: Forest types map (FTM) of Shimla) | 56      |
| 4.     | Location of experimental sites in different forest types across Shimla district                                                    | 58      |
| 5.     | Digital elevation model of Shimla district (HP) and elevation classes from 400 to 5600 m amsl in it                                | 66      |
| 6.     | Distribution of Ban Oak forests in Shimla district                                                                                 | 67      |
| 7.     | Distribution of Moru Oak forests in Shimla district                                                                                | 67      |
| 8.     | Distribution of Deodar forests in Shimla district                                                                                  | 69      |
| 9.     | Distribution of western mixed coniferous forests in Shimla district                                                                | 69      |
| 10.    | Distribution of moist temperate lower deciduous forests in Shimla district                                                         | 70      |
| 11.    | Distribution of Kail forests in Shimla district                                                                                    | 70      |
| 12.    | Distribution of Kharsu Oak forests in Shimla district                                                                              | 71      |
| 13.    | Distribution of upper Oak-Fir forest in Shimla district                                                                            | 72      |
| 14.    | Distribution of moist temperate upper deciduous forests in Shimla district                                                         | 72      |
| 15.    | NDVI of vegetation in Shimla district for the years 2008 (A) and 2013 (B) developed by using LISS III imagery                      | 73      |

# *Chapter-1*

## **INTRODUCTION**

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Forests are as old as the universe and as such have been growing and renewing them naturally since time immemorial. It is a fact that forests preceded civilization in every part of the world. These extensive, complex and biologically productive entities have been clear felled and exploited to meet the food, timber and other multipurpose requirements till the recent past. But now forests are one of the most important capital and are valued for its ecological, aesthetic services and as well as for its economics. Consequent to ever increasing population and development activities many species are facing extinction. The worldwide loss of biodiversity is an indication of indiscriminate human exploitation of natural resources (Savard *et al.* 2000). Human disturbances in forests through selective logging, wood extraction, grazing, fire and land clearing for permanent agriculture may influence many plant communities and their succession patterns (Hong *et al.* 1995; Fujisaka *et al.* 1998). Long-term changes in patterns and processes in forest systems may lead to losses in their biological diversity (Gairola *et al.* 2008; Hobbs and Huenneke 1992).

The mountain ecosystem harbours a wide variety of significant natural resources and plays an important role in the ecological and economic process on the earth. The mountain ecosystem is a separate and distinct ecosystem which is a rich repository of biological diversity and carbon sink (Chandrashekhar *et al.* 2003). The Indian Himalayan region is complex and dynamic ecosystem which provides different ecosystem services (Khan *et al.* 2012). This young mountain chain system not only gauge climate of the region but also provide life, give water to a large part of the Indian subcontinent and harbor a rich biological and cultural diversity (Singh 2006) constituting one of the richest and most unusual ecosystems on earth (Salick *et al.* 2009). The presence of different unique ecological niches in this montane system are due to the varying altitude, topographic, and climatic conditions (Mani 1978) covering about 12.84% of the total geographical area of India (Negi 2009). Himalayan forests are considered to be among the world's most depleted forests (Schickhoff 1995), 23% loss of forest cover was recorded in western Himalayas alone (FSI 2005). The plant community structure and distribution pattern of Himalayan forests, one of the most biologically rich and ecologically productive ecosystems, are poorly understood (Peer *et al.* 2007; Sharma *et al.* 2010a; Dar and Sundarapandian 2015 a & b).

Structure of an ecosystem is primarily the physiognomy and composition of vegetation and, its quantitative analysis is a key factor in describing structure, composition and organization (Kukshal *et al.* 2009). The vegetation dynamics of a forest system is controlled by factors like, available pool of species, growth habit of species, physical characteristics of the land, soil fertility, climate, management practices and more importantly disturbance regimes (Graham *et al.* 1992; Unruh 1993; Gauthier *et al.* 2000; Niu and Duiker 2006; Jana *et al.* 2009; Weifeng *et al.* 2011; Yadav *et al.* 2016). Floristic evaluations are very useful for identifying spatial patterns in plant diversity and composition, and when combined with environmental, geological and historical variables, can provide important information on the processes that maintain high level of species diversity.

Biodiversity is expressed at genetic, species and landscape levels. Though biodiversity expressed at species level is generally appreciated the understanding at the landscape level has been given emphasis globally in the current scenario of excessive forest degradation and enhancing global warming. Species diversity incorporates two components: evenness and richness. Species richness of any community is a function of severity, variability and predictability of the environment in which it develops (Slobodkin and Sanders 1969). At large scales, species diversity is related to climate and forest productivity (Rahbek 2005). Increased species richness in plant communities frequently results in increased aboveground and belowground productivity, which in turn is a measure of their success that is strongly affected by biotic and abiotic factors. Topography, soil, climate and geographical location of a region influence the vegetation diversity of the forest ecosystem (Ramsay and Oxley 1997).

Natural regeneration is essential for preservation and maintenance of biodiversity and is fundamental for evolution of forest ecosystems (Ackzel 1994). Knowledge about the pattern of natural regeneration is important to answer the basic question of forest management (Hossain *et al.* 1999). Regeneration of different species in the natural forest reacts differently under different environment or at different times in the same environment. Regeneration may be promoted by certain types of forest manipulation that can lead intentionally to new and more productive stages of forest growth.

Understanding floral diversity is fundamental for designing different management plans and plays a key role in policy making. (Loreau *et al.* 2001; Fetene *et al.* 2006; Muhumuza and Bysrugaba 2009). Works on phytosociology, diversity and regeneration

status of different forest types of the western and central Himalaya has been carried out by Saxena and Singh (1982), Singhal *et al.* (1986), Singh and Singh (1986), Rawal and Pangtey (1994), Singh *et al.* (1994), Baduni (1996), Baduni and Sharma (1996), Dhar *et al.* (1997), Ghildiyal *et al.* (1998), Ram *et al.* (2004), Kumar and Ram (2005), Sharma *et al.* (2001, 2009a, 2009, 2009c, 2010a, 2010b, 2010c, 2010d), Gairola (2010), Gairola *et al.* (2012), Gupta and Sharma (2015), Gupta *et al.* (2015) and Mehta *et al.* (2015) in the past. Many studies have described altitudinal variation in vegetation type (Adhikari *et al.* 1992) and related it to habitat heterogeneity, biotic interaction, climate and history (Givnish 1999; Currie and Francis 2004; Gonzalez *et al.* 2004; Gupta *et al.* 2015).

Another important significance of plant diversity is carbon dynamics. Knowledge of biomass carbon densities for different forest types is one of the important components for assessing the contribution of forests to mitigate global climate change. A functional relationship between diversity and carbon sequestration could play an important role for the management of carbon sink, for reforestation/afforestation projects and for emission reduction projects that focus on forests as one of the major pools of carbon in terrestrial ecosystems and their role in mitigation of climate change (Nabuurs *et al.* 2007). As trees grow, they sequester carbon in its biomass. About 43 -50 % of the dry biomass of trees consists of carbon (Malhi *et al.* 2002; Negi *et al.* 2003). 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 (UNFCCC). The carbon stock in a forest ecosystem can be broadly categorized as biotic (vegetation carbon) and pedologic (soil carbon) components. (Brown, 2004).

Soil is the largest terrestrial carbon reservoir, stores almost three times the amount of carbon in the vegetation and approximately double that in the atmosphere (Eswaran *et al.* 1993). Soil play a key role in the global carbon budget and can have large impact on carbon releases under climate change scenario (Lal *et al.* 1995). Soil organic matter and organic carbon is an important component of soil quality and productivity (Franzluebbers *et al.* 1995; Bezdicek *et al.* 1996).

Himachal Pradesh, one of mountainous state in Indian Himalayan region, is spread across parts of trans-Himalayan zone and north-west Himalayan region between 30°22'40" to 33°12'40" N latitudes and 75°45'55" to 79°04'20" E longitudes encompassing total geographic area of 55,673 km<sup>2</sup> with 27.12 % of forest cover (FSI 2017). The state is

represented by tropical, temperate, sub-alpine and alpine vegetation. The richness and diversity in flora of the state can be imagined from the fact that, out of total 45,000 species found in the country as many as 3,295 species (7.32%) are reported in the state of which more than 95% of the species are endemic to Himachal Pradesh. Shimla district forms a part of southern Himachal Pradesh situated between the longitudes 76°59'22" and 78°18'40" east and latitudes 30°45'48" and 31° 43' 0" north and it is characterized by high mountains, deep and narrow valleys and river basins. The district has an area of 5,131 sq. kms. The elevation of the district ranges from 300-6,000 meters above mean sea level in the district encompassing number of peaks such as Jakhoo, Siah, Churdhar, Chansal, Hattoo and others. Shimla district is covered by the catchment area of the rivers Satluj, Pabbar and Giri.

The vegetation in the district is dominated by Himalayan moist temperate forest. The chief characteristics of this type of forests is extensive development of coniferous forests. The number of dominant species is small, in fact, more or less pure crops or two species mixtures are the commonest form, the occurrence of species is governed by altitude and aspects. The conifers generally form a fairly dense forests with good height of 24 to 46 m. All species are capable of attaining considerable girth up to 4.5 m or more. The chief coniferous species are *Pinus wallichiana*, *Cedrus deodara*, *Picea smithiana* and *Abies pindrow*. *Taxus* also occurs locally in the lower canopy. Among the broadleaved trees, the genus *Quercus* with different species is prominent and its commonest associate is *Rhododendron arboreum*. The temperate deciduous tree genera like, *Acer*, *Aesculus*, *Prunus*, *Ulmus* etc. are met fairly and form local associations.

Like other states of the Indian Himalayan region, the biodiversity in Himachal Pradesh, in general, and that of Shimla district is facing tremendous pressure due to anthropogenic activities coupled with global climate change. Moreover, there are many biodiversity rich catchments in the state which are unexplored with regard to floristic diversity and carbon stocks. Therefore, it is pertinent to study the biodiversity, regeneration and productivity of such unexplored areas and develop appropriate management plan for conservation.

The conventional methods for collection of information on phyto-diversity and carbon stocks alone are costly and time consuming. Thus, the state of art technology in the form of Geographic Information System (GIS) has become cost effective tool in collecting information of vegetation on large scale in short time especially inaccessible distant areas of



forest. It is being used in decision making policies about resources; doing planning and management of resources and updating resource inventories (ESRI 2003). Along with other technologies such as Remote Sensing (RS), Global Positioning System (GPS) and other information, communication technologies; the GIS tool has become common in forest investigations.

With this background the present investigation was framed to explore ‘Himalayan moist temperate forest’ in Shimla district of Himachal Pradesh for their floristic diversity, biomass production carbon stocks, regeneration status and soil properties with the following objectives:

- i) Assessment of floral diversity and regeneration of Himalayan moist temperate forest in Himachal Pradesh.
- ii) Assessment of carbon stock of Himalayan moist temperate forest in Himachal Pradesh.

## *Chapter-2*

# REVIEW OF LITERATURE

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In this chapter, the relevant information related to the present study entitled **“Assessment of floral diversity and carbon stocks of Himalayan moist temperate forest in Himachal Pradesh”** has been reviewed as under the following heads:

- 2.1 Floristic diversity
- 2.2 Regeneration
- 2.3 Biomass carbon stocks
- 2.4 Soil carbon stock
- 2.5 Use of remote sensing and GIS in floristic studies

### **2.1 FLORISTIC DIVERSITY:**

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.

Bhuyan *et al.* (2003) studied the tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. Tree species richness varied along the disturbance gradient in different stands. The mildly disturbed stand showed the highest species richness (54 of 51 genera). Species richness was lowest (16 of 16 genera) in the highly disturbed stand. In the undisturbed stand, 47 species of 42 genera were recorded while in the moderately disturbed stand 42 species of 36 genera were found. The Shannon Wiener diversity index for tree species ranged from 0.7 to 2.02 in all the stands. The highest tree diversity was recorded in the undisturbed stand and the lowest in the highly disturbed stand. Fagaceae, Dipterocarpaceae and Clusiaceae were the dominant families

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%, 13% and 3.94%, respectively. However, with the increase in elevation, the proportion of genus *Tsuga longibracteata* in the floristic composition decreased.

Singh (2004) conducted phytosociological survey at Shimla, Himachal Pradesh. 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 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% of the total tree density in respective stands. Asteraceae, Euphorbiaceae, Lauraceae, Meliaceae and Rubiaceae were the dominant families.

Rodal *et al.* (2005) carried out study in Northeastern upland forest of Pernambuco, Brazil and observed that the humid forests show higher richness of species and has more floristic similarity with the lowland humid forests. 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 was richness is related to type of communities.

Kumar *et al.* (2006) studied the tree species diversity and distribution patterns in tropical forests of Garo Hills, Western Meghalaya, and Northeast India. They found that the

main vegetation of the region included primary forests, secondary forest and Sal (*Shorea robusta*) plantations, with 162, 132 and 87 tree species respectively. Primary forests were more tree-rich and diverse than secondary forests or Sal plantations. The Shannon-Wiener values for tree species diversity were 4.27, 3.78 and 2.47 for primary forests, secondary forests and Sal plantations respectively.

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 Bashla forest. 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. They reported 40 plants under 7 plant formations. The results indicated that the spatial distribution of tree species was mainly controlled by altitude, soil fertility and biotype humidity.

The study conducted by Zhu and Li (2006) on species composition and biogeography revealed that the mountain rain forests of southern Yunnan China has similar diversity to the lowland rain forest 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 West Himalaya, reported a total 337 species of economic importance, belonging to 111 families and 260 genera. Of these, there were 75 tree species, 69 shrub species and 193 herbs (including 7 species of pteridophytes).

Devi and Yadava (2006) studied the floristic diversity of *Dipterocarpus tuberculatus* dominated forest of Manipur situated along the Indo-Myanmar Border, north-eastern India. A total of 123 species belonging to 48 families were recorded. The quantitative features such as density and importance value index of species varied greatly. In the present study the diversity index of shrubs and herbs were found to be higher than the tree species. The concentration of dominance was recorded highest in the tree species. They suggested that

presence of low number of higher girth class of tree species and higher number of the saplings and seedlings indicates that the forest is young exhibiting frequent regeneration.

Shrestha *et al.* (2007) studied distribution and community structure of treeline 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%), 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) studied the structure, composition, diversity, and regeneration status of different forest types in a moist temperate region of Garhwal, India and revealed that overall diversity increased in *Pinus*-dominated sites which were characterized by more-open canopies (canopy cover < 20%) with scattered trees interspersed with young trees, shrub and herb species compared to *Quercus* forests with a dense crown cover (> 65%). Their study confirmed the direct proportional relationship between tree cover and the diversity of sub-stratum vegetation. 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 with 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 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.

Krishnamurthy *et al.* (2009) studied the floristic diversity of Bhadra Wildlife Sanctuary in the central western Ghats region, Karnataka. A total of 406 species, 294 genera

belonging to 98 families were recorded. *Xylia xylocarpa* form the denser species among the trees in the sanctuary with a total of 614 trees/30 transects ( $D=20.47$  trees/transect) while *Ichnocarpus frutescens* (76 individuals,  $D=2.53$ ) and *Stachytarpetta indica* (79 individuals,  $D=2.68$ ) were dominant among climbers and herbs respectively. The study also recorded a very good Shannon-Wiener and Simpson diversity index of 3.4 and 16.84 for trees, 3.57, 26.14 for climbers and 3.9, 40.2 for herbs. 12 species were designated under endangered threat category while 56 were remarked as endemic to western Ghats and 106 species as rare. Over 234 plant species were commonly distributed in the sanctuary.

Sharma *et al.* (2009) compared different forest association along the altitudinal gradient based on species richness, species diversity and dispersion behaviour 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 (indv./100 m<sup>2</sup>), 1.8 to 21.7 indv./25 m<sup>2</sup>, and 28.1 to 103.7 indv./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.

Tripathi *et al.* (2010) studied the diversity, dominance and population structure of tree species along fragment-size gradient of a subtropical humid forest in Meghalaya. Altogether 103 tree species were recorded from studied forest fragments. Lauraceae and Fagaceae were the most species-rich families followed by Araliaceae, Symplocaceae and Theaceae They found that the intensity of disturbance steadily decreases with increase in size of the fragment and tree species richness increased from 49 species in 1 hectare fragment to 64 species in >5 hectare fragment. Diversity and dominance indices did not vary much along the fragment size

gradient. Out of ten most dominant species, dominance of four species decreased along increasing size gradient while dominance of remaining species consistently decreased from 1 hectare to >5 hectare fragments. Overall tree population structure was pyramid shaped in all the fragments.

Sobuj and Rahman (2011) while studying the diversity of plant species (trees, shrubs and herbs) in Khadimnagar National Park of Bangladesh 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 (3.03/100m<sup>2</sup>), frequency (76.67%), relative density (17.7%), relative frequency (11.3%) and relative dominance (37.3%). On the contrary, *Alstonia scholaris* represented the lowest density (0.07/100m<sup>2</sup>), frequency (6.67%), relative density (0.39%) and relative frequency (0.99%). The study revealed that lowest relative dominance was found for *Sterculia villosa* (0.14%). However, species with the highest abundance was calculated for *Chickrassia tabularis* (4.58) whereas the lowest was recorded for *Alstonia scholaris*, *Cynometra polyandra*, *Sterculia villosa* (1). The study indicated that 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 (1.03/4m<sup>2</sup>) and frequency (50%). In contrast, lowest density (0.08/4m<sup>2</sup>) and frequency (8.33%) 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 (1.03/4m<sup>2</sup>). On the other hand, lowest density was measured in *Seseli indicum* (0.1/4m<sup>2</sup>). The calculation depicted that *Eryngium foetidum* had the highest frequency (45%) and the lowest was in *Seseli indicum* (8.33%). The species with the highest abundance was *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 forests in 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 highest (9) at site-V and lowest (2) at site-I and II, respectively.

Joshi (2011) studied vegetation structure, floristic composition and soil nutrient status in three sites of Tropical dry deciduous forest of West Bengal. A total 77 of woody individuals ( $\geq 1\text{cm dbh}$ ) 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  $\text{ha}^{-1}$  and basal area ranged from 7.66 – 19.55  $\text{m}^2 \text{ha}^{-1}$ . 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.

Ahmed (2012) analysed the forest vegetation in Ranikhet, Kumaon Himalayas, Uttarakhand. He studied the floristic composition and distribution pattern of the different plant species with reference to density, IVI (Importance Value Index), diversity index and the structural characteristics of tree and shrub communities in a moist temperate forest. He found that the oak-pine forest in the study area is dominated by Banj Oak (*Quercus leucotricophora*) in tree layers and is regarded as the climax species. Four major tree associations are recognized in this forest type: a) Oak forest, b) Oak-pine forest, c) Oak-scrub, d) chirpine forest. Phytosociological characteristics differed among different tree species. The Oak-pine forest had the highest species richness and also exhibited the highest species diversity of 0.838. The tree density was found to be 136.1/ha. The concentration of dominance varied between 0.237 and 0.561. The highest was recorded in the chirpine forest.

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.



Viraj *et al.* (2012) examined the floristic diversity along the altitudinal gradient of 3,300 to 5,000 m 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 atosanguinea* in 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.

Sharma *et al.* (2014) studied floristic diversity and changing pattern of vegetation due to various biotic and abiotic factors in Sangla valley of northwest Himalaya, 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. 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 individual/m<sup>2</sup>. 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 above msl 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, Polygonaceae, Lamiaceae, Scrophulariaceae and Ranunculaceae. The number of shrub species was 5 and 4 at elevation of 3700-4200m and 4200-4700m with the dominance of *Juniperus indica* at both the elevation. The number of herbs species was 81 and

62 at 3700-4200m and 4200-4700m with the dominance of *Thymus linearis* at both the elevation. 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.

Rana and Kapoor (2015) studied floristic diversity in Shimla Water Catchment Sanctuary of Himachal Pradesh. A total of 476 species of vascular plants were recorded. Of the total species, 39 species were trees, 81 shrubs, 320 herbs and the remaining 36 species were pteridophytes. Maximum species belonged to family Asteraceae (45 spp.); Lamiaceae (31 spp.) and Poaceae (30 spp.) and 39 families were monotypic.

Verma (2016) studied the plant diversity along an altitudinal gradient with elevations varying from 2200-2600m above msl 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 2200-2400 m and 2400-2600 m 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 and 2400-2600 m 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.

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.

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)

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 revealed that altitudinal range of the different sites varied between 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. Total 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 bouldary 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 458 identified species belong to 117 families and 251 genera, of which 94.10% are phanerogams (Angiosperms: 421 species (spp.) and Gymnosperms: 10 spp.) and 5.90% 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 *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) carried study on floristic composition and natural regeneration status of chir pine forests in Sirmaur district of Himachal Pradesh. The 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 for chir pine tree species. 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 individuals 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 individuals 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

Forest resources are renewable only because they regenerate (Poorter & Arets 2003). Regeneration is the process of sylvigenesis (meaning forest building) by which trees and forest survive over time. The pace at which the older trees are replaced by the younger ones is very important; therefore, regeneration dynamics forms a major thrust area of the study in the management on natural forests (Halle *et al.* 1978; Coates 2002).

Rikhari *et al.* (2000) studied the regeneration status of *Taxus baccata* in Jageshwar area in Kumaon Himalayas, revealed that the poor regeneration of *Taxus baccata* was not only due to excessive harvesting and removal, but also due to other factors like extremely slow growth, poor seed production and germination, unrestricted grazing, accumulation of raw humus, unsatisfactory light conditions, warm and dry summers & chilling temperature in winters etc.

Glaz and Zajackowski (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 the distribution and growth of natural regeneration of *Picea alba* and *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 were already present as the gap formation was predominant. Thus saplings established before gap formation can play an important role in gap refilling.

Sharma and Raj (2004) assessed the status of natural regeneration of *Juniperous macropoda* in Ladakh. They reported that 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 very poor natural regeneration.

Singh (2004) studied natural regeneration of *Cedrus deodara* in different periodic blocks in Koti forests of Himachal Pradesh 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 above sea level. the results were attributed to the grazing which affected the distribution pattern by inhibiting regeneration and establishment.

Balwant *et al.* (2007) in a study provided ecological information on the phenology, relative density and average height, regeneration, conservation and management status of *Cedrus deodara*, *Pinus roxburghii* and *Quercus leucotrichophora* in western Himalaya. The 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 areas in Himachal Pradesh and 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 forests of Himachal Pradesh where a maximum 33.11 per cent established stocking in 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 Forests 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.

Shrestha *et al.* (2007) studied distribution and community structure of treeline birch (*Betula utilis*) forest in a trans-Himalayan dry valley of Manang (central Nepal) with the major focus on regeneration. Regeneration was assessed by a density–diameter curve. *Betula utilis* was regenerating well, as evident from a reverse J-shaped density–diameter curve for

both forests. However, the distribution of seedlings and saplings was spatially heterogeneous and appeared to depend on canopy cover. The stands with highest seedling and sapling densities of *Betula utilis* had no trees. *Betula* seedlings were absent where the tree density and basal area exceeded 20 stems/100 m<sup>2</sup> and 1.0% respectively. It was apparent that *Betula* seedlings could not establish under their own closed canopy even if they produced viable seeds. Partial canopy opening may induce seedling establishment and hence continuous regeneration of *Betula utilis* at mature stands.

Semwal *et al.* (2008) studied structure, composition, diversity, and regeneration status of different forest types in a moist temperate region of Garhwal, India and 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 through grasses is 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 was observed for *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.

Group selection tree harvest system has been proposed as an ecologically sustainable silvicultural technique in mixed conifer forests of the western Bhutan Himalayas. To evaluate this silvicultural technique, the ecological consequences of a group selection tree harvest in mixed conifer forests were studied by assessing 127 circular plots (71 in logged and 56 in unlogged stands) in two forest management units (FMUs). Tree species composition and

diversity were similar between logged and unlogged stands. Seedling density and height growth vary by species and were influenced by logging and microsites, with generally taller seedlings found in the logged versus unlogged stands. Early successional shade-intolerant species colonized logged stands. Seedlings growing on bare soil scarified by harvesting had medium vigour while seedlings growing on bryophyte mats showed good vigour in both logged and unlogged stands. Moist sites with a northerly aspect supported profuse conifer seedling regeneration, compared to sites with a dry southerly aspect. Damage to conifer seedlings from herbivore browsing was minimal. Conifer seedling density and height growth was negatively affected by competition from herbaceous vegetation, most notably *Salvia officinalis*. Group selection tree harvest in southern dry exposures in spruce-dominated stands is silviculturally unsuitable because it alters tree succession. (Moktan *et al.* 2009)

Sharma *et al.* (2010) studied the natural regeneration of *Pinus gerardiana* in dry temperate forest of Kinnaur and reported that 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* forest only *Acacia catechu* was co-dominant species, whereas, in *Anogeissus latifolia* forest the associated species were *Acacia catechu*, *Lannea coromandelica*, and *Embllica 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 *et al.* (2012) compared the vegetation of chir pine forest and 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 were 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) in their 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. *Cedrus deodara* community had highest density of trees (1468 individual ha<sup>-1</sup>), seedlings (1290 individual ha<sup>-1</sup>) and saplings (1172 individual 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 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 density of seedling, sapling and adults of 6050 individuals ha<sup>-1</sup>, 258 individual ha<sup>-1</sup> and 211.25 individual ha<sup>-1</sup>, respectively.

Singh *et al.* (2016) studied the diversity and regeneration status of some oak forests in Garhwal Himalaya, India. A total of 18 tree species belonging to 16 genera and 12 families were reported from the study area. Species richness varied for trees (4–7), saplings (3–10), and seedlings (2–6). Seedling and sapling densities (Ind/ha) varied between 1,376 Ind/ha and 9,600 Ind/ha and 167 Ind/ha and 1,296 Ind/ha, respectively. Maximum tree species (20–80%) had good regeneration. *Quercus floribunda*, the dominant tree species in the study area, showed poor regeneration along with other tree species that show poor or no regeneration.

Kumar *et al.* (2016) conducted studies on Regeneration complexities of *Pinus gerardiana* in dry temperate forests of Indian Himalaya region in Kinnaur District of Himachal Pradesh, India. *P. gerardiana* regeneration success is lower than the requirement of sustainable forest, but varies widely among sites in the dry temperate forest of Himalayas. Results suggest that in different forests, regeneration success that are 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 founded that per cent regeneration ranged from 30-67.50 in Chail wildlife sanctuary. Regeneration was satisfactory in chir (65%) and deodar forest community (67.50%), but deodar + chir (30%), chir + oak (32.50%), mixed (40%), oak (42.50) forest communities had poor regenerated. Chir 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 was 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 (C) was used to differentiate three layers of a species into adults (C > 31.5 cm), saplings (C 10.5–31.4 cm) and seedlings (C < 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%), saplings

(6.80%) and seedlings (92.30%) in both the forests indicated a good regeneration status in general.

### 2.3. BIOMASS AND CARBON STOCKS

Rana *et al.* (1989) studied plant biomass and net primary productivity of a series of forests located along an altitudinal gradient (300–2200 m) in the Central Himalaya. The climate in most of the area is humid with the monsoon pattern of rainfall. The biomass ranged between 199 and 787 t ha<sup>-1</sup>, the lower values being for early successional forests, such as *Pinus roxburghii* forest. The net primary productivity was in the range 12.8–27.9 t ha<sup>-1</sup> year<sup>-1</sup> and was not related to the elevation. In fact the entire elevational range seems to have the potential to support high biomass and productivity values.

Saha and Saxena (1990) studied the productivity of herbage under different trees species and contended that contribution of grasses and sedges in *Quercus leucotrichophora* was around 90 per cent and further reported that *Themeda anathera* contributed 50 per cent of the aboveground biomass in *Pinus roxburghii*.

Singh *et al.* (1994) studied the tree species diversity and biomass and reported that maximum values for forest biomass remained high 500-600 mg/ha up to 2600m elevation but declined at high altitude forest (170 mg/ha) above 3100 m.

Chhetri *et al.* (1995) studied the phytosociological and biomass of standing crop in three different forest type in Teesta sub-catchment area in Namthang-Nagi region in South-Sikkim. They recorded the average standing biomass of ground vegetation (herbs and shrubs including tree seedlings) in three forest types sites were: 8.2t/ha, 1.8t/ha and 16.42t/ha, respectively.

Adhikari *et al.* (1995) studied the structure and functioning of three different forest communities, viz., horse chestnut, silver fir and kharsu oak forests, in a high altitude region of Central Himalaya. Total vegetation biomass was 505 t ha<sup>-1</sup> in horse chestnut, 566 t ha<sup>-1</sup> in silver fir and 593 t ha<sup>-1</sup> in kharsu oak forests, of which maximum contribution was by tree layer followed by shrub, herb, sapling and seedling layers. The forest floor litter biomass was 2.1, 4.7 and 4.2 t ha<sup>-1</sup> in horse chestnut, silver fir and kharsu oak forests, respectively. The total litter fall was 7.3, 6.7 and 9.4 t ha<sup>-1</sup> year<sup>-1</sup>, of which leaf litter contributed 48, 39 and 64% in horse chestnut, silver fir and kharsu oak forests, respectively. Turnover rate of tree

litter was 0.80 in horse chestnut, 0.61 in silver fir and 0.71 in kharsu oak forests. Net primary production of total vegetation was 19.6, 18.9 and 24.9 t ha<sup>-1</sup> year<sup>-1</sup>, of which tree layer contributed maximum proportion followed by herb, shrub, sapling and seedling layers.

Garkoti and Singh (1995) studied described the biomass and net primary productivity of the forests of Central Himalaya occurring in areas where vegetation ranges from close canopy broad leaved forest to stunted open canopy timberline vegetation. The forests studied were *Acer cappadocicum* forest at 2750 m, *Betula utilis* forest at 3150 m, and *Rhododendron campanulatum* forest at 3300 m altitude in Central Himalaya. With the rise in altitude the forest biomass decreased from 308.3 ton/ha in *Acer* forest to 40.5 ton/ha in *Rhododendron* forest. The decrease in net primary productivity was less steep, from 19.6 ton/ha/yr in *Acer* forest to 10.0 ton/ha/yr in *Rhododendron* forest. The production efficiency of leaves (net production per unit leaf weight) in these forests is higher than in low altitude broad leaved forests of Central Himalaya, i.e. from 2.89 in *Acer* forest to 3.41 g net production/g leaf biomass/yr, against 0.81g 1.55 at lower altitudes.

Lal and Singh (2000) reported that new plantations have significantly high biomass productivity value as compared to natural forests and fully developed plantations. The biomass of 25 years old plantations is estimated to be twice 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 been to remove at least 0.125 G t CO<sub>2</sub> from the atmosphere in the year 1995.

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).

Goodale *et al.* (2002) studied forest sector carbon budgets for Canada, U.S.A., Russia, China and Europe and concluded 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.

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.

Forests play an important role in global carbon cycling, since they are large pools 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).

Raizada *et al.* (2003) estimated the rate of carbon flux in selected planted 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 planted 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>.

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 plants 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 management of 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).

Jha and Gupta (2005) studied carbon dynamics in states of Haryana and Punjab, Jammu & Kashmir and Uttar Pradesh of India. He found that 162.49 mt of carbon sink in forests of these states. A study was conducted by Minj (2008) in low & mid hills of western Himalaya during year 2004-06 revealed that mean biomass carbon stock & CO<sub>2</sub> sequestration in Zone-I (sub montane low hills) was found to be 2.09 times higher than Zone-II (mid hills). Maximum mean total carbon stock (107.00 t ha<sup>-1</sup>) was observed in pure plantation system of poplar at an average density of 1066 trees/hectare. It was 2.68-4.86 times higher than other perennial plant based system and about 12.40- 22.57 times higher than annual crops or pure grassland system. It was followed by AS in Zone-I, whereas, SP in Zone-II both having poplar as woody perennial. Quantification of carbon fluxes in tropical deciduous using satellite data was done by Prasad *et al.* (2000). The average mean carbon storage was found to be 64.34 t/ha C for deciduous forests, 129.0 t/ha C for mixed dry deciduous and 0.02 t/ha C for mixed scrub forests.

There are three principle 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 this 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 are found to give high goodness of fit and low percentage of errors for deciduous forests. Generally, the coefficient of determination ( $R^2$ ) was low for evergreen forests, probably due to presence of trees of different height in different canopies that may have different growth rates. The coefficient of determination was high and estimate of error was low for deciduous forests.

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 eucalypt 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 eucalypt bund planting, 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 million ha, 4327.99 million m<sup>3</sup>, 2398.19 metric tons and 1085.06 metric tonnes, respectively in 1984 and with the reduction in forest area, 63.34 million ha, in 1994, wood biomass (2395.12 metric tonnes) and carbon stock (1083.69 metric tons) 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 metric ton carbon was lost during 1984-1994 and 21.35 metric ton carbon during 1991-94 at a rate of 2.48 metric ton yr<sup>-1</sup> and 5.35 metric ton yr<sup>-1</sup> carbon, respectively.

Sanneh (2007) worked on 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 ( $308.96 \text{ t ha}^{-1}$ ), below ground biomass ( $62.09 \text{ t ha}^{-1}$ ) and total biomass ( $371.06 \text{ t ha}^{-1}$ ) 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 ( $\text{t ha}^{-1}$ ) 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  $106.31 \text{ t ha}^{-1}$ ,  $113.19 \text{ t ha}^{-1}$ , and  $141.41 \text{ t ha}^{-1}$ , 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  $\text{ha}^{-1}$ ) 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  $1111 > 833 > 625 > 500 \text{ stems ha}^{-1}$ , and by components was stem > root >> branch > leaf for all plantations. At 10 years, the highest total biomass in the plantation of 1111 stems  $\text{ha}^{-1}$  reached about  $146 \text{ t ha}^{-1}$ , 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  $\text{ha}^{-1}$ , 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.

Thakur *et al.* (2007) studied the structural attributes i.e. density, basal area, aboveground biomass (branchwood and leaves and twigs) and belowground biomass of shrubs and herbaceous vegetation under agri-silviculture (AS), pastoralsilviculture (PS) and pastoral-silvi-horticulture (PSH) in Kuthar forest range in Himachal Pradesh and contended that *Murraya koenigii* contributed maximum to the total biomass production in AS ( $3181.32 \text{ kg/ha}$ ) and PS system ( $8975.50 \text{ kg/ha}$ ). While, *Carissa carandus* was dominant in PSH system ( $1484.64 \text{ kg/ha}$ ). PS system recorded maximum biomass per hectare ( $17650.92 \text{ kg/ha}$ ). *Panicum maximum* in AS system and *Chrysopogon montanus* was dominant under PS and PSH system on the basis of density and basal area. The total aboveground and



belowground biomass production from herbaceous vegetation was recorded maximum in PS system (4355.24 kg/ha) followed by AS system (3688.80 kg/ha) and PSH system (3473.44 kg/ha).

Minj (2008) found that in low and mid hills of western Himalayan during year 2004-06 the mean biomass carbon stock and CO<sub>2</sub> sequestration in Zone-I (Sub mountain low hills) was 2.09 times higher than in Zone-II (mid hills). Maximum mean total carbon stock (107.00 t ha<sup>-1</sup>) was observed in pure plantation system of poplar at an average density of 4,066 t ha<sup>-1</sup>. It was 2.68-4.86 times higher than other perennial plant based system and about 12.40-22.57 times higher than annual crops as pure grassland system.

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.

Garkoti (2008) studied the biomass and productivity of *Acer cappadocicum* forest occurring at an altitude of 2,750 m in the west central Himalayas of India. Total vegetation biomass was 308.3 t ha<sup>-1</sup>, of which the tree layer contributed the most, followed by herbs and shrubs. The seasonal forest-floor litter mass varied between 5.4 t ha<sup>-1</sup> (in rainy season) and 6.6 t ha<sup>-1</sup> (in winter season). The annual litter fall was 6.2 t ha<sup>-1</sup>, of which leaf litter contributed the largest part (59% of the total litter fall). Net primary productivity of total vegetation was 19.5 t ha<sup>-1</sup> year<sup>-1</sup>. The production efficiency of leaves (net primary productivity/leaf mass) was markedly higher (2.9 g g<sup>-1</sup> foliage mass year<sup>-1</sup>) than those of the low-altitude forests of the region.

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 *pinus roxburghii* forests in two sites, Ghoragali and Lehterar, of Pakistan as 126±2.94 and 99±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 broadleaves, 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 in Solan district of Himachal Pradesh. The results revealed that out of 1.07 Mt (Metric tons) 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 obtained total carbon 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% and 60% of the total carbon content in patula pine and teak plantations, respectively.

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) aimed to estimate 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 in 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 year 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) estimates 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, foliages 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, foliages, 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 (2015a) 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.

Muhammad *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>.

Patil *et al.* (2015) assessed biomass in subtropical and temperate forest dominated by tree species of *Quercus semicarpifolia* and *Pinus roxburghii* in Himalayan region of Uttarakhand state. In-situ measurements of the phytomass were taken with clustered sampling approach on a total of 40 plots (0.1 ha each), i.e. in 10 MODIS pixels with 4 plots laid in an individual pixel. The field measured phytomass was found in the range of 67.76 - 1,108 t ha<sup>-1</sup>. Weighted-area phytomass was estimated at an individual MODIS (MOD13Q1, 250m) pixel where in-situ measurements varied from 207.93 t ha<sup>-1</sup> - 1,042 t ha<sup>-1</sup>. The best fit equation of pixel phytomass values was regressed on red, infra-red and vegetation indices (NDVI) derived from the MODIS data. The correlation between the measured phytomass and NDVI was found significant and maximum in the month of December (R value -0.71, p < 0.01). However, such a relationship was not persistent throughout the year. The R<sup>2</sup> value between observed phytomass and predicted phytomass was 0.53. The predicted phytomass based on 250×250 m MODIS data varied from 216.88 - 1,011 t ha<sup>-1</sup>. The average phytomass density in study area was 470.42 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> ( ± σ 0.48) and minimum under Deodar (open) 0.17 t ha<sup>-1</sup> ( ± σ 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> ( ± σ 0.46) and minimum under Blue Pine (open) 0.59 t ha<sup>-1</sup> ( ± σ 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.

## **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 Vetas (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 Kg CO<sub>2</sub> ha<sup>-1</sup> day<sup>-1</sup>) than sandy soil (3.3 CO<sub>2</sub> Kg ha<sup>-1</sup> day<sup>-1</sup>).

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 rises 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 2000). 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; 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 at north-east Brazil and West Africa. In NE 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 was decreased and soils used to loose 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 sequestered 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 while when arable land is converted to forest an increase in soil C is usually apparent. The soil C pool is determined by the balance between C input by litterfall 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 in tropical dry deciduous forest to 92.1 t/ha in littoral and swamp forest. The mean soil organic C density estimates based on 136 observations ranged from 70 t/ha in tropical dry deciduous forest to 162 t/ha 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 Mha<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 PgC in top 50 cm and 6.81 PgC 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% 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; Buringh 1984). 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 fixed 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). He further reported that integration of trees reduced SOC loss which was 3.2 per cent under *Emblia officinalis*, 22 per cent under *Hardwickia binnata* and 35.5 per cent under *Colophospermum mopan* 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% 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, Uthaithani 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 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.

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. TCD ranged between 77.3 CMg ha<sup>-1</sup> on SE aspect (*Quercus leucotrichophora* forest) and 291.6 CMg ha<sup>-1</sup> on NE aspect (moist *Cedrus deodara* forest). SOC varied between 40.3 CMg 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 CMg ha<sup>-1</sup> on SW aspect (Himalayan *Pinus roxburghii* forest) and 469.1 CMg 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 broadleaf 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 broadleaf soils with an amount always lower ( $3.4 \pm 0.2 \text{ kg m}^{-2}$ ).

Javid and Somaiah (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 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) followed by Himalayan Moist Temperate Forests (55.20 tonnes/ha), Himalayan Dry Temperate Forests (47.61 tonnes/ha) and Sub-alpine Forests (45.67 tonnes/ha) and the least was under Tropical Dry Deciduous Forests (36.04 tonnes/ha). 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%) followed by Himalayan Moist Temperate Forests (21%), Himalayan Dry Temperate Forests (19 %), Sub-alpine Forests (18 %) and the least was occupied by Tropical Dry Deciduous Forests (14 %). 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.

Javid *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 forest types 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. 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) forest type, 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 average, the percentages of SOC at 0–10-, 10–20-, and 20–30-cm depths were 53.2, 26.5, and 20.3 %, 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) under. 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 % was ranging 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%, while the highest SOC percentage was found in depth 0 - 10 cm (2.29±0.42%). The per hectare mean SOC stock for van Panchayat was 218.57t.

Krishan *et al.* (2017) investigated belowground carbon flux 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 MgC/ha, whereas stock root carbon



(14.01-38.27 MgC/ha), lateral roots carbon (5.24-17.57 MgC/ha) and fine root carbon (0.67-12.2 MgC/ha) in selected forest types were recorded. The maximum SOC was exhibited by *Abies pindrow* forest ( $110.83 \pm 5.04$  MgC/ha), followed by *Pinus roxburghii* forest ( $108.22 \pm 13.03$  MgC/ha), *Quercus floribunda* forest ( $97.37 \pm 7.64$  MgC/ha), whereas minimum SOC was recorded in *Cedrus deodara* forest ( $56.94 \pm 5.13$  MgC/ha). The maximum value of litter carbon was recorded for *Abies pindrow* forest ( $2.94 \pm 1.02$  MgC/ha), followed by *Quercus semecarpifolia* forest ( $2.22 \pm 0.33$  MgC/ha), *Quercus floribunda* forest ( $2.06 \pm 0.28$  MgC/ha), *Cedrus deodara* forest ( $1.86 \pm 0.26$  MgC/ha), *Quercus leucotrichophora* forest ( $1.44 \pm 0.27$  MgC/ha), *Pinus roxburghii* forest ( $0.84 \pm 0.10$  MgC/ha). 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 seems has maximum in carbon assimilatory capacity, whereas *Cedrus deodara* forest has minimum BGC stocks.

Gandhi & Sundarapandian (2017) studied quantification of soil organic carbon (SOC) stock on a large scale ( $30^{-1}$  ha 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 with a mean value of  $28.26 \pm 1.35$  Mg/ha. 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 USE OF REMOTE SENSING AND GIS IN FLORISTIC STUDIES:

The conventional methods for collection of information on forests carbon stocks and biodiversity alone have been found to be costly and time consuming. Thus there is a need of State of Art technology for biodiversity assessment. The modern technology of remote sensing allow us to collect lot of spatial data rather easily, with speed and on repetitive basis, and together with Geographic Information System (GIS) helps us to analyze the data spatially, offering various options. Remote sensing and GIS can be used as important tools separately or in combination for application in studies of forestry and biodiversity (Salem 2003).

Amarnath *et al.* (2003) studied spatial characterization of evergreen forests of the Western Ghats in Tamil Nadu, India using remote sensing and GIS-based analysis in conjunction with ground-based phytosociological data. A vegetation type map was prepared using IRS LISS III satellite data and was used to study the patch characteristics in terms of patch size, number, shape, porosity and landcover diversity. The phytosociological characteristics, namely species richness, diversity, similarity and community assemblages, were studied using ground data collected from 95 sample points of 0.1 ha size. Patch size and number revealed distinct intactness and disturbance levels in these four hill ranges. Evergreen forests in the Tirunelveli hills comprising 216.09 2 2 km are distributed in 306 patches, and in the Palni hills, with 285 km, forests are distributed in 1029 patches, indicating a high level of fragmentation. LD, indicating the spatial heterogeneity of landcover, was very high in the Nilgiri hills and low in the Tirunelveli hills. The spatial analysis helped to delineate homogenous large patches of evergreen forest, which can be adopted for appropriate conservation strategies. A total of 342 tree species belonging to 4490 stems were evaluated for phytosociology. Only 15–28% of similarity in terms of species distribution was found across the hill ranges. Conjunctive analysis of patch characteristics and species distribution showed high species richness in less fragmented evergreen forests and vice versa.

Luis and Raul (2004) computed relationships among alpha and beta diversity indices from 141 randomly sampled quadrats, and the vegetation classes obtained by multi-spectral satellite image classification which were used as a strategy for mapping plant diversity in a tropical landscape mosaic of Quintana Roo State, on the eastern seaboard of the Yucatan peninsula, southeastern Mexico. Species accumulation models were used to evaluate how representative the sample size was of the different vegetation types. A standard one-way, between-subjects ANOVA confirmed a significant reduction of the within-class variance of plant diversity with respect to their total variance across the landscape. Computed uniformity indices, to assess the internal uniformity of vegetation classes on the diversity indices, confirmed the goodness of the mapped classes in stratifying variability of plant diversity. Which allowed for the use of the mapped classes as spatial interpolators of plant diversity values for estimation and up-scaling purposes. Finally, it was revealed that the plant diversity of the landscape depends, to a large extent, on the diversity contained in the most mature forest class, which is also the most diverse community in the studied area. High and moderate beta diversity values between mature forests and both the secondary associations and the first

stages of succession, respectively, indicated that there is a significant contribution to the diversity of the landscape by those vegetation classes.

Hasmadi *et al.* (2010) studied the lowland tropical forest plant association and composition in Mount Tahan, Malaysia. Plant species, vegetation cover, plant height, and species cover and frequency in untrampled and trampled areas were counted or measured. The analysis included a field survey following the relevance method of Braun-Blanquet and mapping using a GIS. The study was concentrated on altitudinal distribution of specific plants communities located between 1900 m and 2140 m altitude. The data from field survey were mapped and analyzed in GIS. The phytosociological classification revealed that untrampled areas in Botak and Puncak sites were high in species more diversified communities compared to the trampled areas. The results showed that *Leptospermum flavescens* was the dominant species most in both sites i.e. Botak and Puncak, with 48%, specifically at the untrampled site. The abundance class and sociability value are also high for this species with score 4.5 out of 5, respectively. A total number of trees in the area probably play an important role in quantifying the species richness and diversity parameters.

Rocchini *et al.* (2013) studied theoretical background of the mostly used diversity indices stemmed from information theory that are commonly applied to quantify landscape diversity from remotely sensed data and proposing a free and robust open source tool i.e. r.diversity with its source code for calculating diversity indices and allowing an easy potential implementation of new metrics by multiple contributors globally at different spatial scales from remotely-sensed imagery or land use maps, running under the widely used Open Source program GRASS GIS. They stated that r.diversity can be a valuable tool for calculating landscape diversity in an Open Source space given the availability of multiple indices at multiple spatial scales with the possibility to create new indices directly reusing the code.

Egziabher *et al.* (2013) studied integrated approach combining floristic analysis, Geographic Information Systems and Remote Sensing to map the vegetation of a Tigray district, Ethiopia. Vegetation types were identified using a floristic method. For each type the community niche was defined on the basis of altitude and parent material. The combination of the physiognomic map obtained by Remote Sensing with the niches of floristic-vegetation types was obtained with a GIS application using the Digital Elevation Model. A floristic-physiognomic vegetation map combining floristic diversity and physiognomy of vegetation was produced. The map has been used for a numerical classification of administrative units,

based on the percentage of cover of floristic-physiognomic vegetation types. Three main groups of tabias have been defined, each of them related to one altitudinal belt and well characterised by a floristic-physiognomic vegetation type.

Sharma and Shashikant (2014) studied was conducted on sub-tropical forest of districts Jammu and Samba of Jammu province of Jammu and Kashmir state, India with the objective of determining floristic composition, species diversity and structure of woody vegetation in drier Kandi Siwaliks. The entire area under study was demarcated using toposheets and satellite imageries and reconnaissance survey was undertaken to define vegetation type and community association. Traverses along roads, drainage, hills and ridges were made and three forest types were identified on the basis of Champion and Seth classification. Physiographic factors i.e., altitude, slope steepness and direction were measured by GPS (Garmin, Rino-130). Stratified random sampling was adopted for analyzing vegetation composition of woody species. A sample intensity of 0.01 per cent of the total area was adopted covering all vegetation types. Various phytosociological parameters and diversity indices have been used to reveal the community structure, species richness, diversity and evenness. A total of 112 species comprising 65 trees and 47 shrubs belonging to 92 genera and 48 families were recorded from the forest.

Many geospatial tools have been advocated in spatial ecology to estimate biodiversity and its changes over space and time. Such information is essential in designing effective strategies for biodiversity conservation and management. Remote sensing is one of the most powerful approaches to identify biodiversity hotspots and predict changes in species composition in reduced time and costs. This is because, with respect to field-based methods, it allows to derive complete spatial coverages of the Earth surface under study in a short period of time. Furthermore, remote sensing provides repeated coverages of field sites, thus making studies of temporal changes in biodiversity possible (Rocchini 2015)

Malik *et al.* (2015) studied floristic diversity of remote Warwan valley based on information extracted from remotely sensed satellite data along with field surveys undertaken. Analysis of vegetation information from satellite data revealed that 75% of the area is covered with natural vegetation. Apart from the remotely sensed data from satellite, comprehensive field surveys were also conducted to document the floristic diversity of the region. Analysis of species composition showed a total of 285 plant species, belonging to 191 genera in 60 families. Of these, 250 species are herbs, 14 shrubs, 2 sub-shrubs and 19 trees.

Asteraceae emerged as the largest family with 35 species. During the present study, 5 species (*Corydalis cashmeriana*, *Hippophae rhamnoides*, *Primula minutissima*, *Saussurea sacra* and *Inula orientalis*) have been recorded for the first time from this Himalayan region. The study demonstrated the benefits of geo-informatics in floristic studies, particularly the robustness of remotely sensed data in identifying areas with potentially high species richness, which would be otherwise difficult in a complex mountainous terrain using traditional floristic surveys alone.

## *Chapter-3*

# **MATERIALS AND METHODS**

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The present investigation entitled **“Assessment of floral diversity and carbon stocks of Himalayan moist temperate forest in Himachal Pradesh”** was carried out in Shimla district (H.P). The detail of experimental sites, materials used, sampling techniques applied and experimental methodology adopted for completing the objectives of the present study is given below:

### **3.1 SITE DESCRIPTION**

#### **3.1.1 Configuration, Physiography and Geology:**

Shimla district forms a part of southern Himachal Pradesh. The district lies between the longitudes 76°59'22" and 78°18'40" East and latitudes 30°45'48" and 31° 43' 0" North (Figure 1). This district is bounded by Mandi and Kullu districts in the north, Kinnaur in the east, the state of Uttarakhand and Sirmaur district in the south and by Solan district in the west (Fig.1). The district has prominent peaks such as Jakhoo in Shimla Town, Siah near Chail, Churdhar in tehsil Chaupal, and Chansal in Rohru tehsil, Hattoo in Kumharsain tehsil and Shali in Sunni tehsil. Mostly the terrain is rough and the topography of the district is characterised by high mountains, river basins and, deep and narrow valleys. The elevation of the district ranges from 300-6,000 meters above mean sea level. The prevalence of interlocking spurs, narrow and steep sided valleys with high peaks and thick conifers and broadleaved forests throughout the district adds to the youthfulness of its topography. The district has an area of 5,131 km<sup>2</sup> out of total area of 55,673 km<sup>2</sup> of Himachal Pradesh.

#### **3.1.2 Climate:**

The climatic condition in the district varies with elevation due to topographical variations. However, there are four broad seasons. Winter normally starts from mid-November and continues till mid-March. December to February are severe cold months when the winter season is at its peak. The upper reaches have snow and sleet while the rains are frequent in the lower areas. Snow may fall as early as in the beginning of October but usually the areas have snow fall from the latter half of December and continue till middle of March. The higher peaks experience heavier snowfall and its starts melting from March. The

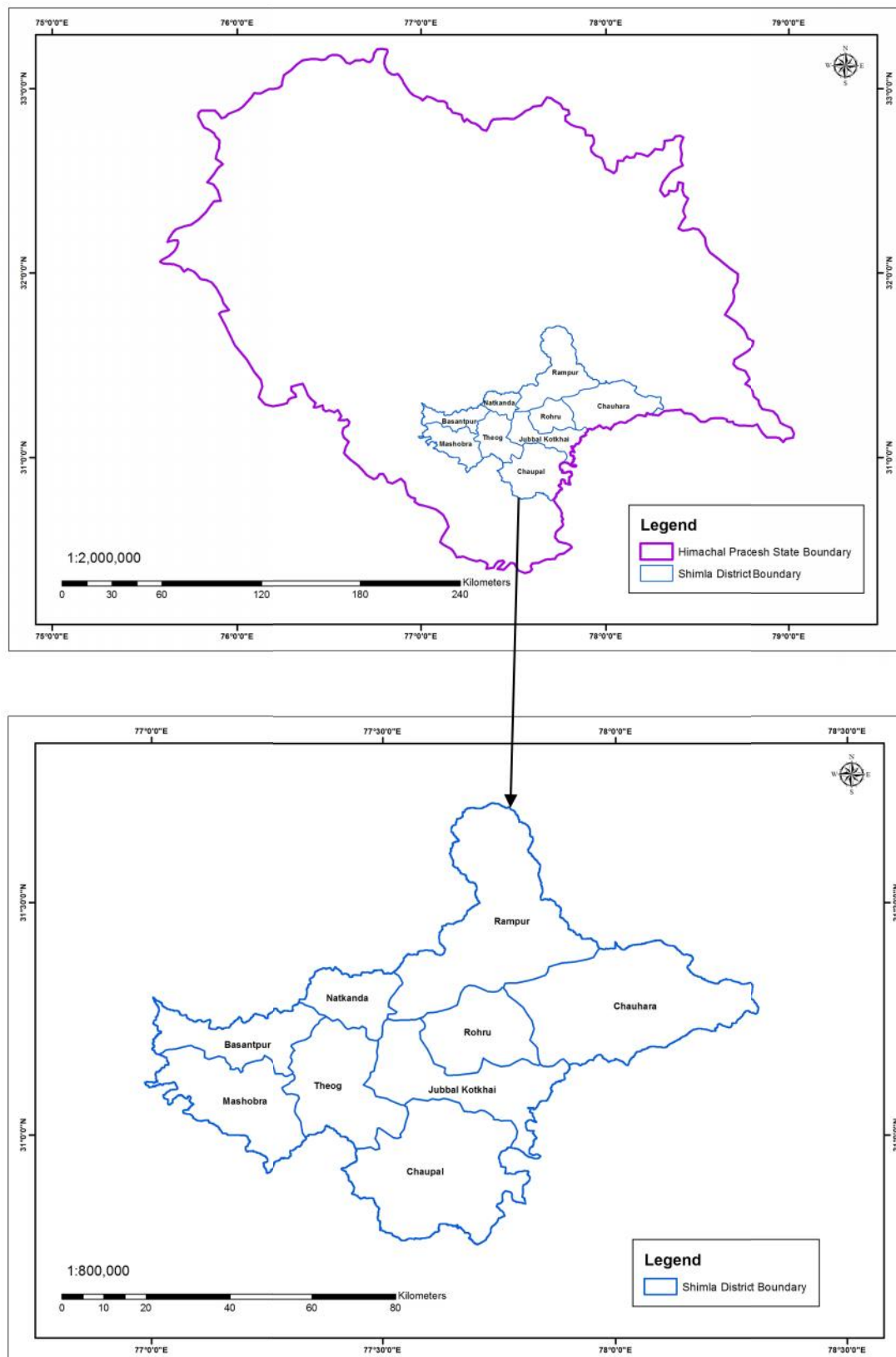


**Figure 1. Boundary of Himachal Pradesh along with Shimla district**

snow is not experienced below 800 metres. The climate of the district is comparatively hot from mid-May to July. Rainy season generally starts from mid-July and extends up to the mid-September. Air temperature ranges from 4 to 31<sup>0</sup>C over the course of year. The average temperature during summer is 19 to 28<sup>0</sup>C and in winter 1 to 10<sup>0</sup>C. Annual average precipitation in the district is around 1500 mm.

### 3.1.3 Forests

Shimla district is endowed with thick and evergreen forests represented by different associations of *Pinus roxburghii* (Chir), *Quercus leucotrichophora* (Ban oak), *Quercus semecarpifolia* (Kharsu oak), *Cedrus deodara* (Deodar), *Pinus wallichiana* (Kail), *Picea smithiana* (Spruce) *Abies pindrow* (Fir), *Taxus wallichiana* (Yew) and mixed broadleaved forests. In the lower elevation scrub forest are found, while in higher altitudes of district, different conifers and broad leaf associations are found. The main marketable forest products are resin from *P. roxburghii*, timber from Chil, Deodar, Kail, Fir and Spruce, along-with pulp wood and fire wood (Census of India, 2011).

### 3.1.4 Forest types

The study area falls under Lower Western Himalayan Temperate Forests (12/C<sub>1</sub>) and Upper Western Himalayan Temperate Forests (12/C<sub>2</sub>) as per the classification of forests of India given by the Champion and Seth (1968) encompassing various sub-forest types such as Oak, Deodar, Kail and western mixed conifers and moist temperate deciduous forests and others. Various Himalayan temperate forests in Shimla district are Ban oak forest (12/c<sub>1a</sub>), Moru oak forest (12/c<sub>1b</sub>), Moist deodar forest (12/c<sub>1c</sub>), Western mixed coniferous forest (12/c<sub>1d</sub>), Moist temperate deciduous forest (12/c<sub>1e</sub>), Low level blue pine forest (12/c<sub>1f</sub>), Kharsu oak forest (12/c<sub>2a</sub>), Upper oak/fir forest (12/c<sub>2b</sub>) and Moist temperate deciduous forest (12/c<sub>2c</sub>).

## 3.2 METHODOLOGY

The preliminary information on different forest types in Shimla district was collected from Forest department of Himachal Pradesh. Out of them the information on Himalayan moist temperate forest was drawn up as given in Table 1. Necessary reference of Champion and Seth (1968) on Forest types in India was also consulted to define and locate different Himalayan moist temperate forest types in Shimla district. Each forest type was delineated into three elevation classes (E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>) as per their distribution along the elevation in



Shimla district. Thus, there were nine types of forests under ‘Himalayan moist temperate forest in Shimla district that were explored for their vegetation composition relative to elevation and other topographic features, the regeneration status in each of them and soil properties.

**Table 1: Types of Himalayan moist temperate forest in Shimla district of Himachal Pradesh, their elevation ranges and delineation of E<sub>1</sub> E<sub>2</sub> and E<sub>3</sub> in each of them for their detailed study**

| Type of Himalayan moist temperate forest | Type (according to Champion & Seth, 1968) | Elevation      |                |                |
|------------------------------------------|-------------------------------------------|----------------|----------------|----------------|
|                                          |                                           | E <sub>1</sub> | E <sub>2</sub> | E <sub>3</sub> |
| Ban Oak forests                          | (12/c1a)                                  | 700 -1300      | 1300-1900      | 1900-2500      |
| Moru Oak forests                         | (12/c1b)                                  | 1800-2300      | 2300-2800      | 2800-3300      |
| Moist Deodar                             | (12/c1c)                                  | 900-1800       | 1800-2700      | 2700-3600      |
| Western mixed coniferous forests         | (12/c1d)                                  | 1200-2100      | 2100-3000      | 3000-3900      |
| Lower moist temperate deciduous forests  | (12/c1e)                                  | 1000-1800      | 1800-2400      | 2400-2700      |
| Kail forests                             | (12/c1f)                                  | 1400-2100      | 2100-2800      | 2800-3600      |
| Kharsu Oak forests                       | (12/C2)                                   | 2300-2800      | 2800-3200      | 3200-3600      |
| Upper Oak - Fir forests                  | (12/c2a)                                  | 2100-2600      | 2600-3100      | 3100-3500      |
| Upper moist temperate deciduous forests  | (12/c2b)                                  | 1700-2300      | 2300-2900      | 2900-3500      |

### 3.2.1 Remote sensing and GIS

To have macro-information on biomass aggregation and carbon stock in Himalayan moist temperate forest of Shimla district in HP use of remote sensing and GIS technology was done using following data sources.

- LISS-III satellite imageries for Shimla district for the years 2008 and 2013 were purchased from National Remote Sensing Agency, Hyderabad.
- Forest types map developed by Forest Survey of India, Dehradun.
- Shuttle Radar Topography Mission (SRTM) data downloaded from NASA (web site - <https://www2.jpl.nasa.gov/srtm>)

#### 3.2.1.1 Procedure

The boundary map of Shimla district was georeferenced accurately using ‘georeferencing’ tool in Arc GIS 10.3 and was converted into a raster image. The SRTM

data relative to Shimla district was downloaded in TIFF format. This vector data was imported in GIS software and by applying requisite tools in GIS software it was transformed into TIN (Triangulated Integrated Network). TIN is used to generate raster image surface with the module TINSURF. Finally, vector data coverage and TIN coverage was used to generate raster layer i.e. DEM (Digital Elevation Model). This DEM was reclassified individually for each forest type into three elevation classes ( $E_1$ ,  $E_2$  and  $E_3$ ) based on its elevation range as given in Table 1. Forest types map taken from Forest Survey of India, Dehradun was overlaid with boundary image (raster format) of Shimla district to extract the extent of different forests occurring in Shimla district. Out of them 'Himalayan moist temperate forest' were retained in it rest were deleted. Separate image for each of the nine types of 'Himalayan moist temperate forest' was made for further processing. Each forest type was overlaid with its reclassified DEM to know its distribution at three elevations. 'Area' tool was run to determine total area under each forest type and area of each forest type under each elevation.

LISS III satellite imagery of the years 2008 and 2013 were processed in ERDAS IMAGINE 2016. Mandatory radiometric and geometric corrections of the imageries were done before their further processing. Each imagery was overlaid by boundary image of Shimla district to extract imagery for Shimla district. These imageries (Shimla district for 2008 and 2013) were then used for obtaining NDVI classes by running 'NDVI' tool based on the principle:

$$NDVI = \frac{(\text{Near infrared} - \text{Red})}{(\text{Near infrared} + \text{Red})}$$

The NDVI images were reclassified into three NDVI classes for each forest type. Both satellite imageries with NDVI classes and reclassified DEM in raster format were converted in vector data format using 'raster polygon' tool from 'conversion' tool box. This conversion was done so as to intersect above generated data in Arc GIS 10.3. Intersection of satellite imagery with NDVI classification, reclassified DEM and Forest types map which was also converted into vector format were overlaid using intersect tool from analysis tool box in Arc Map 10.3 version. Thus, a complete information on area of different forest types under each NDVI class at different elevation classes ( $E_1$ ,  $E_2$  and  $E_3$ ) was generated. The entire procedure employed in generation of cartographic maps has been given in a flowchart (Figure 2) and Figure-3.

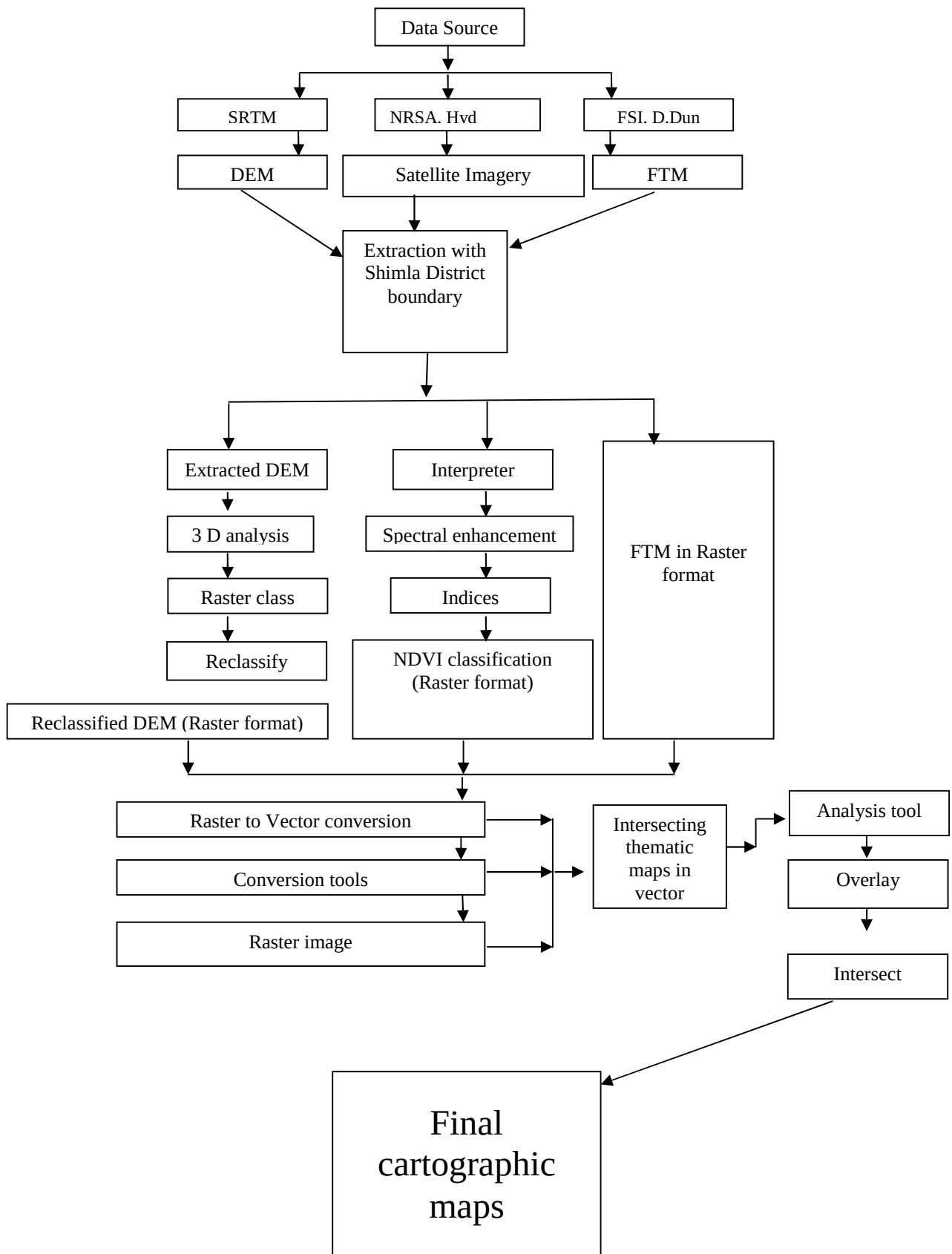
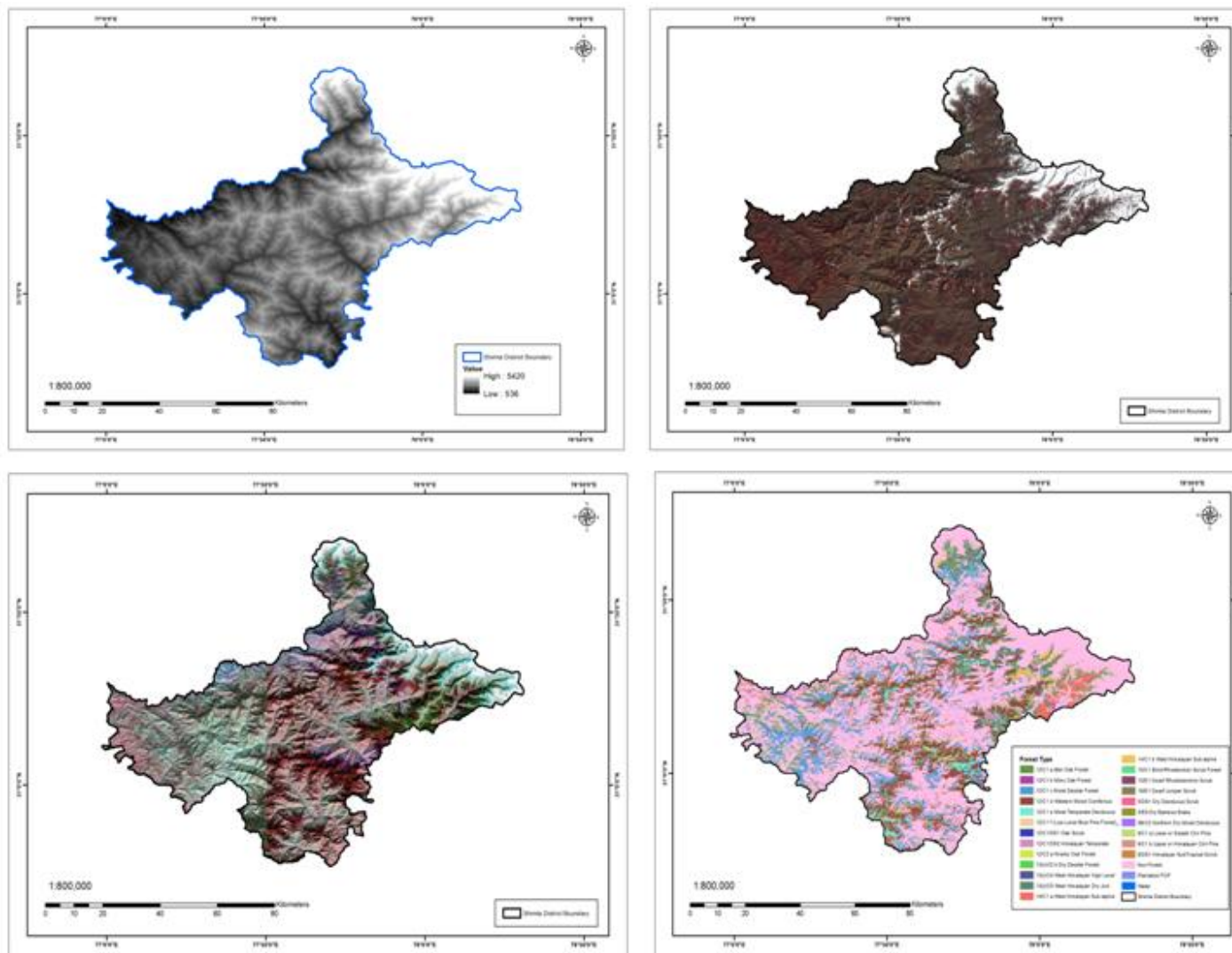


**Figure 2: Flow chart of preparing cartographic maps using remote sensing and GIS**



### 3.2.2 Vegetation study

Each ‘Himalayan moist temperate forest’ in the Shimla district as depicted in the cartographic maps generated through remote sensing and GIS was further used to select experimental sites. In each forest type 4 replications were maintained at each elevation which were marked on the map and the information regarding their geographical coordinates was generated which was used for ground truthing using GPS. The various experimental sites with their coordinates selected in each forest type are given in Table 2 below and these points are depicted in Figure 4.

**Table 2: Experimental sites with their coordinates of the study**

| Forest type                             | Elevation class | Latitude | Longitude |
|-----------------------------------------|-----------------|----------|-----------|
| Ban Oak forests                         | E <sub>1</sub>  | 31.234   | 77.308    |
|                                         | E <sub>2</sub>  | 31.232   | 77.308    |
|                                         | E <sub>3</sub>  | 31.214   | 77.292    |
| Moru Oak forests                        | E <sub>1</sub>  | 31.205   | 78.061    |
|                                         | E <sub>2</sub>  | 31.203   | 78.051    |
|                                         | E <sub>3</sub>  | 31.201   | 78.050    |
| Moist Deodar forests                    | E <sub>1</sub>  | 31.583   | 77.812    |
|                                         | E <sub>2</sub>  | 31.584   | 77.815    |
|                                         | E <sub>3</sub>  | 31.593   | 77.823    |
| Western mixed coniferous forests        | E <sub>1</sub>  | 31.185   | 77.823    |
|                                         | E <sub>2</sub>  | 31.177   | 77.861    |
|                                         | E <sub>3</sub>  | 31.178   | 77.869    |
| Lower moist temperate deciduous forests | E <sub>1</sub>  | 31.588   | 77.744    |
|                                         | E <sub>2</sub>  | 31.588   | 77.778    |
|                                         | E <sub>3</sub>  | 31.586   | 77.777    |
| Kail forests                            | E <sub>1</sub>  | 31.585   | 77.801    |
|                                         | E <sub>2</sub>  | 31.584   | 77.798    |
|                                         | E <sub>3</sub>  | 31.582   | 77.781    |
| Kharsu Oak forests                      | E <sub>1</sub>  | 31.191   | 77.950    |
|                                         | E <sub>2</sub>  | 31.191   | 77.954    |
|                                         | E <sub>3</sub>  | 31.192   | 77.958    |
| Upper Oak-Fir forests                   | E <sub>1</sub>  | 30.850   | 77.728    |
|                                         | E <sub>2</sub>  | 30.849   | 77.720    |
|                                         | E <sub>3</sub>  | 30.840   | 77.681    |
| Upper moist temperate deciduous         | E <sub>1</sub>  | 31.170   | 77.833    |
|                                         | E <sub>2</sub>  | 31.168   | 77.856    |
|                                         | E <sub>3</sub>  | 31.166   | 77.867    |

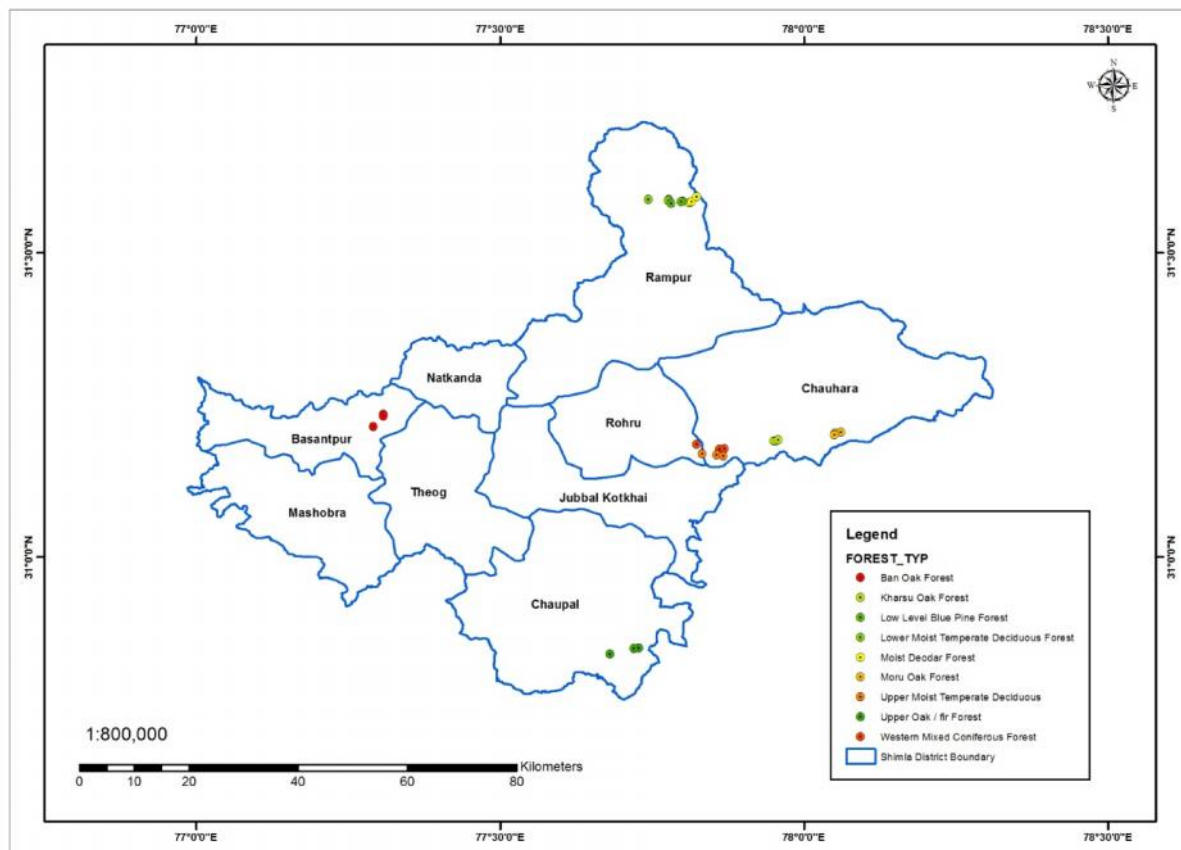


**Figure 4. Location of experimental sites in different forest types across Shimla district**

### 3.2.3 Sampling procedure

In each experimental site (with designated geographical coordinates as given in Table 2) of different forest types three sample plots, randomly distributed around the site, of 0.1ha were marked out to ensure that marking is retained till the sampling is over. The vegetation study in each sample plot was done as follows:

### 3.2.4 Trees

In each sample plot enumeration of trees was done. The number of different tree species were noted. Dbh of each tree was measured with tree calliper. Height of trees was measured by Ravi multimeter.

### 3.2.5 Shrubs

In every sample plot of 0.1 ha laid out for trees in experimental sites, two sub-plots of 10 m x 10 m size were marked out to study phytosociology of shrubs. Number of shrub species in each plot was counted and density of each shrub species was determined. Based on the ocular appearance each shrubs species was segregated into three groups as: large,

medium and small and in each the number of plants were counted. Proportionate sampling method was applied to sample shrub plants from each group to determine the basal area of stem and biomass (aboveground and belowground) of different species. The basal area of stem was determined by vernier calliper.

### **3.2.6 Forbs**

Two line transects were laid out across each sample plot marked for tree study and 6 quadrats of size 50 × 50 cm were randomly selected to harvest herbage at ground level at the time of peak growth of herbage in the month of September. The herbage from each quadrat was segregated into different species. The plants of each species were counted and their basal area was determined at ground level using vernier calliper.

Identification of plants was done with the help of experts in the university herbarium in the Department of Forest Products, YSP University of Horticulture & Forestry, Solan (HP) and from 'Systematic Botany' division in FRI, Dehradun

### **3.2.7 Phytosociology**

The phytosociology of trees, shrubs and herbs comprised of determining individual species density, basal area and importance value index (IVI) which were calculated by following Mishra (1969) as described below.

### **3.2.8 Density**

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats. These values were converted into required units i.e, number/hectare or number/m<sup>2</sup>.

### **3.2.9 Basal Area**

The cross-sectional area of trees, shrubs and herbs recorded while sampling was determined by the formula as:

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

Where:

d = Diameter

### 3.2.10 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 or IVI of the species (Curtis and McIntosh, 1950).

$$\text{Relative density} = \frac{\text{Density of individual species in a quadrat}}{\text{Total density of all species in a quadrat}} \times 100$$

$$\text{Relative basal area} = \frac{\text{Basal area of individual species in a quadrat}}{\text{Total basal area of all species in a quadrat}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of individual species in a quadrat}}{\text{Total frequency of species in a quadrat}} \times 100$$

Importance Value Index (IVI) = Relative density + Relative basal area + Relative frequency

### 3.2.11 Species richness, diversity and dominance indices

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

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

Where,  $S$  = Total number of species.

$N$  = Total number of individual.

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

#### a) Shannon-Wiener index of diversity

The formula for calculating the Shannon- Wiener Index (1963) of diversity is

$$H = -\sum p_i \ln p_i$$



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 index of dominance

The equation use to calculate Simpson's index (1949) is:

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

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).

As  $D$  increase, diversity decreases and Simpson's index was therefore usually expressed as  $1-D$ . Simpson index of dominance for tree we use the above equation, because forests are already classified on the basis of their dominance of tree species. Whereas, in case of shrubs and herbs we use formula  $D-1$ .

## 3.3 BIOMASS ESTIMATION

The biomass estimation for different components of vegetation was done as follows:

### 3.3.1 Trees

Volume of tree species was calculated by using volume equations for specific tree species (APPENDIX I) developed by FSI Dehradun for this region (FSI, 1996) or Forest Survey of India report (2009, 2012). Stem biomass of tree was obtained by multiplying volume with specific gravity (Smith 1954; APPENDIX II).

$$\text{Stem biomass (t/ha)} = \text{VOB} \times \text{WD}$$

Where,  $\text{VOB}$  = volume over bark

$\text{WD}$  = volume weighted average wood density

The aboveground biomass of a tree was calculated following IPCC (2006) by multiplying its volume with a biomass expansion factor. The biomass expansion factor for

hardwood species and conifers was calculated using the equations (Brown *et al.* 1999; APPENDIX III).

$$\text{Aboveground biomass (t/ha)} = \text{Stem biomass (t/ha)} \times \text{BEF}$$

Where: BEF = biomass expansion factor

Using the regression equation by Cairns *et al.* (1997), the belowground biomass (fine and coarse roots) was estimated for each tree (APPENDIX IV) as given by IPCC (2006). Aboveground biomass and belowground biomass was added to derive at total biomass of trees.

### **3.3.2 Shrubs**

Each shrub samples collected for studying the phytosociology was brought to laboratory, segregated into leaves, branches and stem portion. Each component was washed in running water and dried in oven at 70°C for 72 hours till the constant dry weight was obtained. Each sample was weighed to determine aboveground biomass (stem + branch + leaves biomass) of each species. Belowground biomass estimations were done by extracting roots of sample plants (shrubs). These were washed thoroughly and weighed to determine their fresh weight. The root proportion of each species were brought to laboratory, washed thoroughly, packed in paper bags and dried at 70 ± 5°C for 72 hours to determine their dry weight. Total biomass of a shrub species was calculated by adding its aboveground and belowground biomass.

### **3.3.3 Forbs**

The plants species uprooted for phytosociological studies were used to determine aboveground biomass whereas, belowground biomass of herbs was estimated by extracting a monolith of 25 × 25 × 25 cm from each quadrat. The soil was gently removed by tapping and plant species were segregated species wise, washed and dried in oven at 72°C for 72 hours till the constant weight was obtained. Weight of the dried sample was determined by weighing each dried sample.

### **3.3.4 Carbon stock estimation**

Aboveground and belowground carbon content in plants was determined by multiplying biomass of trees, shrubs and herbs with a conversion factor of 0.45 (Magnussen

and Reed 2004; Woomer 1999). Total carbon stock in vegetation was determined by adding aboveground and belowground carbon.

### 3.4 REGENERATION SURVEY

The regeneration survey was carried out in all sample plots. To study the regeneration status of dominant forest species nine quadrats of size 2 m x 2 m within each sample plot were laid out.

The main object of regeneration survey was to assess regeneration status of different forests. The adequacy of regeneration is judged on the basis of number of established plants in a unit area. According to Chacko (1965), desired number of established plants is 2500 per hectare and the quadrat is considered fully stocked when it contained one established plant. For assessment of regeneration status 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:

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

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

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

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

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

On the basis of above estimates following indices were calculated.

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

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

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

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

### 3.5 SOIL ANALYSIS

Composite soil samples (0-30cm) from each sample plot in different forests were collected during autumn season, three replicates of each composite sample were made. They were air dried, crushed and passed through 2 mm sieve and stored in cloth bags.

Bulk density of each soil sample was determined by following Specific gravity method given by Singh, (1980) and Organic carbon in the soil was estimated by the method given by Walkley and Black (1934).

### 3.6 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.

## *Chapter-4*

# **RESULTS AND DISCUSSION**

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The results emerged out of the present investigation entitled “**Assessment of floral diversity and carbon stocks of Himalayan moist temperate forest in Himachal Pradesh**” are presented and discussed in this chapter. The results obtained during the course of investigation are presented in this chapter under following heads.

- 4.1 Remote sensing and GIS
- 4.2 Floristic composition
- 4.3 Vegetation indices
- 4.4 Phytosociology
  - 4.4.1 Phytosociology of trees
  - 4.4.2 Phytosociology of shrubs
  - 4.4.3 Phytosociology of forbs
- 4.5 Regeneration studies
- 4.6 Vegetation Biomass and carbon
  - 4.6.1 Biomass and carbon in trees
  - 4.6.2 Biomass and carbon in shrubs
  - 4.6.3 Biomass and carbon in forbs
- 4.7 Soil studies

### **4.1 REMOTE SENSING AND GIS**

SRTM data (with contours 200 m apart) for Shimla district was processed in GIS software to produce digital elevation model. It was reclassified into elevation classes. In all, 26 elevation classes were made for displaying distribution of 9 forest types under Himalayan moist temperate forest (Figure 5) in Shimla district. The elevation classes in all forest types were given different colour to make it distinguishable. The elevation in Shimla district ranged from 400 to 5600 m amsl and each elevation class covered minimum 300 m elevation.

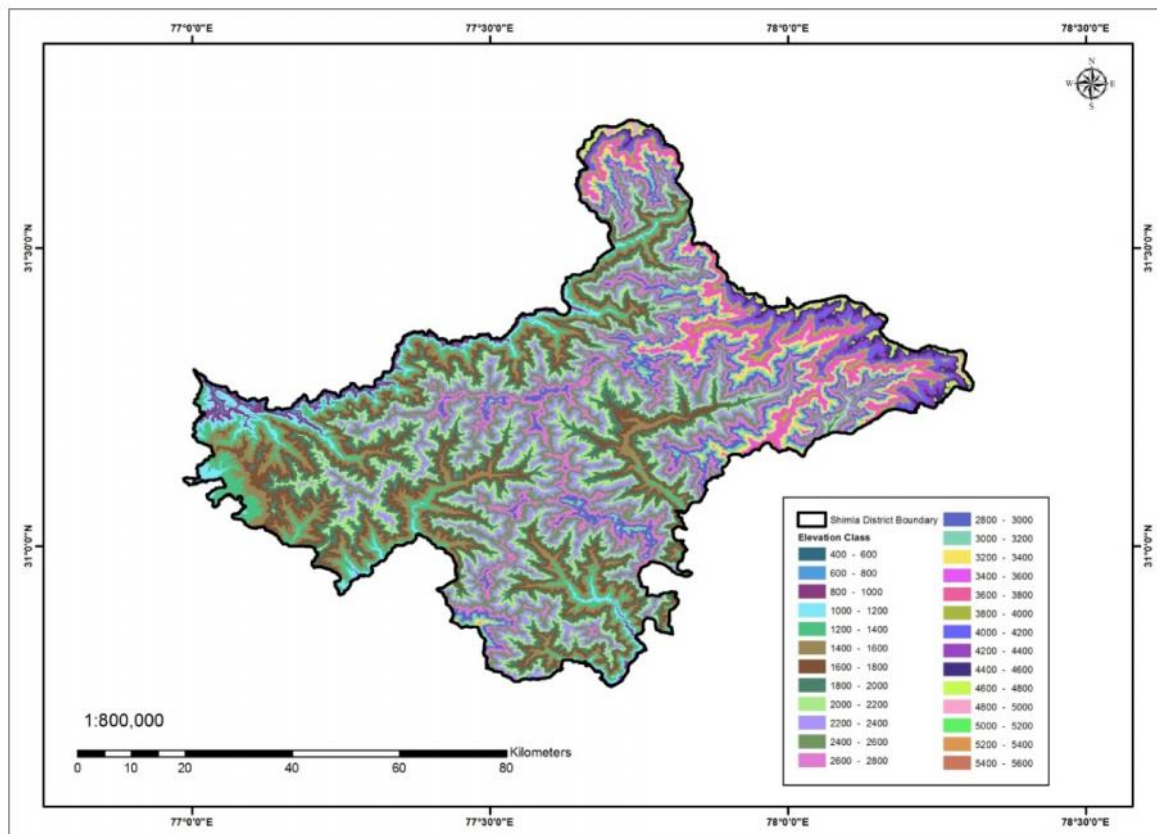


**Figure 5: Digital elevation model of Shimla district (HP) and elevation classes from 400 to 5600 m amsl in it**

Location of nine types of forests and their distribution at different elevations in Shimla district was confirmed by ground truthing. In each forest three elevation classes  $E_1$  (low),  $E_2$  (medium) and  $E_3$  (high) were delineated depending upon the elevation range of each forest.

Figure 6 reveals that Ban Oak forests occurs in north-western and south-western part of Shimla district in 13430.28 ha area. Three elevation classes categorized in Ban Oak forest revealed that in elevation zone,  $E_1 = 700$  to  $1300$  m amsl, an area of  $1277.04$  ha was under this forest, at  $E_2 = 1300$  to  $1900$  m amsl elevation this forest covers an area of  $11963.97$  ha and at  $E_3 = 1900$ - $2500$  m amsl, only  $189.27$  ha is under Ban Oak forest. Thus, major zone of occurrence of Ban Oak forests in Shimla district is between  $1300$  to  $1900$  m amsl. Colour scheme of red for  $E_1$ , blue for  $E_2$  and green for  $E_3$  elevation classes has been used in the figure 6.

Figure 7 reveals that Moru Oak forests occur in southern part of the district and covers an area of  $227.65$  ha in the district and was categorized into three elevation classes as:  $E_1$  elevation class ranging from  $1800$  to  $2300$  m amsl covering an area of  $43.66$  ha,  $E_2$

elevation class ranging from 2300 to 2800 m amsl covering an area of 124.35 ha and E<sub>3</sub> elevation class ranging from 2800 to 3300 m amsl covering an area of 59.64 ha. Thus, major distribution of this forest in Shimla district is between 2300-2800m amsl. Colour scheme of red for low (E<sub>1</sub>), blue for medium (E<sub>2</sub>) and green for high (E<sub>3</sub>) elevation class have been used in the figure 7.

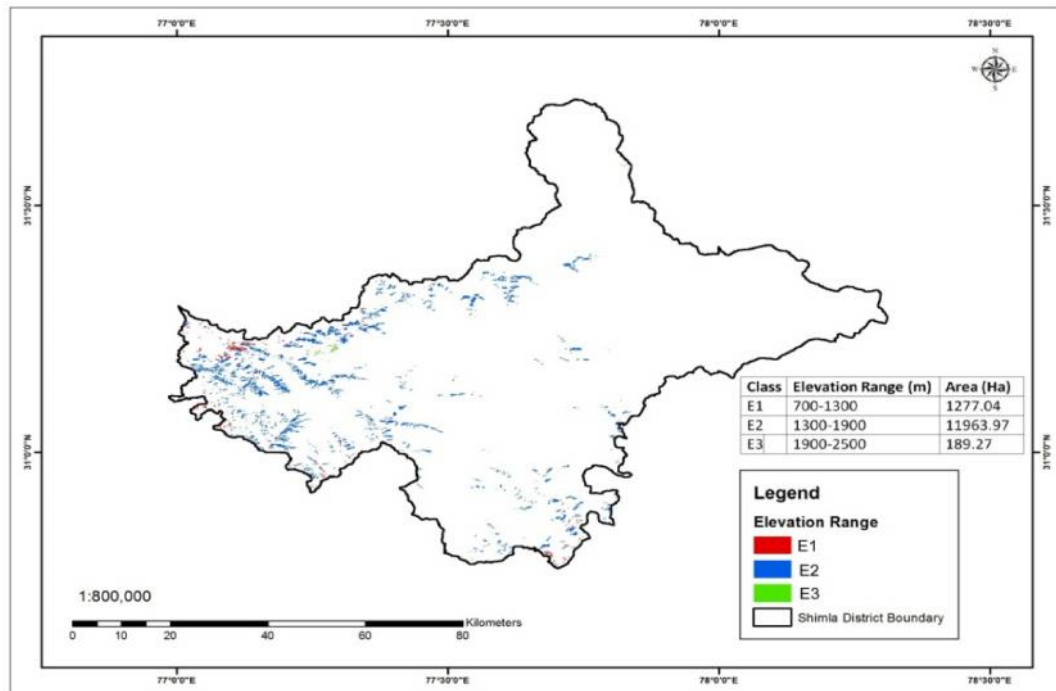


**Figure 6: Distribution of Ban Oak forests in Shimla district**

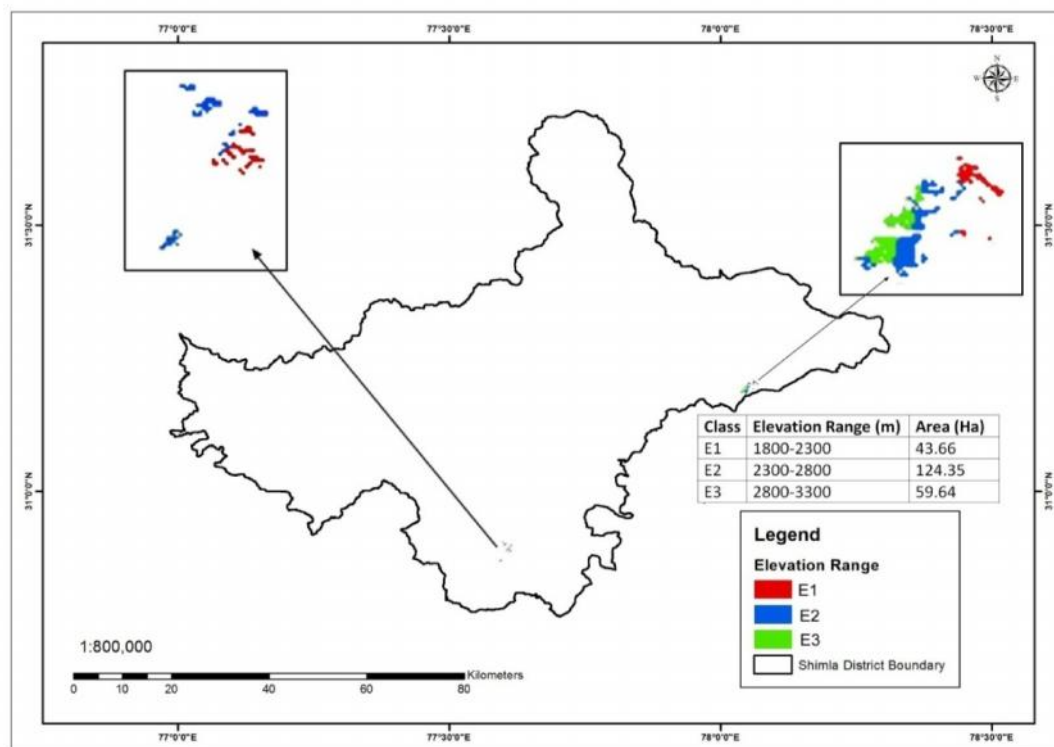


**Figure 7: Distribution of Moru Oak forests in Shimla district**

Figure 8 reveals that coverage of Deodar forests in Shimla district of Himachal Pradesh. It was evident from the result that among the nine types of forests deodar forest is most widely distributed across the district and covers a large area of 54222.31 ha in it. The three elevation classes categorized in it revealed that the elevation class  $E_1$  ranged from 900 to 1800 m amsl covering an area of 11636.54 ha, while the elevation  $E_2$  from 1800 to 2700 m amsl was spread across an area of 41088.61 ha and elevation class  $E_3$  from 2700-3600 m amsl covered an area of 1497.16 ha. The result suggests that major zone of distribution of deodar forest in Shimla district is between 1800-2700 m amsl. Colour scheme of red for low ( $E_1$ ), blue for medium ( $E_2$ ) and green for high ( $E_3$ ) elevation classes were used.

Figure 9 displays the distribution of western mixed coniferous forests in the Shimla district suggesting that this forest is gregariously distributed in and around central part of the Shimla district and covers an area of 69441.06 ha in it.  $E_1$  elevation class in it ranged from 1200 to 2100 m amsl and covered an area of 2011.47 ha at, while  $E_2$  elevation class ranged from 2100 to 3000 m amsl and covered an area of 64579.39 ha whereas,  $E_3$  elevation ranging from 3000-3900 m amsl covered an area of 2850.20 ha. Thus, the distribution of this forest type in the Shimla district suggests that this forest occurs primarily between 2100-3000 m amsl. Colour scheme of red for low ( $E_1$ ), blue for medium ( $E_2$ ) and green for high ( $E_3$ ) elevation class was used.

Figure 10 reveals that moist temperate lower deciduous forest occur in small patches in different parts of the district and covers an area of 720.55 ha in the Shimla district. It was categorized into three elevation classes as:  $E_1$  elevation class ranging from 1000 to 1800 m amsl covering an area of 168.81 ha,  $E_2$  elevation class ranging from 1800 to 2400 m amsl covering an area of 442.20 ha and  $E_3$  elevation class ranging from 2400 to 2700 m amsl covering an area of 109.54 ha. Thus, major distribution of this forest in Shimla district is between 1800-2400 m amsl. Colour scheme of red for low ( $E_1$ ), blue for medium ( $E_2$ ) and green for high ( $E_3$ ) elevation class have been used in the figure 10.

Figure 11 reveals that coverage of Kail forests in Shimla district of Himachal Pradesh. It is evident from the result that among the nine types of forests Kail forest is one of the most widely distributed across the Shimla district covering a was tract of area (17550.64 ha). Three elevation classes categorized in it revealed that the elevation class  $E_1$  ranged from 1400 to 2100 m amsl covering an area of 567.40 ha, while the elevation  $E_2$  from 2100 to 2800 m amsl was spread across an area of 16847.09 ha and elevation class  $E_3$  from 2800-3600 m amsl



covered an area of 136.15 ha. The result suggests that major zone of distribution of Kail forest in Shimla district is between 2100-2800 m amsl. Colour scheme of red for low ( $E_1$ ), blue for medium ( $E_2$ ) and green for high ( $E_3$ ) elevation classes were used.

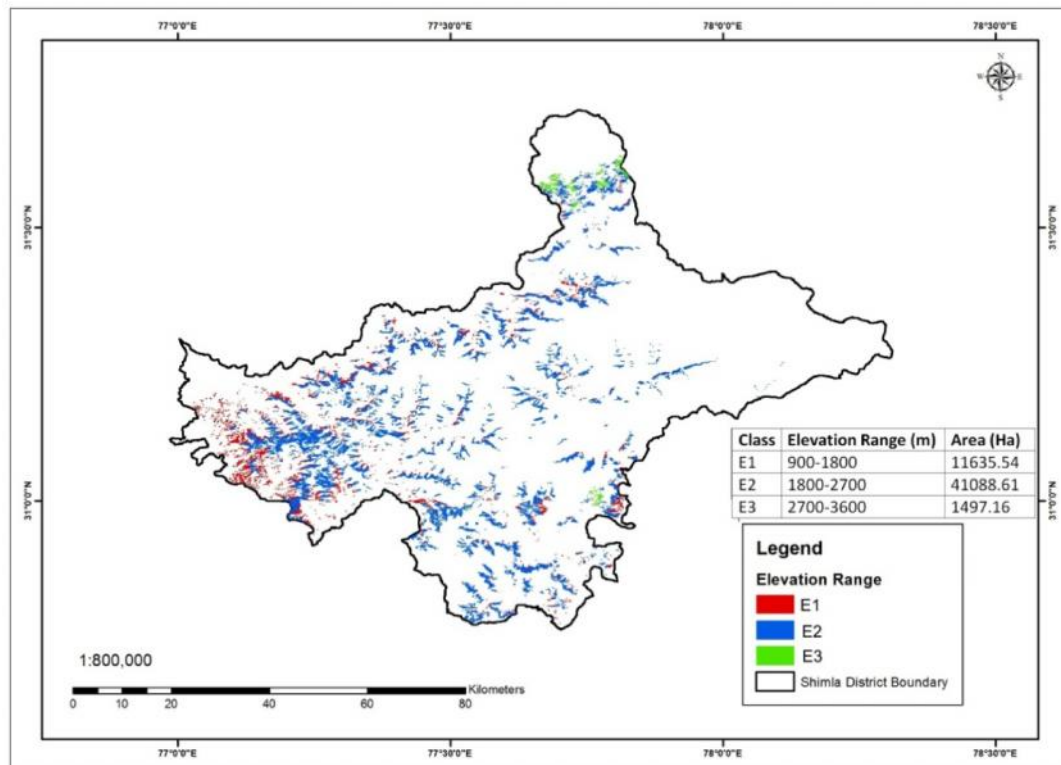


**Figure 8: Distribution of Deodar forests in Shimla district**

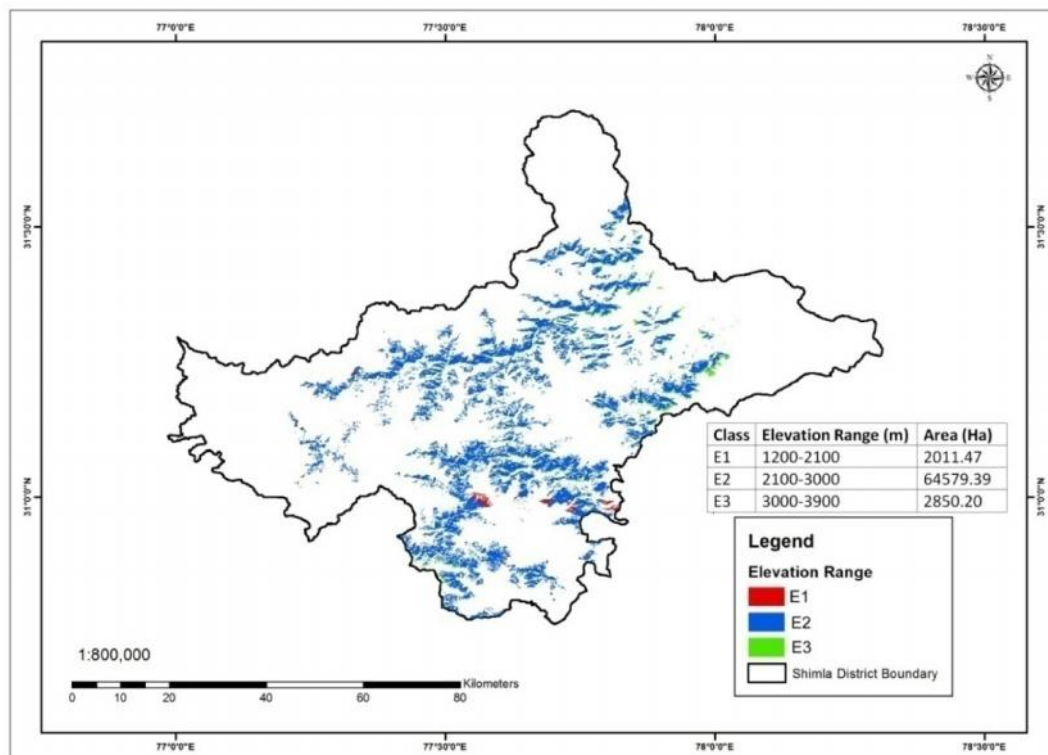


**Figure 9: Distribution of western mixed coniferous forests in Shimla district**

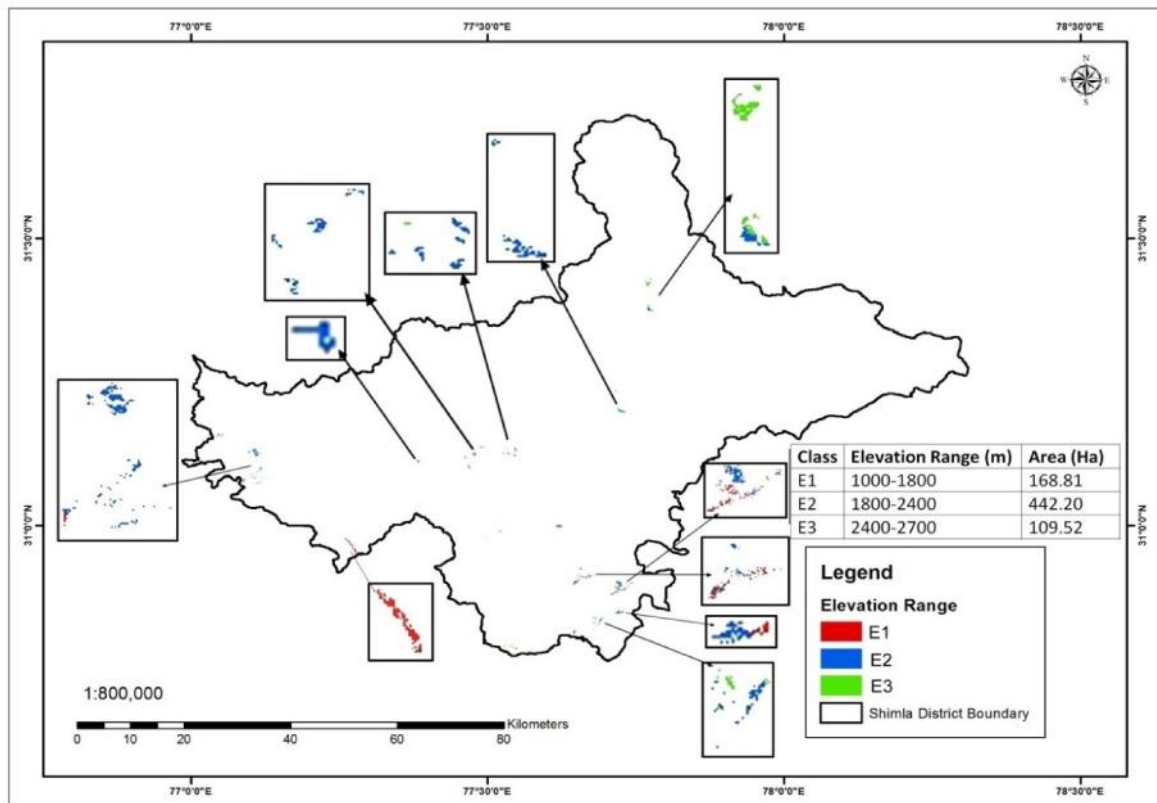


**Figure 10: Distribution of moist temperate lower deciduous forests in Shimla district**

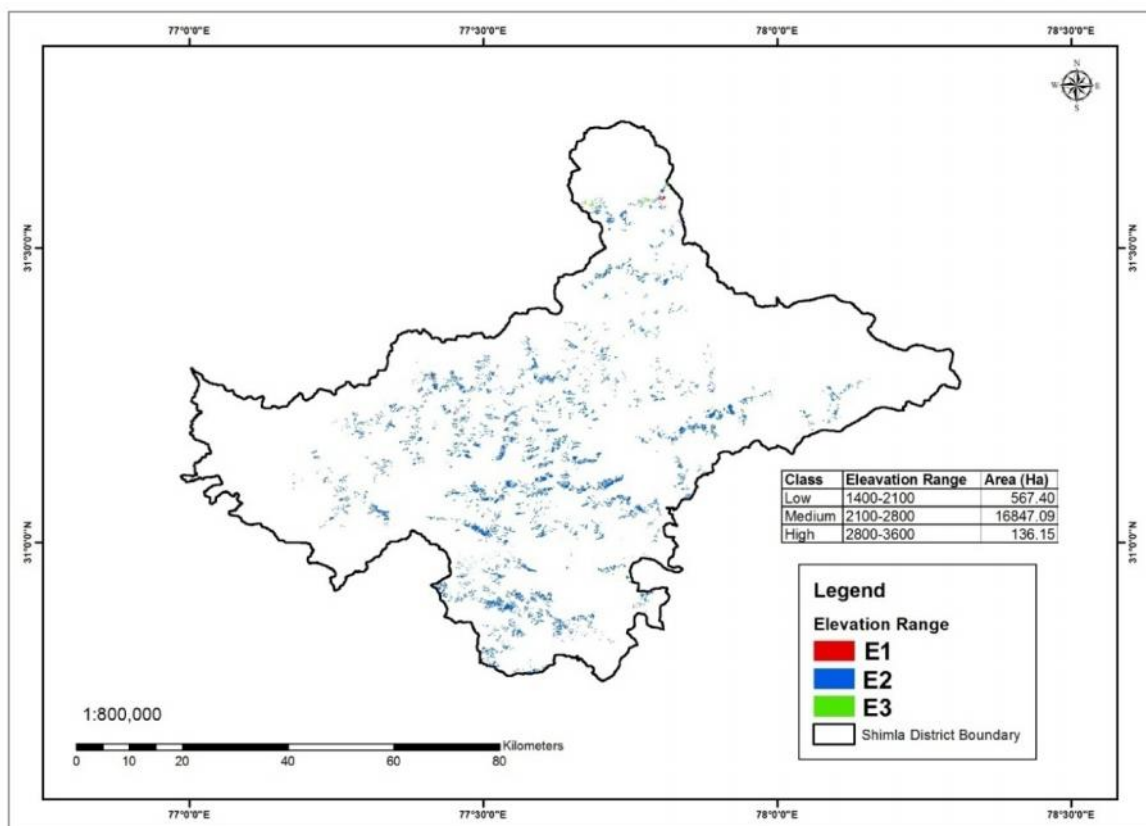


**Figure 11: Distribution of Kail forests in Shimla district.**

Figure 12 reveals that Kharsu Oak forests occur in small sporadic patches in district and covers an area of 284.78 ha in the district and was categorized into three elevation classes as: E<sub>1</sub> elevation class ranging from 2300 to 2800 m amsl covering an area of 59.62 ha, E<sub>2</sub> elevation class ranging from 2800 to 3200 m amsl covering an area of 108.09 ha and E<sub>3</sub> elevation class ranging from 3200 to 3600 m amsl covering an area of 117.07 ha. Thus, major distribution of this forest in Shimla district is between 2800 to 3600 m amsl. Colour scheme of red for low (E<sub>1</sub>), blue for medium (E<sub>2</sub>) and green for high (E<sub>3</sub>) elevation class have been used in the figure 12.

Figure 13 reveals that upper Oak-Fir forests occurs in small concentrated patch along the eastern parts Shimla district. Upper Oak-Fir forests covers an area of 796.05 ha in the district and was categorized into three elevation classes as: E<sub>1</sub> elevation class ranging from 2100 to 2600 m amsl covering an area of 262.62 ha, E<sub>2</sub> elevation class ranging from 2600 to 3100 m amsl covering an area of 507.37 ha and E<sub>3</sub> elevation class ranging from 3100 to 3500 m amsl covering an area of 26.06 ha. Thus, major distribution of this forest in Shimla district is between 2600 to 3500 m amsl. Colour scheme of red for low (E<sub>1</sub>), blue for medium (E<sub>2</sub>) and green for high (E<sub>3</sub>) elevation class have been used in the figure 13.

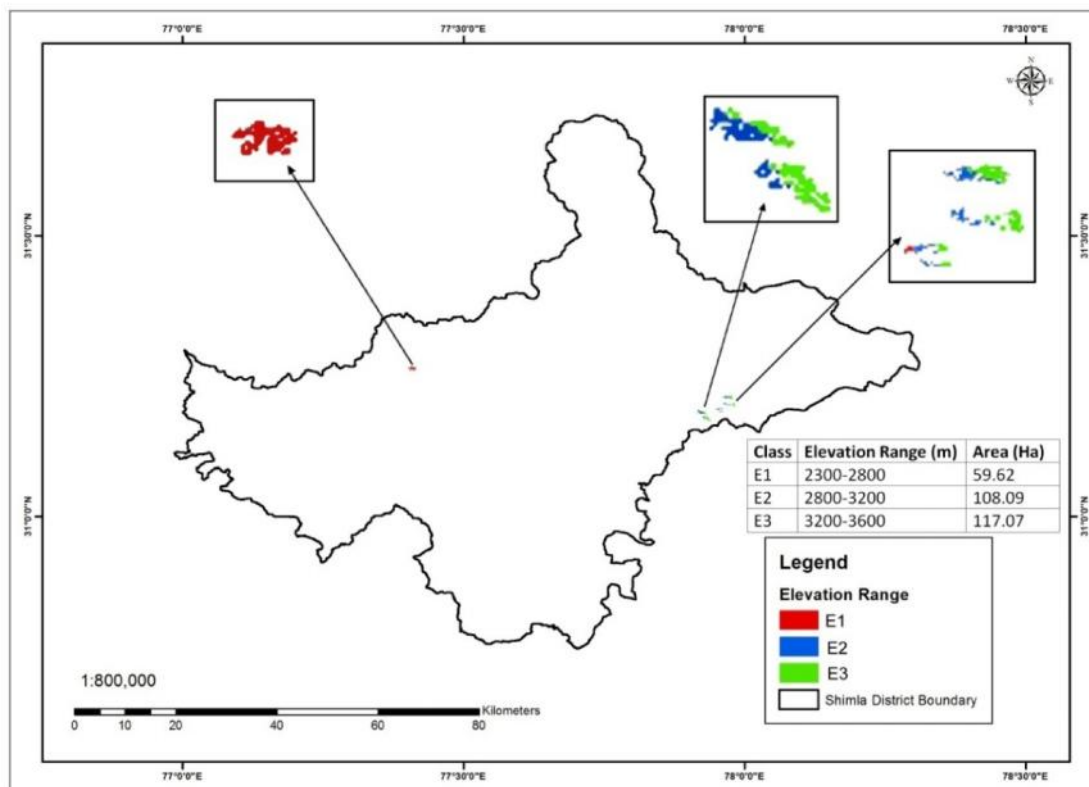


**Figure 12: Distribution of Kharsu Oak forests in Shimla district**

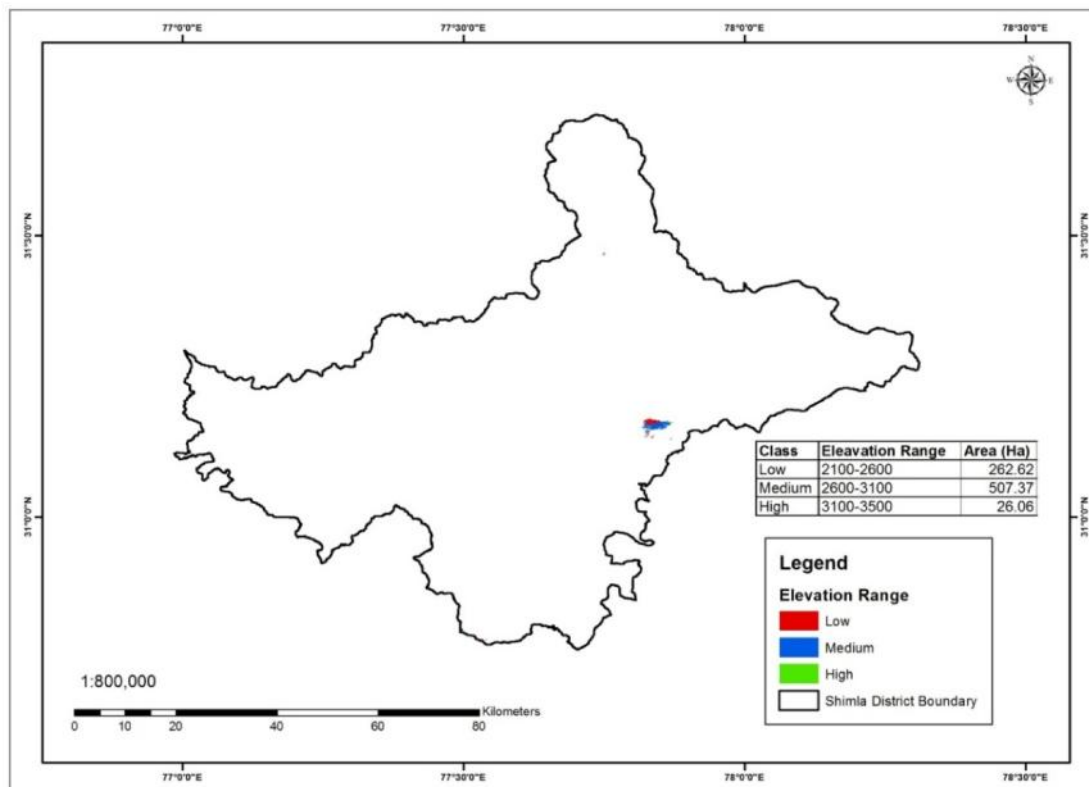


**Figure 13: Distribution of upper Oak-Fir forest in Shimla district**

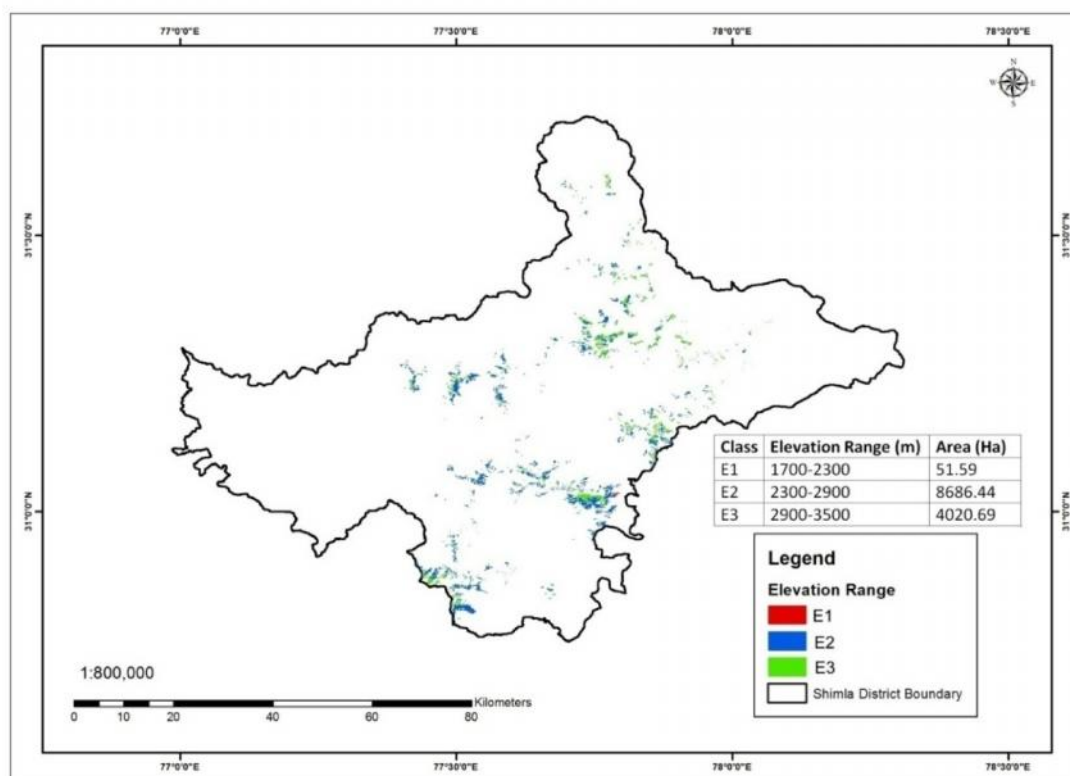


**Figure 14: Distribution of moist temperate upper deciduous forests in Shimla district**

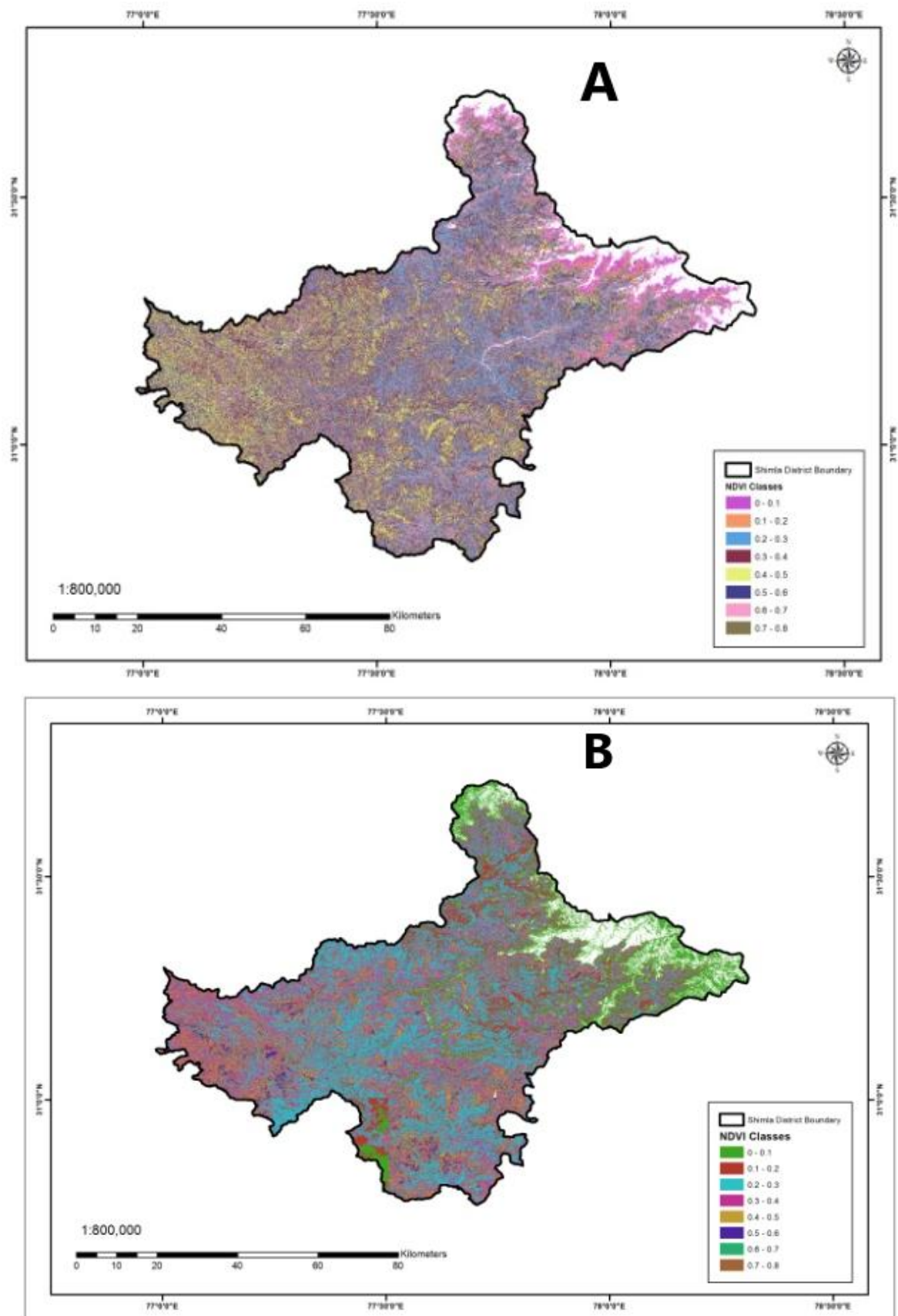


**Figure 15: NDVI of vegetation in Shimla district for the years 2008 (A) and 2013 (B) developed by using LISS III imagery**

Figure 14 reveals that coverage of moist temperate upper deciduous forest in Shimla district of Himachal Pradesh is much concentrated between northern and southern ends of the district, comparatively eastern and western parts are much devoid of this forest type. Moist temperate upper deciduous forests in Shimla covers an area of 12758.72 ha in the district and was categorized into three elevation classes as:  $E_1$  elevation class ranging from 1700 to 2300 m amsl covering an area of 51.59 ha,  $E_2$  elevation class ranging from 2300 to 2900 m amsl covering an area of 8686.44 ha and  $E_3$  elevation class ranging from 2900 to 3500 m amsl covering an area of 4020.69 ha. Thus, major distribution of this forest in Shimla district is between 2300 to 2900m amsl. Colour scheme of red for low ( $E_1$ ), blue for medium ( $E_2$ ) and green for high ( $E_3$ ) elevation class have been used in the figure 10.

LISS III imageries of Shimla district for the years 2008 and 2013 processed for developing Normalized Difference Vegetation Index (NDVI) of vegetation revealed 8 NDVI intervals ranging from 0-0.1 to 0.7-0.8 (Figure 15). The NDVI change matrix (Table 3) obtained from comparing NDVI images revealed that, in the district barren areas and /or infrastructure and /or forest degradation and /or land use change has increased from 2008 to 2013 as there is an increase 82892.06 ha area in the NDVI class from 0-3 conversely it was observed that area in the NDVI range from 0.3 to 0.7, which represent forest vegetation has decreased by 77397.66 ha during this interval.

**Table 3: NDVI change matrix for the years 2008 and 2013.**

| NDVI Range        | Area (ha)        |                  | Change in area (ha) | Trend     |
|-------------------|------------------|------------------|---------------------|-----------|
|                   | 2008             | 2013             |                     |           |
| -1 – 0            | 31889.79         | 26387.44         | 5502.35             | Decreased |
| 0 - 0.1           | 30079.65         | 55768.94         | 25689.29            | Increased |
| 0.1 - 0.2         | 60492.10         | 81350.88         | 20858.78            | Increased |
| 0.2 - 0.3         | 125504.28        | 161848.28        | 36343.99            | Increased |
| 0.3 - 0.4         | 140549.06        | 100672.32        | -39876.74           | Decreased |
| 0.4 - 0.5         | 94454.59         | 63580.02         | -30874.58           | Decreased |
| 0.5 - 0.6         | 23831.90         | 17505.96         | -6325.94            | Decreased |
| 0.6 - 0.7         | 969.09           | 648.70           | -320.40             | Decreased |
| 0.7 - 0.8         | 1.07             | 7.98             | 6.91                | Increased |
| 0.8 - 0.9         | 0.05             | 0.96             | 0.91                | Increased |
| 0.9 – 1.0         | 0.05             | 0.16             | 0.11                | Increased |
| <b>Total area</b> | <b>507771.64</b> | <b>507771.64</b> | <b>165799.99</b>    |           |

Remote sensing and GIS are complementary technologies that, when combined, enable improved monitoring, mapping, and management of forest resources (Franklin 2001).

Especially when area is large and, time and labour oriented. The present study intended to prepare a forest inventory of Himalayan temperate forest in Shimla district of HP which include survey of the location, composition, and distribution of forest resources. To complete the task i.e. entire forest inventory production cycle, from planning to map generation, could have taken several years. Thus, use of remote sensing and GIS was considered to be best. The forest cover in this 'forest type group' was determined by using LISS III imagery of the year 2016 and following the Champion and Seth (1968) classification of 'Forests in India'. Many workers around the world have used this technique for forest mapping (Gupta & Sharma, 2012; Rehman *et al.* 2018; Koppada and Janagoudar, 2017).

The digital elevation model (DEM) of any area provides knowledge on its geophysical features. In present study it was used to identify three elevation classes ( $E_1$ ,  $E_2$  and  $E_3$ ) based on their respective elevation ranges. Many workers have used this technique to define geophysical features of land (Moore *et al.* 1991).

NDVI is another tool that employs the multi-spectral remote sensing data technique to find vegetation index, land cover classification, vegetation, water bodies, open area, scrub area, hilly areas, agricultural area, thick forest, thin forest with few band combinations of the remote sensed data. NDVI of vegetation is also one of the valuable measures of carbon dynamics (Baniya *et al.* 2018). NDVI is used as an ancillary data layer in the classification process to enhance the distinction among vegetation classes to reduce the shadow effect perpetrated by variations in topography. It is highly correlated with vegetation parameters like green leaf biomass, leaf area and health of plant. It is an indicator of the photosynthetic activity of vegetation. The values of NDVI range from -1 to +1.

NDVI method is applied according to its characteristic like vegetation at different NDVI threshold values such as 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5 and so on. NDVI is calculated as a ratio difference between measured canopy reflectance in the red and near infrared bands respectively (Rao *et al.* 2005). NDVI is obtained on pixel by pixel basis subtraction of the value of red band from the value of NIR band and divided by their sum. Very low value of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high value indicates temperate and tropical rainforests (0.6 to 0.8). Bare soil is represented with NDVI values, which are closest to '0' and water bodies are represented with negative NDVI values. Thus, it is explicable from the Table 3 that during the interval between 2008 to 2013 in Shimla district



there was increase in area under grasslands/shrublands and it has been due to degradation of compact forests into thin forests or grasslands or shrublands. Many workers around the world are using this property (NDVI or FCC images) of satellite data in recognising vegetation and its composition and, estimating their functional traits (Maselli and Chiesi 2006; Barbosa *et al.* 2006; Bhandari *et al.* 2012; Almeida *et al.* 2014; Gandhi *et al.* 2015; Jeevalakshmi *et al.* 2016; Reddy and Prasad 2018; Zaitunah *et al.* 2018 and Baniya *et al.* 2018).

## 4.2 FLORISTIC COMPOSITION

Nine types of forests (Ban Oak, Moru Oak, Deodar, Western mixed coniferous, Moist temperate lower deciduous, Kail, Kharsu Oak, Upper Oak-Fir and Moist temperate upper deciduous forests) in Himalayan moist temperate forest of Shimla district had trees species ranging from 9-20 (Table 4). Kail forests showed maximum number of tree species (20) while moist temperate upper deciduous forests had least number of trees species (9). Moru Oak, Ban Oak, Deodar and western mixed coniferous forests had intermediate number of tree species (14-18). Kharsu Oak, moist temperate lower deciduous, moist temperate upper deciduous and upper Oak-Fir forests also had comparatively less number of tree species (9-13). Among different tree species *Abies pindrow*, *Abies spectabilis*, *Acer caesium*, *Cedrus deodara*, *Juglans regia*, *Picea smithiana*, *Pinus roxburghii*, *Pinus wallichiana*, *Prunus cornuta*, *Quercus floribunda* and *Quercus semecarpifolia* recorded in majority of forests. While tree species like, *Alnus nitida*, *Cupressus torulosa*, *Fraxinus micrantha*, *Mallotus philippensis*, *Myrica esculenta*, *Pistacia integerrima*, *Prunus armeniaca*, *Prunus cerasoides*, *Rhamnus triquetra* and *Ulmus wallichiana* were recorded in very few forest types.

The number of shrub species in these forests were 96 and in different forests it varied from 41 to 60 (Table 5). Lowest number of species were recorded in Kharsu Oak and moist temperate upper deciduous forests. Highest number of shrub species were recorded in Ban Oak forests. Though the shrub species number in Deodar, western mixed coniferous, moist temperate lower deciduous and Kail forests was on higher side and in Upper Oak-Fir forests on lower side. Moru oak forests had intermediate shrub species number. The shrub species like, *Andrachne cordifolia*, *Berberis aristata*, *Berberis lycium*, *Buddleja crispa*, *Clematis barbellata*, *Clematis buchananiana*, *Coriaria nepalensis*, *Cotoneaster bacillaris*, *Cotoneaster microphylla*, *Daphne papyracea*, *Debregeasia salicifolia*, *Desmodium elegans*, *Deutzia compacta*, *Elaeagnus parvifolia*, *Elsholtzia fruticosa*, *Hypericum dyeri*, *Indigofera*



**Table 4: Trees species under different forest types in Himalayan moist temperate forest in Shimla district (H.P)**

| Tree Species                    | Forest types |           |           |           |           |           |           |           |          |
|---------------------------------|--------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|
|                                 | FT-1         | FT-2      | FT-3      | FT-4      | FT-5      | FT-6      | FT-7      | FT-8      | FT-9     |
| <i>Abies pindrow</i>            | -            | +         | +         | +         | +         | +         | +         | +         | +        |
| <i>Abies spectabilis</i>        | -            | +         | +         | +         | -         | +         | +         | +         | +        |
| <i>Acer caesium</i>             | -            | +         | -         | +         | +         | +         | +         | +         | +        |
| <i>Acer acuminatum</i>          | -            | -         | -         | -         | -         | -         | +         | +         | -        |
| <i>Aesculus indica</i>          | -            | +         | -         | +         | +         | -         | +         | +         | -        |
| <i>Albizia chinensis</i>        | +            | -         | -         | -         | -         | -         | -         | -         | -        |
| <i>Alnus nitida</i>             | -            | -         | -         | +         | -         | +         | -         | -         | -        |
| <i>Bauhinia variegata</i>       | +            | -         | -         | -         | -         | -         | -         | -         | -        |
| <i>Cedrus deodara</i>           | +            | +         | +         | +         | +         | +         | +         | -         | +        |
| <i>Cupressus torulosa</i>       | -            | +         | -         | -         | -         | +         | -         | -         | -        |
| <i>Fraxinus micrantha</i>       | -            | -         | -         | -         | +         | -         | -         | -         | -        |
| <i>Ilex dipyrena</i>            | -            | +         | +         | +         | -         | -         | -         | -         | -        |
| <i>Juglans regia</i>            | +            | -         | -         | +         | +         | +         | +         | +         | +        |
| <i>Lyonia ovalifolia</i>        | +            | +         | +         | +         | -         | +         | -         | -         | -        |
| <i>Mallotus philippensis</i>    | +            | -         | -         | -         | -         | -         | -         | -         | -        |
| <i>Myrica esculenta</i>         | +            | -         | -         | -         | -         | -         | -         | -         | -        |
| <i>Neolitsea pallens</i>        | +            | -         | +         | +         | -         | +         | -         | -         | -        |
| <i>Picea smithiana</i>          | -            | +         | +         | +         | +         | +         | +         | +         | +        |
| <i>Pinus roxburghii</i>         | +            | -         | +         | -         | -         | -         | -         | -         | -        |
| <i>Pinus wallichiana</i>        | +            | +         | +         | +         | +         | +         | +         | +         | -        |
| <i>Pistacia integerrima</i>     | +            | -         | -         | -         | -         | -         | -         | -         | -        |
| <i>Populus ciliata</i>          | -            | -         | +         | +         | +         | +         | -         | -         | -        |
| <i>Prunus armeniaca</i>         | +            | -         | +         | -         | -         | -         | -         | -         | -        |
| <i>Prunus cerasoides</i>        | -            | -         | +         | -         | -         | +         | -         | -         | -        |
| <i>Prunus cornuta</i>           | -            | +         | +         | -         | +         | +         | +         | +         | +        |
| <i>Pyrus lanata</i>             | -            | +         | -         | -         | +         | -         | -         | -         | -        |
| <i>Pyrus pashia</i>             | +            | -         | +         | -         | -         | +         | -         | -         | -        |
| <i>Quercus floribunda</i>       | -            | +         | +         | -         | -         | +         | +         | +         | -        |
| <i>Quercus leucotrichophora</i> | +            | -         | +         | -         | -         | +         | -         | -         | -        |
| <i>Quercus semecarpifolia</i>   | -            | -         | +         | +         | -         | -         | +         | +         | +        |
| <i>Rhamnus triquetra</i>        | -            | -         | -         | -         | -         | +         | -         | -         | -        |
| <i>Rhododendron arboreum</i>    | +            | +         | +         | +         | -         | +         | -         | -         | -        |
| <i>Taxus wallichiana</i>        | -            | -         | -         | +         | -         | +         | +         | +         | +        |
| <i>Ulmus wallichiana</i>        | -            | -         | -         | -         | +         | -         | -         | -         | -        |
| <b>Total number of trees</b>    | <b>15</b>    | <b>14</b> | <b>18</b> | <b>16</b> | <b>12</b> | <b>20</b> | <b>13</b> | <b>12</b> | <b>9</b> |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests.

**Table 4: Shrubs species under different forest types in Himalayan moist temperate forest in Shimla district (H.P)**

| Shrub species                    | Forest types |      |      |      |      |      |      |      |      |
|----------------------------------|--------------|------|------|------|------|------|------|------|------|
|                                  | FT-1         | FT-2 | FT-3 | FT-4 | FT-5 | FT-6 | FT-7 | FT-8 | FT-9 |
| <i>Agave angustifolia</i>        | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Agave cantula</i>             | +            | +    | -    | -    | -    | -    | -    | -    | -    |
| <i>Andrachne cordifolia</i>      | +            | -    | -    | +    | +    | +    | -    | +    | +    |
| <i>Argyrobolium flaccidum</i>    | +            | -    | -    | -    | +    | -    | -    | +    | +    |
| <i>Asclepias curassavica</i>     | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Asparagus adscendens</i>      | +            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Berberis aristata</i>         | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Berberis lycium</i>           | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Boehmeria platyphylla</i>     | +            | -    | +    | -    | +    | +    | -    | -    | -    |
| <i>Buddleja asiatica</i>         | +            | -    | +    | -    | +    | +    | -    | -    | -    |
| <i>Buddleja crispa</i>           | -            | +    | +    | +    | -    | +    | +    | +    | +    |
| <i>Carissa carandas</i>          | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Clematis barbellata</i>       | -            | +    | +    | +    | +    | +    | -    | -    | -    |
| <i>Clematis buechananiana</i>    | +            | +    | -    | +    | +    | +    | -    | -    | -    |
| <i>Clematis gouriana</i>         | -            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Clematis grata</i>            | +            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Clematis montana</i>          | +            | -    | -    | +    | +    | +    | -    | -    | -    |
| <i>Colebrookia oppositifolia</i> | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Coriaria nepalensis</i>       | +            | +    | +    | +    | +    | +    | -    | -    | -    |
| <i>Cotinus coggygria</i>         | +            | -    | -    | +    | -    | -    | -    | -    | -    |
| <i>Cotoneaster bacillaris</i>    | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Cotoneaster microphylla</i>   | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Daphne papyracea</i>          | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Debregeasia salicifolia</i>   | +            | +    | +    | +    | -    | +    | -    | -    | -    |
| <i>Desmodium concinnum</i>       | -            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Desmodium elegans</i>         | +            | +    | +    | +    | +    | +    | +    | +    | -    |
| <i>Deutzia compacta</i>          | -            | +    | +    | +    | -    | -    | +    | +    | +    |
| <i>Deutzia staminea</i>          | -            | +    | -    | -    | -    | -    | +    | +    | +    |
| <i>Dodonaea viscosa</i>          | +            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Elaeagnus parvifolia</i>      | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Elsholtzia fruticosa</i>      | -            | -    | -    | +    | +    | +    | +    | +    | -    |
| <i>Euphorbia royleana</i>        | +            | -    | +    | -    | +    | -    | -    | -    | -    |
| <i>Flemingia macrophylla</i>     | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Hedera nepalensis</i>         | -            | -    | -    | +    | +    | +    | -    | -    | -    |
| <i>Hypericum dyeri</i>           | +            | -    | -    | +    | +    | +    | +    | +    | -    |
| <i>Hypericum oblongifolium</i>   | +            | +    | +    | -    | -    | -    | -    | -    | -    |
| <i>Indigofera atropurpurea</i>   | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Indigofera dosua</i>          | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Indigofera heterantha</i>     | +            | -    | +    | +    | -    | -    | +    | +    | +    |
| <i>Inula cuspidata</i>           | -            | -    | -    | +    | -    | +    | -    | -    | -    |

| Shrub species                      | Forest types |      |      |      |      |      |      |      |      |
|------------------------------------|--------------|------|------|------|------|------|------|------|------|
|                                    | FT-1         | FT-2 | FT-3 | FT-4 | FT-5 | FT-6 | FT-7 | FT-8 | FT-9 |
| <i>Jasminum humile</i>             | +            | +    | +    | +    | -    | -    | -    | -    | -    |
| <i>Jasminum mesneyi</i>            | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Jasminum officinale</i>         | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Justicia adhatoda</i>           | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Lantana camara</i>              | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Lespedeza gerardiana</i>        | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Lespedeza juncea</i>            | +            | -    | +    | +    | -    | -    | +    | +    | +    |
| <i>Lespedeza stenocarpa</i>        | -            | +    | -    | -    | +    | +    | -    | -    | -    |
| <i>Lonicera angustifolia</i>       | -            | -    | +    | -    | +    | +    | -    | -    | -    |
| <i>Lonicera quinquelocularis</i>   | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Lotus corniculatus</i>          | -            | -    | -    | -    | -    | -    | -    | -    | +    |
| <i>Meriandra strobilifera</i>      | +            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Myrsine africana</i>            | +            | -    | +    | -    | +    | +    | +    | +    | +    |
| <i>Opuntia stricta</i>             | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Osyris quadripartita</i>        | -            | -    | +    | -    | -    | +    | -    | -    | -    |
| <i>Parthenocissus himalayana</i>   | -            | +    | -    | -    | -    | -    | -    | -    | -    |
| <i>Prinsepia utilis</i>            | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Pteracanthus urticifolius</i>   | -            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Rabdosia rugosa</i>             | -            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Randia tetrasperma</i>          | +            | -    | +    | -    | -    | -    | -    | -    | -    |
| <i>Rhamnus virgatus</i>            | -            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Ribes emodense</i>              | -            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Rosa brunonii</i>               | +            | +    | +    | +    | +    | +    | -    | -    | -    |
| <i>Rosa macrophylla</i>            | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Rosa sericea</i>                | -            | +    | -    | +    | +    | +    | +    | +    | +    |
| <i>Rubia cordifolia</i>            | +            | -    | -    | -    | -    | -    | -    | -    | -    |
| <i>Rubus biflorus</i>              | -            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Rubus ellipticus</i>            | +            | -    | +    | +    | +    | +    | -    | -    | -    |
| <i>Rubus foliolosus</i>            | -            | -    | +    | -    | +    | +    | +    | +    | +    |
| <i>Rubus hypargyryus</i>           | -            | +    | -    | -    | +    | +    | +    | +    | +    |
| <i>Rubus macilentus</i>            | -            | +    | -    | +    | +    | -    | -    | -    | -    |
| <i>Sageretia thea</i>              | +            | +    | +    | -    | +    | +    | -    | -    | -    |
| <i>Salix denticulata</i>           | -            | +    | -    | +    | +    | +    | +    | +    | +    |
| <i>Sarcococca saligna</i>          | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Schisandra grandiflora</i>      | -            | +    | +    | -    | +    | -    | -    | -    | -    |
| <i>Scurrula elata</i>              | -            | -    | +    | +    | -    | -    | -    | -    | -    |
| <i>Skimmia laureola</i>            | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Solanum myriacanthum</i>        | +            | +    | +    | -    | -    | -    | -    | -    | -    |
| <i>Sorbaria tomentosa</i>          | -            | -    | -    | +    | +    | +    | +    | +    | +    |
| <i>Spiraea bella</i>               | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Spiraea canescens</i>           | +            | +    | +    | -    | +    | +    | -    | -    | -    |
| <i>Strobilanthes atropurpureus</i> | -            | +    | +    | +    | +    | +    | +    | +    | +    |

| Shrub species                     | Forest types |           |           |           |           |           |           |           |           |
|-----------------------------------|--------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                                   | FT-1         | FT-2      | FT-3      | FT-4      | FT-5      | FT-6      | FT-7      | FT-8      | FT-9      |
| <i>Strobilanthes dalhousianus</i> | -            | +         | -         | +         | +         | +         | -         | -         | -         |
| <i>Taxillus vestitus</i>          | -            | -         | +         | +         | -         | -         | -         | -         | -         |
| <i>Thamnocalamus spathiflorus</i> | -            | +         | -         | +         | +         | +         | +         | +         | +         |
| <i>Viburnum cotinifolium</i>      | +            | +         | +         | +         | +         | +         | +         | +         | +         |
| <i>Viburnum foetens</i>           | -            | -         | -         | +         | +         | +         | +         | +         | +         |
| <i>Viburnum foetida</i>           | -            | +         | -         | -         | -         | -         | -         | -         | -         |
| <i>Viburnum mullaha</i>           | -            | -         | -         | -         | +         | +         | +         | +         | +         |
| <i>Viburnum nervosum</i>          | -            | -         | -         | +         | +         | +         | -         | -         | -         |
| <i>Vitex negundo</i>              | +            | -         | -         | -         | -         | -         | -         | -         | -         |
| <i>Wikstroemia canescens</i>      | -            | +         | +         | +         | -         | -         | +         | +         | +         |
| <i>Woodfordia fruticosa</i>       | +            | -         | +         | -         | -         | -         | -         | -         | -         |
| <i>Yucca gloriosa</i>             | +            | -         | -         | -         | -         | -         | -         | -         | -         |
| <i>Zanthoxylum armatum</i>        | +            | -         | +         | +         | +         | +         | -         | -         | -         |
| <i>Zizyphus oxyphylla</i>         | +            | -         | -         | -         | -         | -         | -         | -         | -         |
| <b>Total number of shrubs</b>     | <b>60</b>    | <b>49</b> | <b>58</b> | <b>54</b> | <b>56</b> | <b>56</b> | <b>41</b> | <b>43</b> | <b>41</b> |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests.

*atropurpurea*, *Indigofera dosua*, *Indigofera heterantha*, *Jasminum officinale*, *Lespedeza gerardiana*, *Lespedeza juncea*, *Lonicera quinquelocularis*, *Myrsine africana*, *Prinsepia utilis*, *Pteracanthus urticifolius*, *Rabdosia rugosa*, *Rhamnus virgatus*, *Ribes emodense*, *Rosa brunonii*, *Rosa macrophylla*, *Rosa sericea*, *Rubus biflorus*, *Rubus ellipticus*, *Rubus foliolosus*, *Rubus hypargyrus*, *Salix denticulata*, *Sarcococca saligna*, *Skimmia laureola*, *Sorbaria tomentosa*, *Spiraea bella*, *Spiraea canescens*, *Strobilanthes atropurpureus*, *Thamnocalamus spathiflorus*, *Viburnum cotinifolium*, *Viburnum foetens*, *Wikstroemia canescens* and *Zanthoxylum armatum* were recorded in majority of forests. While species like *Agave angustifolia*, *Agave cantula*, *Clematis montana*, *Colebrookia oppositifolia*, *Lespedeza stenocarpa*, *Parthenocissus himalayana*, *Viburnum foetida*, *Vitex negundo* and *Zizyphus oxyphylla* were restricted to Ban Oak and/or Moru Oak forests. While, *Inula cuspidata* was restricted to western mixed coniferous and Kail forests.

In Himalayan moist temperate forest of Shimla district 173 forbs species representing herbs, grasses, legumes, ferns, sedges, medicinal plants etc. were recorded in different forests and their number in individual forest varied from 73 to 105. Ban Oak, Kharsu Oak and western mixed coniferous forests showed high number (104-105) of forb species. Moru Oak

and moist temperate lower deciduous forests had intermediate number (95 and 91, respectively) of forb species while Deodar, upper Oak-Fir and moist temperate upper deciduous forests showed low number (73-78) of forb species. Forbs species like, *Arabis amplexicaulis*, *Artemisia indica*, *Aster molliusculus*, *Bergenia ciliata*, *Bistorta amplexicaulis*, *Carex breviculmis*, *Corydalis govaniana*, *Dicliptera bupleuroides*, *Dioscorea deltoidea*, *Galium asperuloides*, *Geranium lucidum*, *Girardinia diversifolia*, *Habenaria intermedia*, *Myriactis nepalensis*, *Nepeta laevigata*, *Plantago depressa*, *Plantago erosa*, *Plectranthus japonicus*, *Podophyllum hexandrum*, *Polygala abyssinica*, *Polygonatum multiflorum*, *Potentilla argyrophylla*, *Primula denticulata*, *Pteris cretica*, *Ranunculus laetus*, *Scrophularia himalensis*, *Stellaria media*, *Themeda anathera*, *Trifolium repens*, *Urtica ardens*, *Urtica dioica*, *Achyranthes bidentata*, *Adiantum venustum*, *Ainsliaea aptera*, *Ajuga bracteosa*, *Androsace lanuginosa*, *Androsace rotundifolia*, *Androsace sarmentosa*, *Anemone obtusiloba*, *Angelica glauca*, *Arisaema flavum*, *Artemisia roxburghiana*, *Astilbe rivularis*, *Bergenia stracheyi*, *Carex cardiolepis*, *Carex remota*, *Chenopodium opulifolium*, *Clinopodium vulgare*, *Erigeron bellidioides*, *Erigeron multicaulis*, *Fagopyrum dibotrys*, *Fragaria nubicola*, *Galium aparine*, *Gypsophila cerastioides*, *Halenia elliptica*, *Heracleum candicans*, *Impatiens scabrida*, *Iris nepalensis*, *Lamium album*, *Lotus corniculatus*, *Pedicularis hoffmeisteri*, *Phragmites communis*, *Polygonatum cirrhifolium*, *Polygonatum verticillatum*, *Primula petiolaris*, *Ranunculus hirtellus*, *Roscoeia purpurea*, *Rumex nepalensis*, *Salvia nubicola*, *Selinum candollii*, *Senecio chrysanthemoides*, *Sibbaldia cuneata*, *Silene griffithii*, *Silene vulgaris*, *Smilacina purpurea*, *Swertia cordata*, *Thalictrum foliolosum*, *Thymus linearis*, *Valeriana jatamansi*, *Valeriana pyrolaefolia*, *Verbascum thapsus*, *Vicatia coniiifolia* and *Viola canescens* were recorded in majority of forests (Table 6).

**Table 6: Forb species under different forest types in Himalayan moist temperate forest in Shimla district (H.P)**

| Forb species                 | Forest types |      |      |      |      |      |      |      |      |
|------------------------------|--------------|------|------|------|------|------|------|------|------|
|                              | FT-1         | FT-2 | FT-3 | FT-4 | FT-5 | FT-6 | FT-7 | FT-8 | FT-9 |
| <i>Achyranthes aspera</i>    | +            | +    | -    | -    | -    | +    | -    | -    | -    |
| <i>Achyranthes bidentata</i> | +            | -    | +    | +    | +    | +    | +    | +    | +    |
| <i>Adiantum venustum</i>     | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Agrimonia pilosa</i>      | -            | +    | +    | +    | +    | -    | -    | +    | +    |
| <i>Ainsliaea aptera</i>      | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Ajuga bracteosa</i>       | +            | +    | +    | +    | +    | +    | +    | +    | +    |
| <i>Ajuga parviflora</i>      | +            | +    | -    | -    | -    | +    | -    | -    | -    |
| <i>Amaranthus blitum</i>     | +            | -    | -    | -    | +    | +    | -    | -    | -    |
| <i>Anaphalis busua</i>       | -            | -    | +    | -    | -    | -    | +    | -    | -    |

|                                  |   |   |   |   |   |   |   |   |   |
|----------------------------------|---|---|---|---|---|---|---|---|---|
| <i>Anaphalis contorta</i>        | + | + | - | - | + | + | + | + | + |
| <i>Androsace lanuginosa</i>      | + | + | - | + | + | + | + | + | + |
| <i>Androsace rotundifolia</i>    | + | + | + | - | - | + | + | + | + |
| <i>Androsace sarmentosa</i>      | + | - | - | + | + | + | + | + | + |
| <i>Anemone obtusiloba</i>        | + | - | - | + | + | + | + | + | + |
| <i>Anemone vitifolia</i>         | - | - | + | - | - | - | - | - | - |
| <i>Angelica glauca</i>           | + | - | + | + | - | + | + | + | + |
| <i>Apluda mutica</i>             | - | + | + | + | + | - | - | - | - |
| <i>Aquilegia fragrans</i>        | - | - | - | + | - | - | + | + | - |
| <i>Arabis amplexicaulis</i>      | + | + | - | - | - | + | + | + | - |
| <i>Arctium lappa</i>             | - | + | - | - | + | - | - | + | + |
| <i>Arisaema flavum</i>           | + | + | - | + | + | + | + | + | + |
| <i>Artemisia indica</i>          | + | + | - | + | - | + | + | + | - |
| <i>Artemisia roxburghiana</i>    | + | + | + | + | + | + | + | + | + |
| <i>Artemisia vestita</i>         | - | - | + | + | + | - | - | - | - |
| <i>Arundinella nepalensis</i>    | - | - | - | - | - | - | + | + | - |
| <i>Asplenium dalhousiae</i>      | - | - | - | + | - | - | - | - | - |
| <i>Asplenium trichomanes</i>     | - | - | - | - | - | - | + | + | + |
| <i>Aster molliusculus</i>        | + | + | - | - | - | + | + | + | - |
| <i>Astilbe rivularis</i>         | + | - | - | + | - | + | + | - | + |
| <i>Atylosia scarabaeoides</i>    | + | + | - | - | - | + | - | - | - |
| <i>Bergenia ciliata</i>          | - | + | + | + | - | - | + | + | - |
| <i>Bergenia stracheyi</i>        | + | + | + | + | + | + | + | + | + |
| <i>Bidens biternata</i>          | + | + | - | - | - | + | - | - | - |
| <i>Bistorta amplexicaulis</i>    | + | + | + | + | + | + | + | + | - |
| <i>Bromus mollis</i>             | - | - | + | + | - | - | - | - | - |
| <i>Bupleurum falcatum</i>        | + | + | - | + | - | + | - | - | - |
| <i>Bupleurum hamiltonii</i>      | + | - | - | - | + | + | - | - | - |
| <i>Capillipedium assimile</i>    | - | - | - | + | - | - | - | - | - |
| <i>Carduus nutans</i>            | - | - | - | + | - | - | + | - | + |
| <i>Carex breviculmis</i>         | + | + | - | + | + | + | + | - | - |
| <i>Carex cardiolepis</i>         | + | + | + | + | + | + | + | - | + |
| <i>Carex remota</i>              | + | + | - | + | + | + | + | + | + |
| <i>Cheilanthes albomarginata</i> | - | + | + | - | - | - | - | - | - |
| <i>Cheilanthes brevifrons</i>    | - | - | + | - | - | - | - | - | - |
| <i>Cheilanthes dalhousiae</i>    | - | - | + | - | - | - | - | - | - |
| <i>Chenopodium ambrosioides</i>  | - | - | + | - | - | - | - | - | - |
| <i>Chenopodium opulifolium</i>   | + | + | + | - | + | + | + | + | + |
| <i>Cirsium wallichii</i>         | - | - | - | + | - | - | + | - | + |
| <i>Cissampelos pareira</i>       | - | - | + | - | - | - | - | - | - |
| <i>Clinopodium vulgare</i>       | + | + | - | + | + | + | + | + | + |
| <i>Corydalis govaniana</i>       | + | + | + | + | + | + | + | + | - |
| <i>Crepis sancta</i>             | + | + | - | - | - | + | - | - | - |
| <i>Cyathula tomentosa</i>        | + | - | - | - | - | + | - | - | - |
| <i>Cynodon dactylon</i>          | - | - | + | - | - | - | - | - | - |
| <i>Cynoglossum glochidiatum</i>  | - | - | - | + | - | - | - | - | - |
| <i>Datura stramonium</i>         | + | + | - | - | - | + | - | - | - |
| <i>Delphinium denudatum</i>      | - | - | + | - | - | - | - | - | - |

|                                   |   |   |   |   |   |   |   |   |   |
|-----------------------------------|---|---|---|---|---|---|---|---|---|
| <i>Dichanthium annulatum</i>      | - | - | + | - | - | - | - | - | - |
| <i>Dicliptera bupleuroides</i>    | + | + | + | - | + | + | - | - | - |
| <i>Digitaria sanguinalis</i>      | - | - | + | - | - | - | - | - | - |
| <i>Dioscorea deltoidea</i>        | + | + | - | + | + | + | - | - | - |
| <i>Dioscorea melanophyma</i>      | - | - | - | + | - | - | - | - | - |
| <i>Dryopteris caroli-hopei</i>    | - | - | + | - | - | - | - | - | - |
| <i>Duchesnea indica</i>           | + | - | - | + | - | + | - | - | + |
| <i>Echinochloa crus-galli</i>     | - | - | + | - | - | - | - | - | - |
| <i>Echinops niveus</i>            | + | + | - | - | - | + | - | - | - |
| <i>Erigeron bellidioides</i>      | + | + | - | + | + | + | + | - | + |
| <i>Erigeron multicaulis</i>       | + | + | - | + | + | + | + | + | + |
| <i>Eriophorum comosum</i>         | - | - | + | + | - | - | + | + | + |
| <i>Fagopyrum dibotrys</i>         | + | + | + | + | + | + | + | + | + |
| <i>Fragaria nubicola</i>          | + | + | + | + | + | + | + | + | + |
| <i>Fumaria indica</i>             | - | - | + | - | - | - | - | - | - |
| <i>Galinsoga parviflora</i>       | - | - | + | - | - | - | - | - | - |
| <i>Galium aparine</i>             | + | + | + | + | + | + | + | + | + |
| <i>Galium asperuloides</i>        | + | + | - | - | + | + | + | + | - |
| <i>Geranium lucidum</i>           | + | - | - | + | + | + | + | - | - |
| <i>Geranium wallichianum</i>      | - | - | - | + | - | - | + | - | + |
| <i>Gerbera gossypina</i>          | + | - | - | - | + | + | - | - | - |
| <i>Girardinia diversifolia</i>    | - | + | + | + | + | - | + | - | - |
| <i>Gypsophila cerastioides</i>    | + | + | - | + | + | + | + | + | + |
| <i>Habenaria intermedia</i>       | + | + | - | + | + | + | + | + | - |
| <i>Halenia elliptica</i>          | + | + | + | + | + | + | + | - | + |
| <i>Heracleum candicans</i>        | + | + | - | + | + | + | - | + | + |
| <i>Impatiens scabrida</i>         | + | - | + | + | + | + | + | + | + |
| <i>Iris nepalensis</i>            | + | + | + | + | + | + | + | + | + |
| <i>Koeleria cristata</i>          | - | - | - | + | - | - | + | + | - |
| <i>Lamium album</i>               | + | + | - | + | + | + | + | - | + |
| <i>Leucas lanata</i>              | + | + | - | - | - | + | - | - | - |
| <i>Lotus corniculatus</i>         | + | + | - | + | + | + | + | + | + |
| <i>Malva verticillata</i>         | - | - | + | - | - | - | - | - | - |
| <i>Malvastrum coromandelianum</i> | - | - | + | + | - | - | - | - | - |
| <i>Mentha longifolia</i>          | - | - | - | + | - | - | + | - | + |
| <i>Micromeria biflora</i>         | + | + | - | - | - | + | - | - | - |
| <i>Myriactis nepalensis</i>       | + | + | - | - | - | + | + | + | - |
| <i>Nasturtium officinale</i>      | - | - | - | + | + | - | + | - | + |
| <i>Nepeta laevigata</i>           | + | - | - | + | + | + | + | - | - |
| <i>Nepeta leucophylla</i>         | - | - | - | - | - | - | + | - | + |
| <i>Oenothera rosea</i>            | + | - | - | + | + | + | - | - | - |
| <i>Origanum vulgare</i>           | - | + | - | + | + | - | - | - | - |
| <i>Oxalis corniculata</i>         | - | - | + | + | - | - | - | - | - |
| <i>Pedicularis hoffmeisteri</i>   | + | + | + | + | + | + | + | - | + |
| <i>Pennisetum flaccidum</i>       | - | - | + | + | - | - | - | - | - |
| <i>Phalaris paradoxa</i>          | - | - | + | - | - | - | - | - | - |
| <i>Phragmites communis</i>        | + | + | + | + | + | + | + | + | + |
| <i>Pimpinella diversifolia</i>    | - | - | - | + | - | - | - | - | - |

|                                   |   |   |   |   |   |   |   |   |   |
|-----------------------------------|---|---|---|---|---|---|---|---|---|
| <i>Plantago depressa</i>          | + | + | + | - | + | + | - | - | - |
| <i>Plantago erosa</i>             | + | + | + | + | + | + | - | - | - |
| <i>Plectranthus japonicus</i>     | + | + | - | + | + | + | + | + | - |
| <i>Podophyllum hexandrum</i>      | + | + | - | + | + | + | + | + | - |
| <i>Polygala abyssinica</i>        | + | + | + | + | + | + | - | - | - |
| <i>Polygonatum cirrhifolium</i>   | + | + | - | + | + | + | + | - | + |
| <i>Polygonatum multiflorum</i>    | + | + | + | + | + | + | + | + | - |
| <i>Polygonatum verticillatum</i>  | - | + | - | + | + | - | + | + | + |
| <i>Polygonum hydropiper</i>       | + | - | - | - | + | + | - | - | - |
| <i>Polygonum nepalense</i>        | - | - | + | + | - | - | + | + | - |
| <i>Polystichum neolobatum</i>     | - | - | - | + | - | - | - | - | - |
| <i>Potentilla argyrophylla</i>    | + | + | - | + | - | + | + | + | - |
| <i>Potentilla atrosanguinea</i>   | + | - | - | - | + | + | - | - | - |
| <i>Potentilla fragarioides</i>    | - | + | + | - | + | - | - | - | - |
| <i>Potentilla leschenaultiana</i> | - | + | - | - | + | - | - | - | + |
| <i>Potentilla nepalensis</i>      | + | - | + | + | - | + | - | - | - |
| <i>Primula denticulata</i>        | + | + | - | + | + | + | + | + | - |
| <i>Primula floribunda</i>         | + | + | - | - | + | + | - | - | - |
| <i>Primula petiolaris</i>         | + | + | + | + | - | + | + | - | + |
| <i>Pteris cretica</i>             | + | + | + | + | + | + | + | + | - |
| <i>Ranunculus hirtellus</i>       | + | - | + | + | + | + | + | + | + |
| <i>Ranunculus laetus</i>          | + | + | - | + | + | + | + | - | - |
| <i>Roscoea purpurea</i>           | + | + | + | + | + | + | + | + | + |
| <i>Rosularia rosulata</i>         | + | + | - | - | - | + | + | - | - |
| <i>Rubia cordifolia</i>           | - | - | + | - | - | - | - | - | - |
| <i>Rumex nepalensis</i>           | + | + | + | + | + | + | + | + | + |
| <i>Saccharum filifolium</i>       | - | + | - | - | + | - | + | - | - |
| <i>Salvia lanata</i>              | + | - | - | + | - | + | + | - | - |
| <i>Salvia nubicola</i>            | + | + | + | + | + | + | + | + | + |
| <i>Scirpus roylei</i>             | - | - | + | - | - | - | + | + | + |
| <i>Scrophularia himalensis</i>    | + | + | - | - | + | + | + | - | - |
| <i>Scutellaria scandens</i>       | + | - | + | - | + | + | - | - | - |
| <i>Selaginella kraussiana</i>     | + | + | - | - | - | + | - | - | - |
| <i>Selinum candollii</i>          | - | + | + | + | + | - | + | + | + |
| <i>Selinum vaginatum</i>          | - | - | - | + | - | - | + | + | - |
| <i>Senecio alatus</i>             | - | - | - | - | - | - | + | + | + |
| <i>Senecio chrysanthemoides</i>   | + | + | - | + | + | + | + | - | + |
| <i>Senecio nudicaulis</i>         | - | + | - | - | + | - | + | - | + |
| <i>Serratula pallida</i>          | - | - | - | - | - | - | + | - | - |
| <i>Sibbaldia cuneata</i>          | + | + | - | + | + | + | + | - | + |
| <i>Silene griffithii</i>          | + | + | + | - | + | + | + | + | + |
| <i>Silene vulgaris</i>            | + | + | + | - | + | + | + | - | + |
| <i>Smilacina purpurea</i>         | + | - | + | + | + | + | + | + | + |
| <i>Smilax aspera</i>              | - | - | + | + | + | - | - | - | - |
| <i>Smilax glaucophylla</i>        | + | + | - | - | + | + | - | - | - |
| <i>Smilax vaginata</i>            | - | + | - | + | - | - | - | - | - |
| <i>Solena amplexicaulis</i>       | - | - | - | - | - | - | + | + | - |
| <i>Sonchus asper</i>              | - | - | - | + | - | - | + | + | + |



|                                   |            |           |           |            |           |            |            |           |           |
|-----------------------------------|------------|-----------|-----------|------------|-----------|------------|------------|-----------|-----------|
| <i>Stellaria media</i>            | +          | +         | -         | +          | -         | +          | +          | +         | -         |
| <i>Swertia cordata</i>            | +          | +         | -         | -          | +         | +          | +          | +         | +         |
| <i>Taraxacum officinale</i>       | -          | -         | -         | -          | -         | -          | +          | -         | +         |
| <i>Thalictrum foliolosum</i>      | +          | +         | +         | +          | -         | +          | +          | +         | +         |
| <i>Thamnocalamus spathiflorus</i> | -          | -         | -         | +          | -         | -          | -          | -         | -         |
| <i>Themeda anathera</i>           | +          | -         | +         | +          | +         | +          | -          | -         | -         |
| <i>Thlaspi cochleariforme</i>     | -          | -         | -         | -          | -         | -          | +          | -         | +         |
| <i>Thymus linearis</i>            | +          | +         | +         | +          | +         | +          | +          | +         | +         |
| <i>Tragopogon gracilis</i>        | -          | -         | -         | -          | -         | -          | +          | -         | +         |
| <i>Trichosanthes bracteata</i>    | -          | -         | -         | +          | -         | -          | -          | -         | -         |
| <i>Trifolium pratense</i>         | -          | +         | -         | -          | +         | -          | -          | -         | -         |
| <i>Trifolium repens</i>           | +          | -         | +         | +          | -         | +          | +          | +         | -         |
| <i>Urtica ardens</i>              | +          | -         | +         | +          | +         | +          | +          | +         | -         |
| <i>Urtica dioica</i>              | +          | +         | +         | +          | -         | +          | +          | -         | -         |
| <i>Valeriana jatamansi</i>        | +          | +         | +         | -          | +         | +          | +          | +         | +         |
| <i>Valeriana pyrolaefolia</i>     | +          | +         | -         | -          | +         | +          | +          | +         | +         |
| <i>Verbascum thapsus</i>          | +          | -         | +         | +          | +         | +          | +          | +         | +         |
| <i>Vicatia coniifolia</i>         | +          | +         | -         | +          | +         | +          | +          | +         | +         |
| <i>Viola canescens</i>            | +          | +         | +         | +          | +         | +          | +          | +         | +         |
| <i>Youngia japonica</i>           | -          | -         | -         | -          | -         | -          | +          | -         | +         |
| <b>Total number of forbs</b>      | <b>105</b> | <b>95</b> | <b>78</b> | <b>103</b> | <b>91</b> | <b>105</b> | <b>104</b> | <b>73</b> | <b>73</b> |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests.

Plant community structure and its diversity patterns are important ecological attributes that correlates with prevailing environment as well as anthropogenic variables. Accelerating rates of species extinction have prompted a growing number of researchers to evaluate richness of biotic forms and examine how this aspect of diversity impacts ecological processes that control the functioning of ecosystems. Each species plays a particular role in an ecosystem, limited by its ecological tolerances, that defines its ecological niche. The range of niche available and occupied in turn determines the biotic range within the ecosystem and in other words its diversity (Goodall and Perry 1979). Diversity has been quantified in a wide variety of ways (Simpson 1949; Macarthur and Macarthur 1961; Pielou 1969; Hill 1973; Peet 1974). Two basic components of species diversity are total number of species actually present and the degree to which they are equally important. In the present study, in all, 303 plant species were recorded in Himalayan moist temperate forest in Shimla district of HP which includes 34 species of trees, 96 species of shrubs and 173 species of forbs. Floral diversity in upper Oak-Fir and moist temperate upper deciduous was less compared to other forests. Total number of plant species in different forests was: Where: FT-1 = 180, FT-2 = 158, FT-3 = 154, FT-4 = 173, FT-5 = 159, FT-6 = 181, FT-7 = 158, FT-8 = 128 and FT-9 = 123. The

differences in floral spectrum among forest types can be related to terrain-related abiotic factors and to biotic interactions among overstory and understory plants; height, biomass and gap frequency are significantly related to changes in elevation and aspect. Higher evergreen understory density is correlated with decrease in forest height and biomass, with an impact observed across moisture, elevation and exposure gradients (Bolstad *et al.* 2018). Control on species distribution in forests by environmental factors (topographic and soil variables) which are function of time, altitude, slope, latitude, aspect, rainfall and humidity of a region have been endorsed by many workers (Whittaker and Marks 1975; Schall and Pinaka 1978; Wright 1983; Singh *et al.* 1994; Adhikari *et al.* 1992; Rahbek 1995; Kharkwal *et al.* 2005; Gupta and Sharma 2015). Forest management and silvicultural practices also have a longer-term impact on the genetic diversity, structure and resilience of long-impacted populations of forest tree (Filippos 2018). In mountain ecosystems slope aspect plays a key role in regulating insolation, which in turn affects soil moisture and temperature regimes in ways that can directly influence the development of local vegetation and ecosystems (Bale *et al.* 1998; Sharma *et al.* 2010a; Yanyan *et al.* 2017). Slope aspect influences almost all properties of vegetation, such as species composition and distribution, plant performance and photosynthetic efficiency, cover and productivity, species diversity and functional diversity, plant invasion and nutrient dynamics. It may also affect plant species establishment through sensitivity to temperature and climatic fitness (Leonelli *et al.* 2009), and the hydrological precipitation pattern and erosion (Aimme and Normaniza 2015).

Since these forests provide many ecosystem services to rural people, where very few livelihood options are available, mountain forests form an essential life-support system for them (Khan *et al.* 2014; Bhandari *et al.* 2016). These forests are subjected to biotic interferences like lopping of trees for fodder (Oak and deciduous forests), minor timber/fuelwood (all forests) and timber pilferage (all forests), thereby canopy disturbance commonly occurs in them which has been advocated to cause compositional changes in forests of Himalaya, especially Ban Oak and mixed broadleaved forests by Airi and Rawal (2015). Thus, the differences in species composition and their distribution among nine forests in the present study can be related to level of canopy disturbance in them.

The plant richness in Himalayan moist temperate forest in the present study is low as compared to findings of Chawla *et al.* (2012) who reported 832 species belonging to 427 genera and 128 families of plants in conifer forest communities of Great National Himalayan

Park (GNHP) of H.P.; Chandrasekar and Srivastava (2009), they reported 513 species belonging to 243 genera in Pin valley National Park, HP but matches the finding of Chawla *et al.* (2008), who recorded 313 plant species in Bhabha valley in Western Himalaya (HP). Since these workers investigated undisturbed areas so high number of plant species can be expected there. Moreover, plant distribution at a place is also governed by an area surveyed beside time of sampling and season (Malik *et al.* 2015). Gairola *et al.* (2010) has reported high number i.e., 338 species (334 angiosperms and 4 gymnosperms) in natural forests of Garhwal in north–west Himalaya. Dar and Sunderpandian (2016) in their studies on temperate forest types viz., *Populus deltoides* (PD), *Juglans regia*, *Cedrus deodara*, *Pinus wallichiana*, mixed coniferous, *Abies pindrow* (AP) and *Betula utilis* (BU) in Kashmir Himalaya reported a total of 177 plant species (158 genera, 66 families). Most of the species were herbs (82.5%), while shrubs account for 9.6% and trees represent 7.9%. Species richness ranged from 24 (PD) to 96 (AP). In the present study in nine types of forests trees accounted for 6.37 (Moist temperate lower deciduous forests) to 11.69 (Deodar forests) % of total species, shrubs 26.11 (Karsu Oak forests) to 37.91 (Deodar forests) % and forbs 50.98 (Deodar forests) to 67.30 (Moru Oak forests) %. Very high number of species was recorded by Kharkwal *et al.* (2005). They found 2487 species (276 trees, 355 shrubs, 112 climbers and 1744 herbs) while studying phytodiversity in Indian Central Himalaya along elevation gradient from 200 to 5800 m amsl and concluded that the distribution and species richness pattern in this region largely depend on the altitude and climatic variables like rainfall, temperature and these parameters decrease with increase in an elevation.

The plant species recorded in the present study in Himalayan moist forests climate of Shimla district are however similar to the plant species recorded by other workers in temperate Himalaya (Gairola *et al.* 2011a; Chawla *et al.* 2012; Sharma *et al.* 2016; Lal and Lodhiyal 2016; Suchita *et al.* 2017; Sharma *et al.* 2018).

### 4.3 VEGETATION INDICES

Shannon-Wiener index of diversity (H) and Simpson index of dominance (D) and Margalef's index of richness ( $D_{mg}$ ) of trees in Himalayan moist temperate forest in Shimla district of H.P. was 1.36, 0.38 and 0.67, respectively (Table 7).

Shannon-Wiener index of diversity (H) of trees in different forests varied from 0.97 to 1.72, Simpson index of dominance (D) of trees in different forests ranged from 0.21 to 0.59

in different forests. Margalef's index of richness ( $D_{mg}$ ) of trees in different forests varied from 0.64 - 0.70. Ban Oak forests exhibited maximum diversity (H) index (1.72) of trees followed by upper Oak-Fir forests (1.57). In Ban Oak forests Shannon-Wiener index of diversity (H) of trees was lowest (0.80) among forests. Ban Oak forests exhibited maximum Simpson index of dominance (0.59) of trees whereas Deodar forests followed it with Simpson index of dominance of 0.53.

**Table 7: Vegetation diversity indices for trees, shrubs and forbs in different forests under Himalayan moist temperate forest in Shimla district HP**

|                                         | Shannon-Wiener index of diversity (H) | Simpson index of dominance (D) | Margalef's index of richness ( $D_{mg}$ ) |
|-----------------------------------------|---------------------------------------|--------------------------------|-------------------------------------------|
| <b>Trees</b>                            |                                       |                                |                                           |
| Ban Oak forests                         | 0.97                                  | 0.59                           | 0.68                                      |
| Moru Oak forests                        | 1.24                                  | 0.42                           | 0.65                                      |
| Deodar forests                          | 1.11                                  | 0.53                           | 0.65                                      |
| Western mixed coniferous forests        | 1.49                                  | 0.28                           | 0.66                                      |
| Moist temperate lower deciduous forests | 1.72                                  | 0.21                           | 0.68                                      |
| Kail forests                            | 1.14                                  | 0.48                           | 0.67                                      |
| Kharsu Oak Forests                      | 1.40                                  | 0.33                           | 0.64                                      |
| Upper Oak-Fir forests                   | 1.57                                  | 0.26                           | 0.70                                      |
| Moist temperate upper deciduous forests | 1.56                                  | 0.24                           | 0.67                                      |
| <b>Average</b>                          | <b>1.36</b>                           | <b>0.38</b>                    | <b>0.67</b>                               |
| <b>Shrubs</b>                           |                                       |                                |                                           |
| Ban Oak forests                         | 3.12                                  | 0.05                           | 0.40                                      |
| Moru Oak forests                        | 2.81                                  | 0.08                           | 0.44                                      |
| Deodar forests                          | 3.00                                  | 0.06                           | 0.44                                      |
| Western mixed coniferous forests        | 2.92                                  | 0.08                           | 0.44                                      |
| Moist temperate lower deciduous forests | 2.99                                  | 0.06                           | 0.43                                      |
| Kail forests                            | 3.10                                  | 0.06                           | 0.44                                      |
| Kharsu Oak Forests                      | 2.68                                  | 0.09                           | 0.44                                      |
| Upper Oak-Fir forests                   | 2.79                                  | 0.09                           | 0.44                                      |
| Moist temperate upper deciduous forests | 2.76                                  | 0.08                           | 0.45                                      |
| <b>Average</b>                          | <b>2.91</b>                           | <b>0.07</b>                    | <b>0.44</b>                               |
| <b>Forbs</b>                            |                                       |                                |                                           |
| Ban Oak forests                         | 3.58                                  | 0.04                           | 0.37                                      |
| Moru Oak forests                        | 3.66                                  | 0.03                           | 0.32                                      |
| Deodar forests                          | 3.57                                  | 0.03                           | 0.32                                      |
| Western mixed coniferous forests        | 3.92                                  | 0.02                           | 0.32                                      |
| Moist temperate lower deciduous forests | 3.62                                  | 0.03                           | 0.32                                      |
| Kail forests                            | 3.75                                  | 0.03                           | 0.33                                      |
| Kharsu Oak Forests                      | 3.93                                  | 0.02                           | 0.32                                      |
| Upper Oak/Fir forests                   | 3.56                                  | 0.03                           | 0.33                                      |
| Moist temperate upper deciduous forests | 3.32                                  | 0.05                           | 0.32                                      |
| <b>Average</b>                          | <b>3.66</b>                           | <b>0.03</b>                    | <b>0.33</b>                               |

Moist temperate lower deciduous forests showed the lowest Simpson index of dominance of trees as 0.21. Margalef's index of species richness ( $D_{mg}$ ) of trees was highest in upper Oak-Fir forests (0.70) followed by Ban Oak forests (0.68) and moist temperate lower deciduous forests (0.68). While Kharsu Oak forests showed lowest species richness of trees among forests ( $D_{mg} = 0.64$ ).

Likewise, The Shannon-Wiener index of diversity (H), Simpson index of dominance (D) and Margalef's index of richness ( $D_{mg}$ ) of shrubs in Himalayan moist temperate forest of Shimla district of HP was 2.91, 0.07 and 0.44, respectively (Table 7). The Shannon-Wiener index of diversity (H) of shrubs in different forests varied from 2.76 to 3.12. The Simpson index of dominance (D) of shrubs in different forests showed very little variation (0.05 - 0.09). In Ban Oak forests Shannon-Wiener index of diversity of shrubs was maximum ( $H = 3.12$ ) while moist temperate upper deciduous forests had least value of Shannon-Wiener index of diversity of shrubs ( $H = 2.76$ ). Maximum Margalef's index of richness ( $D_{mg}$ ) of shrubs was recorded in moist temperate upper deciduous forests (0.45) while least values of 0.40 of Margalef's index of richness ( $D_{mg}$ ) of shrubs was recorded in Ban Oak forests.

Similarly, the Shannon-Wiener index of diversity (H), Simpson index of dominance (D) and Margalef's index of richness ( $D_{mg}$ ) of forbs in Himalayan moist temperate forest in Shimla district of HP is 3.66, 0.03 and 0.33, respectively (Table 7). The Margalef's index of richness ( $D_{mg}$ ) of forbs in different forests varied from 0.32 to 0.37, The Shannon-Wiener index of diversity (H) ranged from 3.32 to 3.93 in different forests types. Kharsu Oak forests exhibited maximum Shannon-Wiener index of diversity (H) index (3.93) followed by western mixed coniferous forests ( $H = 3.92$ ). Whereas, moist temperate upper deciduous forests exhibited least Shannon-Wiener index of diversity ( $H = 3.32$ ). The Simpson index of dominance (D) of shrubs in different forests varied in a small range from 0.02- 0.05. Maximum Margalef's index of richness of forbs was recorded in Ban Oak forests ( $D_{mg} = 0.37$ ), followed by Kharsu Oak forests and upper Oak-Fir forests ( $D_{mg} = 0.33$ ). While, Moru Oak forests along with Deodar forests, western mixed coniferous forests, moist temperate lower deciduous forests, Kharsu Oak forests and moist temperate upper deciduous forests had lowest Margalef's index of richness ( $D_{mg} = 0.32$ ). Simpson index of dominance of forbs among different forests types was 0.05 for moist temperate upper deciduous forests, followed

by Ban Oak forests ( $D = 0.04$ ). Whereas, Western mixed coniferous forests and Kharsu Oak forests exhibited least Simpson index of dominance ( $D = 0.02$ ).

On perusal of Table 7 it is evident that Shannon-Wiener index of diversity ( $H$ ) has increasing trend as: herbs ( $H = 3.66$ ) > shrubs ( $H = 2.65$ ) > trees ( $H = 1.34$ ). While Simpson index of dominance ( $D$ ) has shown a reverse trend i.e. trees ( $D = 0.38$ ) > shrubs ( $D = 0.07$ ) > herbs ( $D = 0.03$ ). Margalef's index of richness ( $D_{mg}$ ) has also shown a decreasing trend as: trees ( $D_{mg} = 0.67$ ) > shrubs ( $D_{mg} = 0.44$ ) > herbs ( $D_{mg} = 0.33$ ).

Diversity represents a key concept in ecology and there are various methods of assessing it such as Shannon, Simpson, Pielou, Brillouin, Berger-Parker, McIntosh, Margalef, Menhinick and Gleason diversity indices (Palaghianu 2014). The Shannon diversity index ( $H$ ) and Simpson's index of dominance are commonly used to characterize species diversity in a community. Both accounts for abundance and evenness of the species present. Further, both are the indicators of level of disturbance in a community. Different levels of disturbance have different effects on diversity. If one intends to preserve biodiversity in a given area, he needs to understand how diversity is impacted by different management strategies. Because diversity indices provide more information than simply the number of species present (i.e., they account for some species being rare and others being common), they serve as valuable tools that enable biologists to quantify diversity in a community and describe its numerical structure. The Margalef index measures species richness of a community.

There are different aspects of diversity that can be assessed at landscape level, population level or even regarding to certain individual attributes. That is because diversity and heterogeneity of a system are frequently related to its superior stability. A more complex and diverse system can manifest a higher resilience to external disturbances. In forestry, due to a relatively low number of tree species in the stands located in the temperate region, the researchers rather focus on structural or dimensional diversity. This type of diversity is also related to a higher structural stability (Zenner and Hibbs 2000; Zenner 2005; Davies and Pommerening 2008).

In the present investigation the Simpson's index of dominance was higher for trees as compared to shrubs and forbs revealing that in trees relative abundance of different tree species was appreciably high as compared shrubs and forbs as it accounts for the number of species present, as well as the relative abundance of each species and, as species richness and

evenness increase, so diversity increases. The result revealed that among different forests in Ban Oak, Moru Oak, Deodar and Kail forests the relative abundance of their constituent tree species was high as compared to other forests while in shrubs and forbs very few species dominated the ecosystem.

Shannon-Wiener index of diversity (H) of trees, shrubs and forbs in different forests clearly reveals that though the number of species of trees was less in them, but species evenness was higher as compared to shrubs and forbs resulting in low H (0.80-1.57). Conversely, though total number of species of shrubs and forbs was more but species evenness was low resulting in high H (0.80 -3.10 for shrubs and 3.32-3.93 for forbs). Shannon-Wiener index of diversity (H) in different plant categories changed in the order: trees < shrubs < forbs. Many workers have recorded similar diversity index of trees in temperate forests of Himalaya. Lal and Lodhiyal (2016) estimated tree species diversity ranging between 1.38-2.57 in Oak dominated forests, Singh *et al.* (2014) reported the range 1.31 to 2.69 of Oak dominated forests and, Pandey and Lodhiyal (2015) recorded a range of 1.01 to 1.65 for Oak mixed forests in Himalaya. Pandey *et al.* 2016 studied vegetation diversity in forests of Langtang National Park in Central Himalaya and reported Shannon diversity index ranged from 1.10 to 2.34 with the highest value in the lower temperate zone. Both Simpson index (0.89) and Evenness (0.86) were high in the lower temperate zone. Sharma *et al.* 2018 studied plant diversity in ridge forests of Garhwal Himalaya and reported highest Shannon index value ( $0.83 \pm 0.14$ ) in *Anogeissus latifolia*–*Mallotus philippensis* forest association and lowest ( $0.26 \pm 0.09$ ) in *Q. semecarpifolia*–*C.deodara* forest association. Lal and Lodhiyal (2016) studied Oak dominated forests mixed with other broadleaved trees in central Himalaya and reported diversity of tree species ranging from 0.03 to 0.16. Gosain *et al.* 2015 studied eighteen forest stands dominated by *Pinus roxburghii* and *Quercus leucotrichophora* forests in Almora Himalaya and they computed Simpson's Index (D) for tree as 0.599, for shrubs as 0.115 and for herbs as 0.112 in Oak forests and, Shannon-Wiener range = 0.833-2.21 and Simpson's index range = 0.112 -0.693 for different plant categories in different forests. They further contended that higher species diversity is generally thought to indicate a more complex and healthier community because a greater variety of species allows more species interactions, hence greater system stability, and indicates good environmental conditions (Prescott 2002, Giri *et al.* 2006). Shannon-Wiener index range of 0.33-2.95 for central Himalayan forests has reported by earlier workers (Saxena and Singh 1982; Ralhan *et al.* 1982; Tripathi *et al.* 1987; Bargali and Singh 1997).

The Margalef index of diversity for trees, shrubs and forbs in different forests suggest that species richness increased in them in the order: trees < shrubs < forbs.

#### 4.4 PHYTOSOCIOLOGY

##### 4.4.1 Phytosociology of trees

Ban Oak forests in Himalayan moist temperate forest comprised of trees of *Quercus leucotrichophora* along with *Cedrus deodara*, *Pinus wallichiana*, *Lyonia ovalifolia* and *Pyrus pashia* at different elevations (Table 8). In all, 10 tree species were recorded at E<sub>2</sub> highest among three elevations as compared to E<sub>1</sub> with 9 and E<sub>3</sub> with 7 tree species. Highest tree density (540.09 trees/ha) and their total basal area (62.24 m<sup>2</sup>/ha) was recorded at elevation E<sub>1</sub> that descended to 505.02 trees/ha and 56.60 m<sup>2</sup>/ha at E<sub>2</sub>. The lowest tree density (435.08 trees/ha) and basal area (47.76 m<sup>2</sup>/ha) was recorded at elevation E<sub>3</sub>.

With respect to individual trees, *Quercus leucotrichophora* showed highest density and basal area at all elevations. The density (420.07 trees/ha) and basal area (53.71 m<sup>2</sup>/ha) of *Quercus leucotrichophora* at E<sub>2</sub> was higher as compared to E<sub>1</sub> and E<sub>3</sub>. Lowest density (2.50 trees/ha) among trees was recorded for *Mallotus philippensis* at E<sub>1</sub> and E<sub>2</sub>, whereas least basal area (0.03 m<sup>2</sup>/ha) was shown by *Neolitsea pallens* and *Prunus armeniaca* at E<sub>2</sub> and E<sub>3</sub>, respectively (Table 8).

*Quercus leucotrichophora* was dominant tree species at all three elevations with IVI of 198.07, 172.63 and 167.99 at E<sub>2</sub>, E<sub>1</sub> and E<sub>3</sub>, respectively. *Pinus roxburghii* was the co-dominant species at E<sub>1</sub> with IVI of 22.49 and *Pyrus pashia* was associate species having IVI of 20.82. Whereas, *Pistacia integerrima* (IVI = 24.03) was co-dominant and *Myrica esculenta* (IVI = 19.05) was associate species at E<sub>2</sub>. Whereas at E<sub>3</sub>, *Pinus wallichiana* was co-dominant (IVI = 38.68) and *Juglans regia* (IVI = 28.29) was associate species. Lowest IVI of 5.02, 5.55 and 5.64 were exhibited by *Mallotus philippensis*, *Neolitsea pallens* and *Prunus armeniaca* at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively and thus, were the rare species at respective elevations (Table 8).

The prominent species of Moru Oak forests was *Quercus floribunda* with *Abies spectabilis*, *Cedrus deodara*, *Picea smithiana*, *Pinus wallichiana* etc. as an associate species at different elevations (Table 9). Eight number of tree species was recorded at E<sub>2</sub> as compared to E<sub>1</sub> and E<sub>3</sub> with seven tree species each. Among three elevations, at E<sub>1</sub> highest tree density



(535.09 trees/ha) and basal area (54.58 m<sup>2</sup>/ha) was recorded that descended at E<sub>2</sub> with density as 482.58 trees/ha with their total basal area as 48.10 m<sup>2</sup>/ha. While the lowest tree density (365.06 trees/ha) and basal area (43.80 m<sup>2</sup>/ha) was recorded at elevation E<sub>3</sub>.

**Table 8: Density, basal area, and importance value index (IVI) of trees in Ban Oak (*Q. leucotrichophora*) forests at different elevations**

| Tree species                                   | Density<br>(trees/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI           |
|------------------------------------------------|-----------------------|------------------------------------|---------------|
| <b>Elevation - E<sub>1</sub> (700 -1300 m)</b> |                       |                                    |               |
| <i>Albizia chinensis</i>                       | 5.00                  | 2.91                               | 9.95          |
| <i>Bauhinia variegata</i>                      | 17.50                 | 0.38                               | 12.55         |
| <i>Lyonia ovalifolia</i>                       | 25.00                 | 0.76                               | 18.90         |
| <i>Mallotus philippensis</i>                   | 2.50                  | 0.13                               | 5.02          |
| <i>Pinus roxburghii</i>                        | 25.00                 | 3.00                               | 22.49         |
| <i>Pistacia integerrimma</i>                   | 25.00                 | 0.58                               | 18.60         |
| <i>Prunus armeniaca</i>                        | 27.50                 | 0.56                               | 19.04         |
| <i>Pyrus pashia</i>                            | 37.51                 | 0.51                               | 20.82         |
| <i>Quercus leucotrichophora</i>                | 375.07                | 53.40                              | 172.63        |
| <b>Total</b>                                   | <b>540.09</b>         | <b>62.24</b>                       | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (1300-1900 m)</b> |                       |                                    |               |
| <i>Lyonia ovalifolia</i>                       | 5.00                  | 0.07                               | 6.11          |
| <i>Mallotus philippensis</i>                   | 2.50                  | 0.04                               | 5.56          |
| <i>Myrica esculenta</i>                        | 17.50                 | 0.33                               | 19.05         |
| <i>Neolitsea pallens</i>                       | 2.52                  | 0.03                               | 5.55          |
| <i>Pinus roxburghii</i>                        | 15.00                 | 1.77                               | 11.09         |
| <i>Pistacia integerrimma</i>                   | 17.50                 | 0.32                               | 24.03         |
| <i>Prunus armeniaca</i>                        | 15.00                 | 0.19                               | 18.30         |
| <i>Pyrus pashia</i>                            | 5.00                  | 0.05                               | 6.09          |
| <i>Quercus leucotrichophora</i>                | 420.07                | 53.71                              | 198.07        |
| <i>Rhododendron arboreum</i>                   | 5.00                  | 0.09                               | 6.15          |
| <b>Total</b>                                   | <b>505.02</b>         | <b>56.60</b>                       | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (1900-2500 m)</b> |                       |                                    |               |
| <i>Cedrus deodara</i>                          | 37.51                 | 5.97                               | 41.11         |
| <i>Juglans regia</i>                           | 20.00                 | 1.76                               | 28.29         |
| <i>Myrica esculenta</i>                        | 7.50                  | 0.12                               | 11.97         |
| <i>Pinus wallichiana</i>                       | 35.01                 | 5.08                               | 38.68         |
| <i>Prunus armeniaca</i>                        | 2.50                  | 0.03                               | 5.64          |
| <i>Quercus leucotrichophora</i>                | 327.56                | 34.72                              | 167.99        |
| <i>Rhododendron arboreum</i>                   | 5.00                  | 0.08                               | 6.32          |
| <b>Total</b>                                   | <b>435.08</b>         | <b>47.76</b>                       | <b>300.00</b> |

Among different trees *Quercus floribunda* exhibited highest density and basal area at all three elevations. At E<sub>1</sub> its density (377.57 trees/ha) and basal area (38.86 m<sup>2</sup>/ha) was highest amongst three elevations. At E<sub>2</sub> its density was 245.04 trees/ha and basal area was 21.74 m<sup>2</sup>/ha while at E<sub>3</sub>, its density was 222.54 trees/ha and basal area was 18.83 m<sup>2</sup>/ha.

*Prunus cornuta* had least density of 5.00 trees/ha and basal area of 0.48 m<sup>2</sup>/ha at E<sub>1</sub>, *Ilex dipyrena* exhibited least density (7.50 trees/ha) and basal area (0.16 m<sup>2</sup>/ha) at E<sub>2</sub> and *Acer caesium* showed lowest density (2.50 trees/ha) and basal area (0.27 m<sup>2</sup>/ha) at E<sub>3</sub> (Table 9).

**Table 9: Density, basal area, and importance value index (IVI) of trees in Moru Oak (*Q. floribunda*) forests at different elevations**

| Tree species                                  | Density (Trees/ha) | Basal Area (m <sup>2</sup> /ha) | IVI           |
|-----------------------------------------------|--------------------|---------------------------------|---------------|
| <b>Elevation- E<sub>1</sub> (1800-2300 m)</b> |                    |                                 |               |
| <i>Cedrus deodara</i>                         | 97.52              | 9.07                            | 57.07         |
| <i>Cupressus torulosa</i>                     | 17.50              | 2.13                            | 18.28         |
| <i>Lyonia ovalifolia</i>                      | 17.50              | 2.17                            | 23.92         |
| <i>Prunus cornuta</i>                         | 5.00               | 0.48                            | 7.38          |
| <i>Pyrus lanata</i>                           | 10.00              | 1.12                            | 15.04         |
| <i>Quercus floribunda</i>                     | 377.57             | 38.86                           | 163.99        |
| <i>Rhododendron arboreum</i>                  | 10.00              | 0.74                            | 14.33         |
| <b>Total</b>                                  | <b>535.09</b>      | <b>54.58</b>                    | <b>300.01</b> |
| <b>Elevation- E<sub>2</sub> (2300-2800 m)</b> |                    |                                 |               |
| <i>Abies pindrow</i>                          | 52.51              | 7.09                            | 39.90         |
| <i>Cedrus deodara</i>                         | 67.51              | 10.01                           | 53.85         |
| <i>Ilex dipyrena</i>                          | 7.50               | 0.16                            | 11.40         |
| <i>Lyonia ovalifolia</i>                      | 20.00              | 0.43                            | 14.56         |
| <i>Picea smithiana</i>                        | 32.51              | 3.82                            | 24.20         |
| <i>Pinus wallichiana</i>                      | 45.01              | 4.24                            | 27.66         |
| <i>Quercus floribunda</i>                     | 245.04             | 21.74                           | 115.03        |
| <i>Rhododendron arboreum</i>                  | 12.50              | 0.62                            | 13.40         |
| <b>Total</b>                                  | <b>482.58</b>      | <b>48.10</b>                    | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (2800-3300 m)</b> |                    |                                 |               |
| <i>Abies spectabilis</i>                      | 32.51              | 6.88                            | 44.61         |
| <i>Acer caesium</i>                           | 2.50               | 0.27                            | 6.31          |
| <i>Aesculus indica</i>                        | 2.50               | 0.32                            | 6.41          |
| <i>Cedrus deodara</i>                         | 42.51              | 9.04                            | 52.28         |
| <i>Ilex dipyrena</i>                          | 7.50               | 0.07                            | 12.21         |
| <i>Picea smithiana</i>                        | 55.01              | 8.40                            | 54.24         |
| <i>Quercus floribunda</i>                     | 222.54             | 18.83                           | 123.95        |
| <b>Total</b>                                  | <b>365.06</b>      | <b>43.80</b>                    | <b>300.00</b> |

At three elevations, *Quercus floribunda* was the dominant tree species with IVI of 164.00, 115.03 and 124.00 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. At elevation E<sub>1</sub> *Cedrus deodara* was the co-dominant species and *Lyonia ovalifolia* was associate species with IVI of 57.07 and 23.92, respectively. At E<sub>2</sub> *Cedrus deodara* with IVI of 115.03 was co-dominant species and *Abies spectabilis* with IVI of 39.91 was associate species. While at E<sub>3</sub> *Picea smithiana* (IVI=

54.24) and *Cedrus deodara* (IVI = 52.28) were co-dominant species and *Abies spectabilis* with IVI of 44.61 was associate species. *Prunus cornuta*, *Ilex dipyrena* and *Acer caesium* at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> exhibited lowest IVI values of 7.38, 11.40 and 6.31, respectively and thus were the rare species (Table 9).

In Deodar forests beside *Cedrus deodara* other prominent species were *Quercus leucotrichophora*, *Abies pindrow*, *Abies spectabilis*, *Picea smithiana*, *Pinus wallichiana* and *Quercus semecarpifolia* at different elevations (Table 10). In these forests highest number of tree species (13) were recorded at E<sub>2</sub> as compared to 8 at E<sub>3</sub> and 7 at E<sub>1</sub>. There was declining trend in density and basal area of trees at three elevations in the order: E<sub>1</sub> > E<sub>2</sub> > E<sub>3</sub>. Among the three elevations, highest tree density (562.60 trees/ha) and basal area (88.13 m<sup>2</sup>/ha) of trees occurred at E<sub>1</sub>, followed tree density as 494.53 trees/ha with basal area of 63.46 m<sup>2</sup>/ha at E<sub>2</sub>. While the lowest density (391.74 trees/ha) and basal area (47.73 m<sup>2</sup>/ha) of trees was recorded at elevation E<sub>3</sub>.

At elevation E<sub>1</sub> density of individual trees ranged from 5.00 trees/ha (*Neolitsea pallens*) to 480.08 trees/ha (*Cedrus deodara*), at E<sub>2</sub> it ranged from 5.00 trees/ha (*Neolitsea pallens*) to 342.00 trees/ha (*Cedrus deodara*) and at E<sub>3</sub> it varied from 6.67 trees/ha (*Quercus semecarpifolia*) to 205.04 trees/ha (*Cedrus deodara*). Likewise, the basal area of individual trees at E<sub>1</sub> varied from 0.16 m<sup>2</sup>/ha (*Pyrus pashia*) to 80.54 m<sup>2</sup>/ha (*Cedrus deodara*), at E<sub>2</sub> from 0.08 (*Rhododendron arboreum*) to 53.55 m<sup>2</sup>/ha (*Cedrus deodara*) and at E<sub>3</sub> from 0.68 (*Abies pindrow*) to 42.90 m<sup>2</sup>/ha (*Cedrus deodara*). Thus, among different trees species *Cedrus deodara* exhibited highest density and basal area at all elevations and accounted for more than 90% of the total density and basal area of trees at each elevation. At E<sub>1</sub> its density (480.08 trees/ha) and basal area (80.54 m<sup>2</sup>/ha) was highest amongst three elevations. At E<sub>2</sub> its density was 342.00 trees/ha and basal area was 53.55 m<sup>2</sup>/ha while at E<sub>3</sub> its density was 205.04 trees/ha and basal area was 42.90 m<sup>2</sup>/ha (Table 10).

*Cedrus deodara* was the dominant tree species at all elevations with IVI of 197.77, 164.35 and 158.23 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. At elevation E<sub>1</sub>, *Q. leucotrichophora* was the co-dominant species and *Prunus armeniaca* was associate species with their respective IVI of 32.84 and 18.85, respectively. At E<sub>2</sub>, *Picea smithiana* (IVI of 21.25) was codominant and *Abies pindrow* (IVI of 18.83) was associate species and at E<sub>3</sub>, *Abies spectabilis* with IVI of 34.49 was the co-dominant species and *Populus ciliata* with IVI of 25.11 was associate species. Many tree species at different elevations reported very low values (less than or

around 10) of IVI like, *Lyonia ovalifolia*, *Neolitsea pallens*, *Quercus floribunda*, *Prunus cornuta*, *Quercus leucotrichophora*, *Quercus semecarpifolia* and *Rhododendron arboreum* and thus were the rare species at their respective elevations (Table 10).

**Table 10: Density, basal area, and importance value index (IVI) of trees in Deodar (*Cedrus deodara*) forests at different elevations**

| Tree Species                                   | Density<br>(trees/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI           |
|------------------------------------------------|-----------------------|------------------------------------|---------------|
| <b>Elevation - E<sub>1</sub> (900-1800 m)</b>  |                       |                                    |               |
| <i>Cedrus deodara</i>                          | 480.08                | 80.54                              | 197.77        |
| <i>Lyonia ovalifolia</i>                       | 5.29                  | 1.27                               | 7.60          |
| <i>Neolitsea pallens</i>                       | 5.00                  | 0.79                               | 12.31         |
| <i>Prunus armeniaca</i>                        | 15.00                 | 0.35                               | 18.85         |
| <i>Prunus cerasoides</i>                       | 10.00                 | 0.91                               | 18.60         |
| <i>Pyrus pashia</i>                            | 7.50                  | 0.16                               | 12.04         |
| <i>Quercus leucotrichophora</i>                | 40.01                 | 4.12                               | 32.84         |
| <b>Total</b>                                   | <b>562.60</b>         | <b>88.13</b>                       | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (1800-2700 m)</b> |                       |                                    |               |
| <i>Abies pindrow</i>                           | 20.00                 | 2.52                               | 18.83         |
| <i>Cedrus deodara</i>                          | 342.00                | 53.55                              | 164.35        |
| <i>Ilex dipyrrena</i>                          | 10.00                 | 0.13                               | 10.34         |
| <i>Lyonia ovalifolia</i>                       | 7.50                  | 0.10                               | 7.08          |
| <i>Neolitsea pallens</i>                       | 5.00                  | 0.06                               | 6.51          |
| <i>Picea smithiana</i>                         | 25.00                 | 3.42                               | 21.25         |
| <i>Pinus wallichiana</i>                       | 15.00                 | 1.72                               | 13.86         |
| <i>Prunus armeniaca</i>                        | 15.00                 | 0.45                               | 11.85         |
| <i>Prunus cornuta</i>                          | 12.50                 | 0.14                               | 8.15          |
| <i>Quercus leucotrichophora</i>                | 7.50                  | 0.23                               | 9.99          |
| <i>Quercus floribunda</i>                      | 10.00                 | 0.44                               | 8.12          |
| <i>Quercus semecarpifolia</i>                  | 20.00                 | 0.62                               | 13.13         |
| <i>Rhododendron arboreum</i>                   | 5.16                  | 0.08                               | 6.55          |
| <b>Total</b>                                   | <b>494.53</b>         | <b>63.46</b>                       | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (2700-3600 m)</b> |                       |                                    |               |
| <i>Abies spectabilis</i>                       | 82.51                 | 0.68                               | 34.49         |
| <i>Cedrus deodara</i>                          | 205.04                | 42.90                              | 158.23        |
| <i>Picea smithiana</i>                         | 20.00                 | 0.75                               | 18.68         |
| <i>Pinus wallichiana</i>                       | 22.50                 | 1.28                               | 20.43         |
| <i>Populus ciliata</i>                         | 27.50                 | 1.00                               | 25.11         |
| <i>Prunus cornuta</i>                          | 20.00                 | 0.60                               | 22.37         |
| <i>Quercus floribunda</i>                      | 7.50                  | 0.38                               | 10.20         |
| <i>Quercus semecarpifolia</i>                  | 6.67                  | 0.13                               | 10.49         |
| <b>Total</b>                                   | <b>391.74</b>         | <b>47.73</b>                       | <b>300.00</b> |

In western mixed coniferous forests common tree species at different elevations were: *Abies pindrow* with *Picea smithiana*, *Pinus wallichiana*, *Quercus semecarpifolia* etc. (Table 11). Highest number of tree species (10) in this forest was recorded at both E<sub>1</sub> and E<sub>2</sub> whereas 7 tree species were present at E<sub>3</sub>. Among three elevations, highest tree density (500.09 trees/ha) and basal area (65.68 m<sup>2</sup>/ha) was observed at E<sub>1</sub> followed by E<sub>2</sub> with tree density as 420.07 trees/ha and basal area of 61.20 m<sup>2</sup>/ha. While the lowest density (367.56 trees/ha) and basal area (43.74 m<sup>2</sup>/ha) of trees was recorded at E<sub>3</sub>.

**Table 11: Density, basal area, and importance value index (IVI) of trees in western mixed coniferous forests at different elevations**

| Tree Species                                   | Density (trees/ha) | Basal area (m <sup>2</sup> /ha) | IVI           |
|------------------------------------------------|--------------------|---------------------------------|---------------|
| <b>Elevation - E<sub>1</sub> (1200-2100 m)</b> |                    |                                 |               |
| <i>Abies pindrow</i>                           | 165.03             | 25.36                           | 86.40         |
| <i>Aesculus indica</i>                         | 7.50               | 0.64                            | 13.61         |
| <i>Alnus nitida</i>                            | 7.50               | 0.32                            | 9.40          |
| <i>Cedrus deodara</i>                          | 117.52             | 12.97                           | 58.12         |
| <i>Juglans regia</i>                           | 2.53               | 0.19                            | 4.48          |
| <i>Lyonia ovalifolia</i>                       | 12.50              | 0.33                            | 14.13         |
| <i>Neolitsea pallens</i>                       | 2.50               | 0.01                            | 4.17          |
| <i>Picea smithiana</i>                         | 137.52             | 19.62                           | 72.20         |
| <i>Pinus wallichiana</i>                       | 40.01              | 6.01                            | 28.32         |
| <i>Rhododendron arboreum</i>                   | 7.50               | 0.23                            | 9.33          |
| <b>Total</b>                                   | <b>500.09</b>      | <b>65.68</b>                    | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (2100-3000 m)</b> |                    |                                 |               |
| <i>Abies pindrow</i>                           | 187.53             | 27.33                           | 105.97        |
| <i>Acer caesium</i>                            | 7.50               | 0.58                            | 11.07         |
| <i>Aesculus indica</i>                         | 7.50               | 0.55                            | 11.02         |
| <i>Alnus nitida</i>                            | 2.50               | 0.34                            | 5.32          |
| <i>Cedrus deodara</i>                          | 42.51              | 5.04                            | 35.01         |
| <i>Ilex dipyrena</i>                           | 2.48               | 0.02                            | 4.80          |
| <i>Juglans regia</i>                           | 2.50               | 0.09                            | 4.91          |
| <i>Picea smithiana</i>                         | 137.52             | 23.38                           | 87.60         |
| <i>Pinus wallichiana</i>                       | 27.50              | 3.58                            | 29.07         |
| <i>Populus ciliata</i>                         | 2.50               | 0.29                            | 5.24          |
| <b>Total</b>                                   | <b>420.07</b>      | <b>61.20</b>                    | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (3000-3900 m)</b> |                    |                                 |               |
| <i>Abies spectabilis</i>                       | 137.52             | 17.16                           | 100.19        |
| <i>Cedrus deodara</i>                          | 47.51              | 5.01                            | 42.03         |
| <i>Picea smithiana</i>                         | 122.52             | 15.38                           | 92.03         |
| <i>Pinus wallichiana</i>                       | 15.00              | 1.74                            | 19.82         |
| <i>Populus ciliata</i>                         | 7.50               | 0.73                            | 9.60          |
| <i>Quercus semecarpifolia</i>                  | 32.51              | 3.61                            | 28.87         |
| <i>Taxus wallichiana</i>                       | 5.00               | 0.10                            | 7.47          |
| <b>Total</b>                                   | <b>367.56</b>      | <b>43.74</b>                    | <b>300.00</b> |

Among different trees species *Abies pindrow* exhibited maximum density and basal area at all elevations. At E<sub>1</sub> its density (165.03 trees/ha) and basal area (25.36 m<sup>2</sup>/ha) was highest amongst three elevations. At E<sub>2</sub> *Abies pindrow* exhibited density of 187.53 trees/ha and basal area of 27.33 m<sup>2</sup>/ha while at E<sub>3</sub> its density was 137.52 trees/ha and basal area was 17.16 m<sup>2</sup>/ha. *Neolitsea pallens* had least density (2.50 trees/ha) and basal area (0.01 m<sup>2</sup>/ha), at E<sub>1</sub>. While, *Ilex dipyrena* had least density (2.48 trees/ha) and basal area (0.02m<sup>2</sup>/ha) at E<sub>2</sub> and *Taxus wallichiana* exhibited minimum density (5.00 trees/ha) and basal area (0. 10 m<sup>2</sup>/ha) at E<sub>3</sub> (Table 11).

At three elevations, *Abies* was the dominant tree species with IVI of 86.44, 105.97 and 100.19 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. At three elevations *Picea smithiana* was co-dominant with IVI of 72.20, 87.60 and 92.03 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. *Cedrus deodara* was associate species with IVI of 58.12, 35.01 and 42.03 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. *Neolitsea pallens*, *Ilex dipyrena* and *Taxus wallichiana* at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> exhibited lowest IVI as 4.17, 4.80 and 7.47, respectively and thus were the rare species in western mixed coniferous forests (Table 11).

In moist temperate lower deciduous forests 10 tree species were recorded (Table 12). More number of tree species (9) were recorded at E<sub>1</sub> as compared to E<sub>2</sub> (7) and E<sub>3</sub> (6). Among three elevations, at E<sub>1</sub> highest tree density (422.57 trees/ha) and basal area (62.29 m<sup>2</sup>/ha) was recorded followed by E<sub>2</sub> with tree density as 362.56 trees/ha and basal area of 53.20 m<sup>2</sup>/ha. While the lowest density (297.55 trees/ha) and basal area (44.42 m<sup>2</sup>/ha) of trees was recorded at elevation E<sub>3</sub>.

Among different trees species *Acer caesium* exhibited highest density and basal area at all elevations. At E<sub>1</sub> its density (130.02 trees/ha) and basal area (19.68 m<sup>2</sup>/ha) was highest amongst three elevations. At E<sub>2</sub> its density and basal area was 130.02 trees/ha and 10.54 m<sup>2</sup>/ha respectively while at E<sub>3</sub>, its density was 102.52 trees/ha and basal area was 11.74 m<sup>2</sup>/ha. *Pyrus lanata* had least density of 12.50 trees/ha and basal area of 0.70 m<sup>2</sup>/ha at E<sub>1</sub>, *Juglans regia* exhibited least density (10.00 trees/ha) and basal area (1.09 m<sup>2</sup>/ha) at E<sub>2</sub> and *Populus ciliata* showed least density (2.50 trees/ha) and basal area (0.06 m<sup>2</sup>/ha) at E<sub>3</sub> (Table 12).

At E<sub>1</sub>, *Acer caesium* was dominant tree species with an IVI of 77.74 and *Pinus wallichiana* was co-dominant tree with IVI of 70.36. However, *Pyrus lanata* was rare species

with lowest IVI as 11.77. While at E<sub>2</sub>, *Cedrus deodara* was dominant tree species with IVI of 74.08 along with it, *Acer caesium* exhibited IVI of 73.06 which can be considered as equally dominant tree species. *Pinus wallichiana* was co-dominant tree species with IVI of 48.57. At E<sub>2</sub>, least IVI was observed for *Juglans regia* as 18.04 and was thus rare species here. At E<sub>3</sub>, *Acer caesium* was dominant tree species with an IVI of 79.93 while *Picea smithiana* was co-dominant tree species with an IVI of 63.08. *Populus ciliata* was rare species with lowest IVI of 5.73 (Table 12).

**Table 12: Density, basal area, and importance value index (IVI) of trees in moist temperate lower deciduous forests at different elevations**

| Tree species                                  | Density (trees/ha) | Basal Area (m <sup>2</sup> /ha) | IVI           |
|-----------------------------------------------|--------------------|---------------------------------|---------------|
| <b>Elevation- E<sub>1</sub> (1000-1800 m)</b> |                    |                                 |               |
| <i>Acer caesium</i>                           | 130.02             | 19.68                           | 77.74         |
| <i>Aesculus indica</i>                        | 25.00              | 2.60                            | 17.78         |
| <i>Cedrus deodara</i>                         | 60.01              | 9.68                            | 45.13         |
| <i>Fraxinus micrantha</i>                     | 27.50              | 2.79                            | 22.52         |
| <i>Juglans regia</i>                          | 12.50              | 1.69                            | 13.37         |
| <i>Pinus wallichiana</i>                      | 102.52             | 19.13                           | 70.36         |
| <i>Prunus cornuta</i>                         | 12.50              | 1.00                            | 12.26         |
| <i>Pyrus lanata</i>                           | 12.50              | 0.70                            | 11.77         |
| <i>Ulmus wallichiana</i>                      | 40.01              | 5.02                            | 29.07         |
| <b>Total</b>                                  | <b>422.57</b>      | <b>62.29</b>                    | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (1800-2400 m)</b> |                    |                                 |               |
| <i>Acer caesium</i>                           | 130.02             | 10.54                           | 73.06         |
| <i>Aesculus indica</i>                        | 35.01              | 2.69                            | 27.75         |
| <i>Cedrus deodara</i>                         | 75.01              | 19.15                           | 74.08         |
| <i>Fraxinus micrantha</i>                     | 32.51              | 2.86                            | 27.38         |
| <i>Juglans regia</i>                          | 10.00              | 1.19                            | 18.04         |
| <i>Pinus wallichiana</i>                      | 47.51              | 11.93                           | 48.57         |
| <i>Ulmus wallichiana</i>                      | 32.51              | 4.84                            | 31.11         |
| <b>Total</b>                                  | <b>362.56</b>      | <b>53.20</b>                    | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (2400-2700 m)</b> |                    |                                 |               |
| <i>Abies pindrow</i>                          | 55.01              | 11.32                           | 63.03         |
| <i>Acer caesium</i>                           | 102.52             | 11.74                           | 79.93         |
| <i>Fraxinus micrantha</i>                     | 30.01              | 3.39                            | 36.76         |
| <i>Picea smithiana</i>                        | 57.51              | 10.97                           | 63.08         |
| <i>Populus ciliata</i>                        | 2.50               | 0.06                            | 5.73          |
| <i>Ulmus wallichiana</i>                      | 50.01              | 6.93                            | 51.46         |
| <b>Total</b>                                  | <b>297.55</b>      | <b>44.42</b>                    | <b>300.00</b> |

The Kail forests were dominated by *Pinus wallichiana*. Other species like, *Quercus leucotrichophora*, *Cedrus deodara*, *Rhododendron arboreum*, *Abies pindrow*, *Picea smithiana* etc. were also recorded at different elevations (Table 13). More number of tree species (14) were recorded at E<sub>2</sub> as compared to E<sub>1</sub> (12) and E<sub>3</sub> (6). Among three elevations, at E<sub>1</sub> highest tree density (457.58 trees/ha) and basal area (52.67 m<sup>2</sup>/ha) was recorded followed by E<sub>2</sub> where density of tree was 405.07 trees/ha and basal area was 52.67 m<sup>2</sup>/ha. While the lowest density (362.56 trees/ha) and basal area (43.66 m<sup>2</sup>/ha) of trees was recorded at E<sub>3</sub>.

Among different trees species *Pinus wallichiana* exhibited highest density and basal area at all elevations. At E<sub>1</sub> its density (302.55 trees/ha) and basal area (52.01 m<sup>2</sup>/ha) was highest amongst three elevations. At E<sub>2</sub> its density was 277.54 trees/ha and basal area was 37.04 m<sup>2</sup>/ha while at E<sub>3</sub>, its density was 252.55 trees/ha and basal area was 35.64 m<sup>2</sup>/ha. *Lyonia ovalifolia* was found to have least density of 2.50 trees/ha and basal area of 0.04 m<sup>2</sup>/ha at E<sub>1</sub>, *Prunus cornuta* exhibited least density (5.00 trees/ha) and basal area (0.06 m<sup>2</sup>/ha) at E<sub>2</sub> and *Acer caesium* showed least density (2.50 trees/ha) and basal area (0.74 m<sup>2</sup>/ha) at E<sub>3</sub> (Table 13).

At all three elevations *Pinus wallichiana* was the dominant tree species with IVI of 172.97, 144.44 and 183.17 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. At elevation E<sub>1</sub> *Quercus leucotrichophora* was co-dominant species and *Rhododendron arboreum* was associate species with their respective IVI of 36.34 and 14.99. Whereas, *Cedrus deodara* (IVI= 45.10) at E<sub>2</sub> and 46.47 at E<sub>3</sub> was co-dominant and *Picea smithiana* (IVI = 16.38) at E<sub>2</sub> and 30.60 at E<sub>3</sub> was associate species. *Lyonia ovalifolia* (IVI=5.37), *Quercus leucotrichophora* (IVI=5.54) and *Acer caesium* (5.54 = 8.64) at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively recorded lowest importance value index thus were the rare species (Table 13).

The prominent tree species in Kharsu Oak forests were *Quercus semicarpifolia*, *Abies pindrow*, *Abies spectabilis*, *Cedrus deodara*, *Picea smithiana*, *Pinus wallichiana* at different elevations (Table 14). More number of tree species (10) were recorded at E<sub>1</sub> as compared to E<sub>2</sub> (7) and E<sub>3</sub> (5). Among three elevations, at E<sub>1</sub> highest tree density (610 .11 trees/ha) and basal area (75.31 m<sup>2</sup>/ha) was recorded followed by E<sub>2</sub> with tree density as 525.09 trees/ha with basal area as 65.45 m<sup>2</sup>/ha. While the lowest density (407.57 trees/ha) and basal area (56.04 m<sup>2</sup>/ha) of trees was recorded at elevation E<sub>3</sub>.



**Table 13: Density, basal area, and importance value index (IVI) of trees in Kail (*Pinus wallichiana*) forests at different elevations**

| Tree species                                  | Density<br>(trees/ha) | Basal Area<br>(m <sup>2</sup> /ha) | IVI           |
|-----------------------------------------------|-----------------------|------------------------------------|---------------|
| <b>Elevation- E<sub>1</sub> (1400-2100 m)</b> |                       |                                    |               |
| <i>Alnus nitida</i>                           | 5.00                  | 0.57                               | 6.81          |
| <i>Cupressus torulosa</i>                     | 5.00                  | 0.14                               | 6.09          |
| <i>Juglans regia</i>                          | 5.00                  | 0.63                               | 6.91          |
| <i>Lyonia ovalifolia</i>                      | 2.50                  | 0.04                               | 5.37          |
| <i>Neolitsea pallens</i>                      | 12.50                 | 0.14                               | 12.49         |
| <i>Pinus wallichiana</i>                      | 302.55                | 52.01                              | 172.97        |
| <i>Prunus cerasoides</i>                      | 12.50                 | 0.14                               | 12.49         |
| <i>Prunus cornuta</i>                         | 15.00                 | 0.17                               | 13.09         |
| <i>Pyrus pashia</i>                           | 7.50                  | 0.06                               | 6.51          |
| <i>Quercus leucotrichophora</i>               | 62.51                 | 4.97                               | 36.34         |
| <i>Rhamnus triquetra</i>                      | 5.00                  | 0.05                               | 5.94          |
| <i>Rhododendron arboreum</i>                  | 22.50                 | 0.33                               | 14.99         |
| <b>Total</b>                                  | <b>457.58</b>         | <b>59.24</b>                       | <b>300.00</b> |
| <b>Elevation-E<sub>2</sub> (2100-2800 m)</b>  |                       |                                    |               |
| <i>Abies pindrow</i>                          | 7.50                  | 0.76                               | 12.11         |
| <i>Alnus nitida</i>                           | 7.50                  | 0.93                               | 6.56          |
| <i>Cedrus deodara</i>                         | 65.01                 | 9.10                               | 45.10         |
| <i>Juglans regia</i>                          | 5.00                  | 0.57                               | 8.19          |
| <i>Lyonia ovalifolia</i>                      | 5.00                  | 0.07                               | 7.25          |
| <i>Picea smithiana</i>                        | 15.00                 | 2.03                               | 16.38         |
| <i>Pinus wallichiana</i>                      | 252.54                | 37.04                              | 144.44        |
| <i>Populus ciliata</i>                        | 10.00                 | 0.58                               | 12.40         |
| <i>Prunus cornuta</i>                         | 5.00                  | 0.06                               | 7.23          |
| <i>Pyrus pashia</i>                           | 5.00                  | 0.07                               | 7.24          |
| <i>Quercus floribunda</i>                     | 7.50                  | 0.41                               | 8.52          |
| <i>Quercus leucotrichophora</i>               | 7.50                  | 0.40                               | 5.54          |
| <i>Rhododendron arboreum</i>                  | 7.50                  | 0.11                               | 10.89         |
| <i>Taxus wallichiana</i>                      | 5.00                  | 0.55                               | 8.15          |
| <b>Total</b>                                  | <b>405.07</b>         | <b>52.67</b>                       | <b>300.00</b> |
| <b>Elevation-E<sub>3</sub> (2800-3600 m)</b>  |                       |                                    |               |
| <i>Abies spectabilis</i>                      | 7.50                  | 0.88                               | 16.59         |
| <i>Acer caesium</i>                           | 2.50                  | 0.74                               | 8.64          |
| <i>Cedrus deodara</i>                         | 42.51                 | 4.25                               | 46.47         |
| <i>Picea smithiana</i>                        | 27.50                 | 1.86                               | 30.60         |
| <i>Pinus wallichiana</i>                      | 277.55                | 35.64                              | 183.17        |
| <i>Taxus wallichiana</i>                      | 5.00                  | 0.29                               | 14.53         |
| <b>Total</b>                                  | <b>362.56</b>         | <b>43.66</b>                       | <b>300.00</b> |

Among different trees, *Quercus semecarpifolia* exhibited highest density and basal area at all elevations. At E<sub>1</sub> its density (330.06 trees/ha) and basal area (35.62 m<sup>2</sup>/ha) was highest amongst three elevations. At E<sub>2</sub> its density was 265.05 trees/ha and basal area was

34.44 m<sup>2</sup>/ha while at E<sub>3</sub>, its density was 187.53 trees/ha and basal area was 23.76 m<sup>2</sup>/ha. Among different trees, *Quercus floribunda* had least density of 2.50 trees/ha and basal area of 0.18 m<sup>2</sup>/ha at E<sub>1</sub>, *Prunus cornuta* exhibited least density (2.50 trees/ha) and basal area (0.07 m<sup>2</sup>/ha) at E<sub>2</sub> and *Taxus wallichiana* showed least density (5.00 trees/ha) and basal area (0.37 m<sup>2</sup>/ha) at E<sub>3</sub> (Table 14).

**Table 14: Density, basal area, and importance value index (IVI) of trees in Kharsu Oak (*Q. semecarpifolia*) forests at different elevations**

| Tree species                                  | Density (Trees/ha) | Basal Area (m <sup>2</sup> /ha) | IVI           |
|-----------------------------------------------|--------------------|---------------------------------|---------------|
| <b>Elevation- E<sub>1</sub> (2300-2800 m)</b> |                    |                                 |               |
| <i>Abies pindrow</i>                          | 82.51              | 13.80                           | 48.52         |
| <i>Acer caesium</i>                           | 50.01              | 6.79                            | 29.71         |
| <i>Aesculus indica</i>                        | 15.00              | 1.08                            | 12.22         |
| <i>Cedrus deodara</i>                         | 32.51              | 4.60                            | 19.78         |
| <i>Juglans regia</i>                          | 7.50               | 1.53                            | 11.60         |
| <i>Picea smithiana</i>                        | 45.01              | 6.31                            | 28.25         |
| <i>Pinus wallichiana</i>                      | 40.01              | 5.23                            | 21.83         |
| <i>Prunus cornuta</i>                         | 5.00               | 0.18                            | 5.22          |
| <i>Quercus floribunda</i>                     | 2.50               | 0.18                            | 4.81          |
| <i>Quercus semecarpifolia</i>                 | 330.06             | 35.62                           | 118.06        |
| <b>Total</b>                                  | <b>610.11</b>      | <b>75.31</b>                    | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (2800-3200 m)</b> |                    |                                 |               |
| <i>Abies spectabilis</i>                      | 105.02             | 11.90                           | 59.24         |
| <i>Acer acuminatum</i>                        | 42.51              | 5.30                            | 31.98         |
| <i>Cedrus deodara</i>                         | 22.50              | 2.68                            | 18.91         |
| <i>Picea smithiana</i>                        | 70.01              | 8.80                            | 42.57         |
| <i>Pinus wallichiana</i>                      | 17.50              | 2.25                            | 17.30         |
| <i>Prunus cornuta</i>                         | 2.50               | 0.07                            | 5.85          |
| <i>Quercus semecarpifolia</i>                 | 265.05             | 34.44                           | 124.14        |
| <b>Total</b>                                  | <b>525.09</b>      | <b>65.45</b>                    | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (3200-3600 m)</b> |                    |                                 |               |
| <i>Abies spectabilis</i>                      | 95.02              | 14.74                           | 76.28         |
| <i>Picea smithiana</i>                        | 95.02              | 14.44                           | 75.74         |
| <i>Pinus wallichiana</i>                      | 25.00              | 2.75                            | 24.37         |
| <i>Quercus semecarpifolia</i>                 | 187.53             | 23.76                           | 115.07        |
| <i>Taxus wallichiana</i>                      | 5.00               | 0.37                            | 8.55          |
| <b>Total</b>                                  | <b>407.57</b>      | <b>56.04</b>                    | <b>300.00</b> |

At all three elevations, *Quercus semecarpifolia* was the dominant tree species with IVI of 118.06, 124.14 and 115.07 at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. At elevation E<sub>1</sub> *Abies pindrow* was the co-dominant species and *Acer caesium* was associate species with their

respective IVI of 48.52 and 29.71 respectively. Whereas at E<sub>2</sub>, *Abies spectabilis* was co-dominant and *Picea smithiana* was associate species with IVI of 59.24 and 42.57, respectively. E<sub>3</sub>, *Abies spectabilis* was co-dominant and *P. smithiana* was associate species with IVI of 76.28 and 75.74 respectively. *Quercus floribunda*, *Prunus cornuta* and *Taxus wallichiana* at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> exhibited lowest IVI values of 4.81, 5.85 and 8.55, respectively and thus were the rare tree species (Table 14).

In upper Oak-Fir forest *Abies pindrow*, *Acer spectabilis*, *Quercus semecarpifolia*, *Picea smithiana*, *Pinus wallichiana* and *Acer caesium* were common tree species (Table 15). More number of tree species were recorded at E<sub>1</sub> (9) followed by E<sub>2</sub> (7) and E<sub>3</sub> (5). Highest tree density (387.57 trees/ha) and basal area (67.66 m<sup>2</sup>/ha) was recorded at elevation E<sub>1</sub> followed by E<sub>2</sub> with tree density as 280.66 trees/ha and basal area as 62.29 m<sup>2</sup>/ha. While the lowest density (277.55 trees/ha) and basal area (43.22 m<sup>2</sup>/ha) of trees was recorded at elevation E<sub>3</sub>.

*Abies pindrow* displayed highest density (152.53 trees/ha) and basal area (28.02 m<sup>2</sup>/ha) at elevation E<sub>1</sub>. While at E<sub>2</sub>, *Abies spectabilis* and *Quercus semecarpifolia* displayed highest but almost equal density (92.52 and 85.63 trees/ha, respectively) with their basal area of 22.75 and 22.21 m<sup>2</sup>/ha, respectively. At E<sub>3</sub>, maximum density (105.02 trees/ha) and basal area (17.37 m<sup>2</sup>/ha) was recorded for *Quercus semecarpifolia*, followed by *Abies spectabilis* with density as 87.52 trees/ha and basal area as 14.57 m<sup>2</sup>/ha (Table 15).

At E<sub>1</sub> *Abies pindrow* was dominant tree species with IVI as (93.68) and *Quercus semecarpifolia* was co-dominant tree species with IVI as 65.16. At E<sub>2</sub> *Abies spectabilis* and *Quercus semecarpifolia* maintained equal dominance with IVI of 86.88 and 86.02, respectively. Whereas, *Acer acuminatum* and *Picea smithiana* were co-dominant species with IVI as 33.38 and 34.72, respectively. While at E<sub>3</sub>, maximum IVI (101.56) was recorded for *Quercus semecarpifolia* thus, it was dominant species and *Abies spectabilis* was co-dominant species with IVI as 88.78. At E<sub>1</sub>, least IVI of 9.23 was recorded for *Prunus cornuta*, at E<sub>2</sub> for *Quercus floribunda* (7.91), and at E<sub>3</sub> for *Pinus wallichiana* (16.69) designating them as rare species in upper Oak-Fir forests (Table 15).

In upper moist temperate deciduous forests common tree species were: *Acer caesium*, *Abies pindrow*, *Abies spectabilis*, *Quercus semecarpifolia*, and *Picea smithiana* (Table 16). In these forests highest number of tree species (7) was recorded at E<sub>1</sub> as compared to E<sub>2</sub> (6) and

E<sub>3</sub> (5). Highest tree density (435.08 trees/ha) and basal area (65.31 m<sup>2</sup>/ha) was recorded at elevation (E<sub>1</sub>), followed by E<sub>2</sub> with tree density as 387.57 trees/ha and basal area as 49.78 m<sup>2</sup>/ha. While the lowest tree density (332.56 trees/ha) and basal area (40.57 m<sup>2</sup>/ha) was recorded at E<sub>3</sub>.

**Table 15: Density, basal area, and importance value index (IVI) of trees in upper Oak-Fir forests at different elevations**

| Tree species                                   | Density<br>(Trees/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI           |
|------------------------------------------------|-----------------------|------------------------------------|---------------|
| <b>Elevation - E<sub>1</sub> (2100-2600 m)</b> |                       |                                    |               |
| <i>Abies pindrow</i>                           | 152.53                | 28.03                              | 93.68         |
| <i>Acer caesium</i>                            | 30.01                 | 5.31                               | 28.50         |
| <i>Aesculus indica</i>                         | 20.00                 | 2.73                               | 22.10         |
| <i>Juglans regia</i>                           | 20.00                 | 3.47                               | 23.19         |
| <i>Picea smithiana</i>                         | 25.00                 | 4.36                               | 22.57         |
| <i>Pinus wallichiana</i>                       | 15.00                 | 2.80                               | 17.69         |
| <i>Prunus cornuta</i>                          | 7.50                  | 0.57                               | 9.23          |
| <i>Quercus floribunda</i>                      | 17.50                 | 2.49                               | 17.87         |
| <i>Quercus semecarpifolia</i>                  | 100.02                | 17.90                              | 65.16         |
| <b>Total</b>                                   | <b>387.57</b>         | <b>67.66</b>                       | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (2600-3100 m)</b> |                       |                                    |               |
| <i>Abies spectabilis</i>                       | 92.52                 | 22.75                              | 86.88         |
| <i>Acer acuminatum</i>                         | 30.01                 | 2.97                               | 33.38         |
| <i>Picea smithiana</i>                         | 30.01                 | 6.63                               | 34.72         |
| <i>Pinus wallichiana</i>                       | 20.00                 | 3.62                               | 26.40         |
| <i>Prunus cornuta</i>                          | 17.50                 | 3.09                               | 24.69         |
| <i>Quercus floribunda</i>                      | 5.00                  | 1.02                               | 7.91          |
| <i>Quercus semecarpifolia</i>                  | 85.63                 | 22.21                              | 86.02         |
| <b>Total</b>                                   | <b>280.66</b>         | <b>62.29</b>                       | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (3100-3500 m)</b> |                       |                                    |               |
| <i>Abies spectabilis</i>                       | 87.52                 | 14.57                              | 88.78         |
| <i>Picea smithiana</i>                         | 55.01                 | 9.59                               | 65.53         |
| <i>Pinus wallichiana</i>                       | 7.50                  | 0.96                               | 16.70         |
| <i>Quercus semecarpifolia</i>                  | 105.02                | 17.37                              | 101.56        |
| <i>Taxus wallichiana</i>                       | 22.50                 | 0.73                               | 27.44         |
| <b>Total</b>                                   | <b>277.55</b>         | <b>43.22</b>                       | <b>300.00</b> |

With respect to tree species, *Acer caesium* showed highest density and basal area at all the three elevations. Its density (142.53 trees/ha) and basal area (20.64 m<sup>2</sup>/ha) at E<sub>1</sub> was highest, at E<sub>2</sub> its density was 120.02 trees/ha and its basal area was 19.07 m<sup>2</sup>/ha while, at E<sub>3</sub> its density was 132.52 trees/ha and basal area was 14.90 m<sup>2</sup>/ha. Whereas, lowest density and basal area was recorded for *Taxus wallichiana* (7.50 trees/ha and 0.39 m<sup>2</sup>/ha) at E<sub>1</sub> and (12.50

trees/ha and 0.12 m<sup>2</sup>/ha) at E<sub>3</sub>. *Prunus cornuta* exhibited least density and basal area and at E<sub>2</sub> as 10 trees/ha and 1.10 m<sup>2</sup>/ha, respectively (Table 16).

Highest IVI was recorded for *Acer caesium* (at E<sub>1</sub> as 82.54, at E<sub>2</sub> as 88.64 and at E<sub>3</sub> as 94.64) at all three elevations signifying it as the dominant species, followed by *Quercus semecarpifolia* (at E<sub>1</sub> as 46.68, at E<sub>2</sub> as 68.74 and at E<sub>3</sub> as 90.34) as a co-dominant species and *Abies pindrow* (at E<sub>1</sub> as 43.33 and at E<sub>2</sub> as 52.61) as an associate species. Whereas, at E<sub>3</sub> *Abies spectabilis* with IVI of 56.05 was an associate species. At E<sub>1</sub> and E<sub>3</sub> very low IVI was recorded for *Taxus wallichiana* showing that they it was rare species at its respective elevation (Table 16).

**Table 16: Density, basal area, and importance value index (IVI) of trees in upper moist temperate deciduous forests at different elevations**

| Tree species                                    | Density<br>(Trees/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI           |
|-------------------------------------------------|-----------------------|------------------------------------|---------------|
| <b>Elevation - E<sub>1</sub> (1700-2300 m)</b>  |                       |                                    |               |
| <i>Abies pindrow</i>                            | 45.01                 | 10.01                              | 43.33         |
| <i>Acer caesium</i>                             | 142.53                | 20.64                              | 82.54         |
| <i>Cedrus deodara</i>                           | 62.51                 | 10.01                              | 43.17         |
| <i>Juglans regia</i>                            | 32.51                 | 5.16                               | 33.55         |
| <i>Picea smithiana</i>                          | 62.51                 | 9.91                               | 39.31         |
| <i>Quercus semecarpifolia</i>                   | 82.51                 | 9.19                               | 46.68         |
| <i>Taxus wallichiana</i>                        | 7.50                  | 0.39                               | 11.42         |
| <b>Total</b>                                    | <b>435.08</b>         | <b>65.31</b>                       | <b>300.0</b>  |
| <b>Elevation – E<sub>2</sub> (2300-2900 m)</b>  |                       |                                    |               |
| <i>Abies pindrow</i>                            | 62.51                 | 8.85                               | 52.61         |
| <i>Acer caesium</i>                             | 120.02                | 19.07                              | 88.64         |
| <i>Juglans regia</i>                            | 35.00                 | 3.35                               | 30.77         |
| <i>Picea smithiana</i>                          | 42.50                 | 6.70                               | 39.44         |
| <i>Prunus cornuta</i>                           | 10.00                 | 1.10                               | 19.80         |
| <i>Quercus semecarpifolia</i>                   | 117.52                | 10.69                              | 68.74         |
| <b>Total</b>                                    | <b>387.57</b>         | <b>49.78</b>                       | <b>299.99</b> |
| <b>Elevation – E<sub>3</sub> (2900 -3500 m)</b> |                       |                                    |               |
| <i>Abies spectabilis</i>                        | 50.01                 | 7.09                               | 56.05         |
| <i>Acer caesium</i>                             | 132.52                | 14.90                              | 94.64         |
| <i>Picea smithiana</i>                          | 37.51                 | 5.74                               | 43.08         |
| <i>Quercus semecarpifolia</i>                   | 100.02                | 12.68                              | 90.34         |
| <i>Taxus wallichiana</i>                        | 12.50                 | 0.15                               | 15.89         |
| <b>Total</b>                                    | <b>332.56</b>         | <b>40.57</b>                       | <b>300.00</b> |

Comparing nine types of forests for functional attributes of their trees viz., density and basal area it was evident from Table 17 that there was significant difference in density and basal of trees among the forests. It was also recorded that there was decrease in density (trees/ha) in the following sequence: Kharsu Oak forests (514.26) > Ban Oak forests (493.40) > Deodar forests (482.96) > Moru Oak forests (460.91) > Western mixed coniferous (429.24) > Kail forests (408.40) > Moist temperate upper deciduous (385.07) > Moist temperate lower deciduous forests > upper Oak-Fir forests (315.20). Further insight in to the table reveals that highest density of trees (610.11 trees/ha) was present in Kharsu Oak forests at elevation  $E_1$  and minimum density of 277.55 trees/ha occurred in upper Oak forests at elevation  $E_3$ . The effect of elevation on density of trees showed that tree density in forests decreased with increase in elevation. The mean tree density in forests followed the sequence:  $E_1$  (494.53 trees/ha) >  $E_2$  (429.24 trees/ha) >  $E_3$  (259.69 trees/ha). Likewise, difference in basal area ( $m^2/ha$ ) of trees in different forests was statistically significant (Table 17). Basal area of trees was at par in Deodar forests and Kharsu Oak forests but significantly higher than other forests. Whereas, in Moru Oak forests the basal area was significantly low ( $48.59 m^2/ha$ ). There was significant decrease in mean basal area ( $m^2/ha$ ) of trees in forests as  $E_1$  (66.72) >  $E_2$  (56.97) >  $E_3$  (45.52). It was also recorded that interaction of forest types and elevations had significant effect of density and basal area of trees in forests.

The difference in density of trees among forests can be related to change in elevation, climate, soil and other topographic feature where skewed distribution pattern of individuals among constituent species in different forest types due to specific niche differentiation by constituent species under the prevailing climatic and biotic interference environment resulted in dominance of few species in different habitats which can be attributed to differences in basal area of trees in forest types. Airi and Rawal (2015) reported canopy disturbance also strongly impact vegetation compositional attributes in temperate forests (i.e., mixed broad-leaf and banj-Oak forests) in west Himalaya in India and concluded that tree density and basal area exhibits significant decline from undegraded to degraded stands, thus site quality impacts density and basal area of trees. Sequel to canopy disturbance is the change in patterns of tree size class distribution in forests responsible for possible future changes in composition, this can be attributed to difference in basal area of trees in forests. Climatic factors like temperature and water and edaphic factors water, nutrients, and probably soil aeration are important growth factors and thus drivers of tree species distributions but,

Walthert and Meier (1975) contended that soil properties are more important than climate variables in shaping tree species distribution in temperate forests.

Likewise, the decrease in density and basal area of trees from  $E_1$  to  $E_3$  can be related to increasing extreme environmental conditions especially decrease in temperature; steep slopes and other topographic features which suggest that at the upper end of the range of elevation of any species growth attributes are reduced perhaps due to non-congenial climatic conditions. Difference in species richness, density and basal area of trees along elevation might be because altitude and aspect are the most important determinants of vegetation distribution due to their direct impact on microclimate of the habitat (Rawal and Pangtey, 1994a; Kharkwal *et al.* 2005; Eilu and Obua 2005; Singh *et al.* 2009). Locality factors too affect vegetation dynamics of the mountainous regions along the altitudinal gradients (Rajput *et al.* 2017). Beside them factors like size of the forest cover, climate conditions, pattern of temperature, short period of growing season and other ecological factors also affect the distribution of species at different altitudinal gradients. The reduction in species in higher altitudinal gradient could also be attributed to eco-physiological constraints, such as extremely low temperature, short period of growing season and geographical barriers. (Chawla *et al.* 2008) might have resulted in low density and basal area of trees.

**Table 17: Change in density and basal area of trees among forests (F) and elevations (E)**

| Forest Types (F) | Density (trees/ha) at different elevations (E) |                |                | Mean          | Basal area (m <sup>2</sup> /ha) at different elevations (E) |                |                | Mean         |
|------------------|------------------------------------------------|----------------|----------------|---------------|-------------------------------------------------------------|----------------|----------------|--------------|
|                  | E <sub>1</sub>                                 | E <sub>2</sub> | E <sub>3</sub> |               | E <sub>1</sub>                                              | E <sub>2</sub> | E <sub>3</sub> |              |
| <b>FT-1</b>      | 540.09                                         | 505.02         | 435.08         | <b>493.40</b> | 62.24                                                       | 56.60          | 47.16          | <b>55.53</b> |
| <b>FT-2</b>      | 535.09                                         | 482.58         | 365.06         | <b>460.91</b> | 54.58                                                       | 48.10          | 43.10          | <b>48.59</b> |
| <b>FT-3</b>      | 562.60                                         | 494.53         | 391.74         | <b>482.96</b> | 88.13                                                       | 63.46          | 47.73          | <b>66.44</b> |
| <b>FT-4</b>      | 500.09                                         | 420.07         | 367.56         | <b>429.24</b> | 65.68                                                       | 61.20          | 43.74          | <b>56.87</b> |
| <b>FT-5</b>      | 422.57                                         | 362.56         | 297.55         | <b>360.89</b> | 62.29                                                       | 53.20          | 44.42          | <b>53.30</b> |
| <b>FT-6</b>      | 457.58                                         | 405.07         | 362.56         | <b>408.40</b> | 59.24                                                       | 52.67          | 43.66          | <b>51.86</b> |
| <b>FT-7</b>      | 610.11                                         | 525.09         | 407.57         | <b>514.26</b> | 75.31                                                       | 65.45          | 56.04          | <b>65.60</b> |
| <b>FT-8</b>      | 387.57                                         | 280.66         | 277.55         | <b>315.20</b> | 67.66                                                       | 62.29          | 43.22          | <b>57.72</b> |
| <b>FT-9</b>      | 435.08                                         | 387.57         | 332.56         | <b>385.07</b> | 65.31                                                       | 49.78          | 40.57          | <b>51.87</b> |
| <b>Mean</b>      | <b>494.53</b>                                  | <b>429.24</b>  | <b>359.69</b>  |               | <b>66.72</b>                                                | <b>56.97</b>   | <b>45.52</b>   |              |
|                  | C.D. <sub>0.05</sub>                           |                |                |               | C.D. <sub>0.05</sub>                                        |                |                |              |
|                  |                                                | <b>C.D.</b>    | <b>SE (d)</b>  |               |                                                             | <b>C.D.</b>    | <b>SE (d)</b>  |              |
|                  | <b>F</b>                                       | 18.49          | 9.19           |               | <b>F</b>                                                    | 3.73           | 1.85           |              |
|                  | <b>E</b>                                       | 10.67          | 5.30           |               | <b>E</b>                                                    | 2.15           | 1.07           |              |
|                  | <b>F X E</b>                                   | 32.02          | 15.91          |               | <b>F X E</b>                                                | 6.46           | 3.21           |              |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in  $E_1$ ,  $E_2$  and  $E_3$  is different.

Comparable values of tree density in temperate forests of Himalaya has been reported by Saxena and Singh (1982) who reported tree density of 540/ha from Nainital, Indian Himalayas, Gairola *et.al.* (2011b) in moist temperate forests of Garhwal Himalayas reported 493 stems/ha, Singh *et.al.* (1994) in Kumaun Himalaya (420-680 stems/ha), Sharma *et al.* (2001) in Pauri Garhwal Himalaya reported 220 - 640 stems/ha, Sharma *et al.* (2010) in moist temperate deciduous forests reported 485-610 trees/ha and Pande *et al.* (2002) in Chakrata Forest division, Uttarakhand reported 235.6-416.2 trees/ha. Many workers have recorded wide range of density variation in Himalayan temperate forests, tree density 420-1640 ind. ha<sup>-1</sup> was reported for temperate forests of Kumaon Himalaya by Saxena and Singh (1982); 320-2080 ind. ha<sup>-1</sup> in temperate ecosystems by Singh and Singh (1997); 980-1100 ind ha<sup>-1</sup> was reported in Oak dominated forests mixed with other broad leaved tree species in centrl Himalaya by Lal and Lodhiyal (2016); 920-1345 ind. ha<sup>-1</sup> for natural forests in Kumaun Himalaya by Lodhiyal *et al.* (2014); 550-1250 ind. ha<sup>-1</sup> in Oak dominated forests in Kumaun Himalaya by Singh *et al.* (2014); 960-1170 ind. ha<sup>-1</sup> in Van Panchayat forest in Kumaun Himalaya by Pandey and Lodhiyal (2015) and 1040-1260 ind. ha<sup>-1</sup> in pine forests of Kumaun Himalaya by Lal and Lodhiyal (2015); 570-760 ind. ha<sup>-1</sup> in Oak forest by Rawat and Singh (1988) and 295-850 ind.ha<sup>-1</sup> in temperate and tropical forests of Garhwal Himalaya by Sharma *et al.* (2010). There is change in tree density along the elevational gradient was recorded by Sharma *et al.* (2018) in ridge forests in Garhwal Himalaya. The maximum mean tree density (708±153treesha<sup>-1</sup>) was recorded in *Abies spectabilis*–*Quercus semecarpifolia* forest association (between 2800 and 3100m asl), while minimum (425±32treesha<sup>-1</sup>) in *Q. semecarpifolia*–*Cedrus deodara* forest association (between 3100 and 3400m asl).

In other parts of India, Paul (2008) reported higher tree density of 192-1852 trees/ha. in Himalayan forests in Arunachal, while Banday (2014) reported 370-710 trees/ha in subtropical forests of Himachal Pradesh.

In the present study there was significant difference in basal area of trees among forests. The mean basal area of trees in Himalayan moist temperate forest of Shimla district in HP is 51.52 m<sup>2</sup> /ha with a range of 48.59-66.44 m<sup>2</sup>/ha in different types of forests. Such difference in basal area of trees among forest types is a function of individuals of constituent species and their inherent growth behavior. Many workers have reported similar range of basal area of trees in temperate forests of Himalaya. Saxena and Singh (1982) reported basal area of 58.7-93.0 m<sup>2</sup> ha<sup>-1</sup> in natural forests of Kumaun Himalaya. Singh and Singh (1992)



reported 33.9-36.8 m<sup>2</sup> ha<sup>-1</sup> for Oak forests; Lal and Lodhiyal (2015) reported basal area of 36.3-56.4 m<sup>2</sup> ha<sup>-1</sup> for pine forests in Kumaun Himalaya; Shaheen *et al.* (2012) reported range of basal area of trees from 42.3-100.8 m<sup>2</sup>/ha in moist temperate forests of Kashmir Pakistan; Gairola *et al.* (2011a) reported tree basal area range of 41.25-86.56 m<sup>2</sup> /ha in moist temperate forests of Garhwal Himalaya and Singh *et al.* (1994) have reported tree basal area range of 5-114 m<sup>2</sup> /ha in temperate forests of Kumaun, central Himalaya. There is change in basal area of trees along the elevational gradient was recorded by Sharma *et al.* (2018) in ridge forests of Garhwal Himalaya and reported basal cover values ranging between 28.80±5.27m<sup>2</sup>ha<sup>-1</sup> (below 700m asl) to 99.69±29.64m<sup>2</sup>ha<sup>-1</sup> (above 3400m asl).

Some worker's results are close to our findings like, Baduni and Sharma (1996) reported basal area values for trees ranging from 31.50-57.33 m<sup>2</sup> /ha in temperate forests of Pauri Garhwal, Himalaya; Lal and Lodhiyal (2016) computed basal area of 31.81-63.93 m<sup>2</sup>ha<sup>-1</sup> for Oak dominated forests in Kumaun Himalaya; Gairola *et al.* (2011b) reported basal area of trees as 35.08-84.25 m<sup>2</sup>/ha in *Abies pindrow* forest in moist temperate forests of Garhwal Himalaya and Bhandari *et al.* (1997) have reported basal area of trees as 15-60 m<sup>2</sup> /ha in temperate forests of Garhwal Himalaya. Results of present study are also similar to those reported by Lata and Bisht (1991) who gave basal area range of 13.60-71.25 m<sup>2</sup>/ha; Pande (2001) reported basal area of 56-126 m<sup>2</sup>/ha; Koirala (2004) recorded basal area of 56.90-69.80 m<sup>2</sup>/ha; Bhat (2012) reported basal area of 2.91-37.96 m<sup>2</sup> /ha; Raturi (2012) reported basal area of 3.18-43.62 m<sup>2</sup>/ha; Singh (2013) gave a basal area range of 18-100 m<sup>2</sup>/ha and, Malik and Bhatt (2015) reported 10.49-42.92 m<sup>2</sup>/ha basal area of trees in different forests of Himachal Pradesh and Garhwal Hiamalaya.

However, the results obtained in our study are higher than the findings of Ghildiyal *et. al.* (1998) who reported basal area of 24-29 m<sup>2</sup>/ha in Oak forests in Garhwal Himalaya and, Baduni and Sharma (1999) reported basal area of trees in *Quercus floribunda* forests of Garhwal Himalaya as 18.45-38.25 m<sup>2</sup>/ha. Basal area of trees in Deodar forests recorded in the present study was higher than the findings of Sharma *et al.* (2014) who reported basal area of 42.41 m<sup>2</sup>/ha for Sangla valley north-west Himalaya. Result obtained in present study is on the lower side of the findings of Ahmed *et al.* (2006) and Shah *et al.* (2009) who have reported basal area of 70 m<sup>2</sup>/ha in Himalayan forests.

## Phytosociology of shrubs

In Ban Oak forests 60 shrub species were recorded at different elevations (Table 18). Among three elevations, at E<sub>1</sub> highest total shrub density (10000 plants/ha) and basal area (21.232 m<sup>2</sup>/ha) with 29 shrub species was recorded that declined to 8433.33 plants/ha and 19.187 m<sup>2</sup>/ha at E<sub>2</sub> with 30 shrub species. While lowest density and basal area of shrubs was recorded at elevation E<sub>3</sub> i.e. 8333.33 plants/ha and 16.116 m<sup>2</sup>/ha with 32 shrub species.

At elevation E<sub>1</sub>, *Prinsepia utilis* showed maximum density (866.67 plants/ha), followed by *Carissa carandas* (800 plants/ha) and *Meriandra strobilifera* (766.67 plants/ha). Lowest density and basal area was exhibited by *Agave cantula* (33.33 plants/ha) and *Asparagus adscendens* (0.006 m<sup>2</sup>/ha) respectively. At elevation E<sub>2</sub>, maximum density (1166.67 plants/ha) and basal area (6.980 m<sup>2</sup>/ha) was exhibited by *Berberis lycium* and minimum density (33.33 plants/ha) was recorded each for *Buddleja asiatica*, *Clematis buchananiana* and *Rosa macrophylla*. While at elevation E<sub>3</sub> *Zanthoxylum armatum* showed maximum density as 1133.33 plants/ha. Lowest density and basal area was recorded for *Jasminum humile* as 33.33 plants/ha and *Lespedeza gerardiana* as 0.009 m<sup>2</sup>/ha (Table 18 ).

*Carissa carandas* was the dominant shrub species at E<sub>1</sub> with highest IVI of 31.04, *Prinsepia utilis* and *Berberis lycium* were the co-dominant and associate species with IVI of 22.88 and 22.14 respectively, whereas least IVI was recorded for *Asparagus adscendens* (2.97). At E<sub>2</sub>, highest IVI of 59.74 was observed in *Berberis lycium* and was the dominant shrub with *Carissa carandas* (IVI = 29.20) and *Lantana camara* (IVI = 21.63) as co-dominant and associate shrub species, lowest IVI was recorded in *Clematis buchananiana* (2.00). Whereas at E<sub>3</sub> *Zanthoxylum armatum* (IVI = 33.11) and *Berberis lycium* (IVI =31.54) can be considered equally dominant species, *Rosa macrophylla* with IVI of 22.34 was the co-dominant species. *Lespedeza gerardiana* had minimum IVI of 2.37 and was rare species (Table 18).

**Table 18: Density, basal area, and importance value index (IVI) of shrubs in Ban Oak (*Q. leucotrichophora*) forests at different elevations**

| Shrub species                                  | Density<br>(plants/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI   |
|------------------------------------------------|------------------------|------------------------------------|-------|
| <b>Elevation - E<sub>1</sub> (700 -1300 m)</b> |                        |                                    |       |
| <i>Agave cantula</i>                           | 266.67                 | 1.784                              | 17.89 |
| <i>Andrachne cordifolia</i>                    | 33.33                  | 0.190                              | 3.50  |
| <i>Asclepias curassavica</i>                   | 66.67                  | 0.036                              | 3.11  |

|                                                |                 |               |               |
|------------------------------------------------|-----------------|---------------|---------------|
| <i>Asparagus adscendens</i>                    | 66.67           | 0.006         | 2.97          |
| <i>Berberis lycium</i>                         | 466.67          | 2.746         | 22.14         |
| <i>Boehmeria platyphylla</i>                   | 600.00          | 0.131         | 8.89          |
| <i>Carissa carandas</i>                        | 800.00          | 3.443         | 31.04         |
| <i>Colebrookia oppositifolia</i>               | 100.00          | 0.352         | 4.93          |
| <i>Coriaria nepalensis</i>                     | 700.00          | 0.240         | 14.95         |
| <i>Cotinus coggygria</i>                       | 500.00          | 0.206         | 10.51         |
| <i>Desmodium elegans</i>                       | 400.00          | 0.127         | 9.15          |
| <i>Dodonaea viscosa</i>                        | 433.33          | 0.168         | 7.40          |
| <i>Elaeagnus parvifolia</i>                    | 233.33          | 0.262         | 5.84          |
| <i>Flemingia macrophylla</i>                   | 133.33          | 0.011         | 3.66          |
| <i>Hypericum oblongifolium</i>                 | 200.00          | 0.739         | 7.75          |
| <i>Indigofera atropurpurea</i>                 | 133.33          | 0.008         | 3.64          |
| <i>Jasminum humile</i>                         | 166.67          | 1.250         | 9.82          |
| <i>Jasminum mesneyi</i>                        | 300.00          | 1.277         | 11.29         |
| <i>Justicia adhatoda</i>                       | 366.67          | 0.469         | 8.15          |
| <i>Lantana camara</i>                          | 366.67          | 0.933         | 10.33         |
| <i>Lespedeza juncea</i>                        | 100.00          | 0.173         | 4.08          |
| <i>Meriandra strobilifera</i>                  | 766.67          | 0.199         | 13.15         |
| <i>Opuntia stricta</i>                         | 66.67           | 0.343         | 6.83          |
| <i>Prinsepia utilis</i>                        | 866.67          | 2.052         | 22.88         |
| <i>Randia tetrasperma</i>                      | 466.67          | 0.577         | 11.93         |
| <i>Rubus ellipticus</i>                        | 200.00          | 0.649         | 7.33          |
| <i>Vitex negundo</i>                           | 333.33          | 0.947         | 12.34         |
| <i>Woodfordia fruticosa</i>                    | 733.33          | 1.349         | 18.23         |
| <i>Zizyphus oxyphylla</i>                      | 133.33          | 0.565         | 6.27          |
| <b>Total</b>                                   | <b>10000.00</b> | <b>21.232</b> | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (1300-1900 m)</b> |                 |               |               |
| <i>Asclepias curassavica</i>                   | 133.33          | 0.059         | 5.06          |
| <i>Asparagus adscendens</i>                    | 366.67          | 0.034         | 10.87         |
| <i>Berberis lycium</i>                         | 1166.67         | 6.981         | 59.74         |
| <i>Buddleja asiatica</i>                       | 33.33           | 0.040         | 8.54          |
| <i>Carissa carandas</i>                        | 900.00          | 3.250         | 29.20         |
| <i>Clematis buchananiana</i>                   | 33.33           | 0.004         | 2.00          |
| <i>Clematis grata</i>                          | 200.00          | 0.017         | 5.64          |
| <i>Coriaria nepalensis</i>                     | 200.00          | 0.101         | 6.07          |
| <i>Cotoneaster microphylla</i>                 | 100.00          | 0.065         | 3.11          |
| <i>Desmodium elegans</i>                       | 233.33          | 0.129         | 5.02          |
| <i>Euphorbia royleana</i>                      | 133.33          | 1.522         | 12.69         |
| <i>Hypericum oblongifolium</i>                 | 133.33          | 0.378         | 6.72          |
| <i>Indigofera dosua</i>                        | 466.67          | 0.025         | 8.84          |
| <i>Indigofera heterantha</i>                   | 133.33          | 0.007         | 4.79          |
| <i>Jasminum officinale</i>                     | 366.67          | 1.245         | 17.19         |
| <i>Justicia adhatoda</i>                       | 200.00          | 0.159         | 6.37          |
| <i>Lantana camara</i>                          | 366.67          | 2.097         | 21.63         |
| <i>Lespedeza juncea</i>                        | 166.67          | 0.039         | 5.36          |
| <i>Myrsine africana</i>                        | 400.00          | 0.438         | 8.61          |
| <i>Prinsepia utilis</i>                        | 200.00          | 0.730         | 7.76          |

|                                                |                |               |               |
|------------------------------------------------|----------------|---------------|---------------|
| <i>Rosa brunonii</i>                           | 66.67          | 0.323         | 4.06          |
| <i>Rosa macrophylla</i>                        | 33.33          | 0.101         | 2.51          |
| <i>Rubia cordifolia</i>                        | 300.00         | 0.028         | 6.88          |
| <i>Sarcococca saligna</i>                      | 166.67         | 0.011         | 3.62          |
| <i>Skimmia laureola</i>                        | 166.67         | 0.026         | 3.70          |
| <i>Solanum myriacanthum</i>                    | 666.67         | 0.065         | 13.01         |
| <i>Spiraea bella</i>                           | 100.00         | 0.015         | 2.85          |
| <i>Viburnum cotinifolium</i>                   | 100.00         | 0.062         | 3.09          |
| <i>Woodfordia fruticosa</i>                    | 200.00         | 0.450         | 7.89          |
| <i>Zanthoxylum armatum</i>                     | 700.00         | 0.787         | 17.16         |
| <b>Total</b>                                   | <b>8433.33</b> | <b>19.187</b> | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (1900-2500 m)</b> |                |               |               |
| <i>Andrachne cordifolia</i>                    | 233.33         | 0.055         | 7.69          |
| <i>Argyrobium flaccidum</i>                    | 100.00         | 0.068         | 3.13          |
| <i>Berberis aristata</i>                       | 266.67         | 0.954         | 10.63         |
| <i>Berberis lycium</i>                         | 566.67         | 3.255         | 31.54         |
| <i>Clematis bueharianiana</i>                  | 66.67          | 0.011         | 2.38          |
| <i>Clematis grata</i>                          | 100.00         | 0.017         | 2.82          |
| <i>Clematis montana</i>                        | 333.33         | 0.039         | 8.79          |
| <i>Coriaria nepalensis</i>                     | 133.33         | 0.116         | 3.84          |
| <i>Cotoneaster bacillaris</i>                  | 433.33         | 0.348         | 11.91         |
| <i>Daphne papyracea</i>                        | 100.00         | 0.015         | 2.81          |
| <i>Debregeasia salicifolia</i>                 | 200.00         | 0.229         | 6.85          |
| <i>Elaeagnus parvifolia</i>                    | 133.33         | 0.038         | 3.35          |
| <i>Hypericum dyeri</i>                         | 233.33         | 0.997         | 12.02         |
| <i>Hypericum oblongifolium</i>                 | 300.00         | 1.473         | 15.77         |
| <i>Indigofera atropurpurea</i>                 | 266.67         | 0.024         | 7.89          |
| <i>Indigofera dosua</i>                        | 400.00         | 0.036         | 9.57          |
| <i>Indigofera heterantha</i>                   | 333.33         | 0.043         | 7.30          |
| <i>Jasminum humile</i>                         | 33.33          | 0.413         | 4.48          |
| <i>Jasminum officinale</i>                     | 200.00         | 0.941         | 11.27         |
| <i>Lespedeza gerardiana</i>                    | 66.67          | 0.009         | 2.37          |
| <i>Lonicera quinquelocularis</i>               | 100.00         | 0.014         | 2.80          |
| <i>Myrsine africana</i>                        | 300.00         | 0.588         | 11.80         |
| <i>Prinsepia utilis</i>                        | 466.67         | 1.906         | 21.97         |
| <i>Rosa brunonii</i>                           | 133.33         | 0.566         | 6.63          |
| <i>Rosa macrophylla</i>                        | 566.67         | 1.772         | 22.34         |
| <i>Rubia cordifolia</i>                        | 266.67         | 0.024         | 6.38          |
| <i>Sageretia thea</i>                          | 66.67          | 0.167         | 3.35          |
| <i>Sarcococca saligna</i>                      | 200.00         | 0.019         | 5.55          |
| <i>Solanum myriacanthum</i>                    | 166.67         | 0.015         | 5.13          |
| <i>Spiraea canescens</i>                       | 166.67         | 0.015         | 5.13          |
| <i>Yucca gloriosa</i>                          | 266.67         | 0.514         | 9.42          |
| <i>Zanthoxylum armatum</i>                     | 1133.33        | 1.436         | 33.11         |
| <b>Total</b>                                   | <b>8333.33</b> | <b>16.116</b> | <b>300.00</b> |

A perusal of the data presented in Table 19 reveals that in Moru Oak forests 49 shrub species were recorded at different elevations. Maximum number of species was recorded at

E<sub>2</sub> (32) followed by E<sub>1</sub> (23) and E<sub>3</sub> (22). Among three elevations, at E<sub>1</sub> highest shrub density (11000.00 plants/ha) and basal area (21.562 m<sup>2</sup>/ha) was recorded followed by E<sub>2</sub> with shrub density as 9221.20 plants/ha with basal area of 19.386 m<sup>2</sup>/ha. While the lowest density (8100.00 plants /ha) and basal area (16.437 m<sup>2</sup>/ha) of shrubs was recorded at elevation E<sub>3</sub>.

At elevation E<sub>1</sub>, maximum density of an individual shrub was recorded for *Rosa brunonii* (1866.67 plants/ha) followed by *Agave cantula* (1200.00 plants/ha) while least density (33.33 plants /ha) was recorded for *Schisandra grandiflora*. Highest basal area was recorded for *Rosa brunonii* (7.373 m<sup>2</sup>/ha), while the least basal area was observed for *Schisandra grandiflora* (0.002 m<sup>2</sup>/ha). At elevation E<sub>2</sub>, highest density (933.33 plants/ha) was recorded for *Jasminum humile*, followed by *Sarcococca saligna* (866.67 plants/ha), while lowest density of 33.33 plants/ha was exhibited by each: *Lespedeza juncea*, *Lonicera quinquelocularis* and *Prinsepia utilis*. Highest basal area was observed for *Hypericum oblongifolium* (3.862 m<sup>2</sup>/ha) followed by 3.296 m<sup>2</sup>/ha for *Berberis aristata* while lowest basal area of 0.001 m<sup>2</sup>/ha was recorded for each: *Indigofera dosua*, *Strobilanthes dalhousianus* and *Spiraea bella*. At elevation E<sub>3</sub>, *Cotoneaster microphylla* exhibited highest shrub density per hectare (1500.00 plants/ha), followed by *Lespedeza juncea* (1033.33 plants/ha). Whereas lowest density was recorded for *Elaeagnus parvifolia* (66.67 plants /ha). At E<sub>3</sub> highest basal area was observed for *Rubus biflorus* (4.008 m<sup>2</sup>/ha), followed by *Salix denticulata* as 1.598 m<sup>2</sup>/ha while lowest basal area was recorded for *Strobilanthes atropurpureus* as 0.007 m<sup>2</sup>/ha (Table 19).

**Table 19: Density, basal area, and importance value index (IVI) of shrubs in Moru Oak (*Q. floribunda*) forests at different elevations**

| Shrub species                                 | Density (Plants/ha) | Basal area (m <sup>2</sup> /ha) | IVI   |
|-----------------------------------------------|---------------------|---------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (1800-2300 m)</b> |                     |                                 |       |
| <i>Agave cantula</i>                          | 1200.00             | 5.328                           | 49.68 |
| <i>Berberis aristata</i>                      | 1166.67             | 5.245                           | 47.43 |
| <i>Cotoneaster bacillaris</i>                 | 100.00              | 0.043                           | 2.67  |
| <i>Daphne papyracea</i>                       | 33.33               | 0.006                           | 1.89  |
| <i>Debregeasia salicifolia</i>                | 133.33              | 0.179                           | 3.60  |
| <i>Desmodium elegans</i>                      | 333.33              | 0.077                           | 8.08  |
| <i>Hypericum oblongifolium</i>                | 933.33              | 2.142                           | 21.54 |
| <i>Indigofera dosua</i>                       | 900.00              | 0.015                           | 14.50 |
| <i>Lespedeza stenocarpa</i>                   | 433.33              | 0.010                           | 5.55  |
| <i>Prinsepia utilis</i>                       | 633.33              | 0.184                           | 15.99 |
| <i>Pteracanthus urticifolius</i>              | 100.00              | 0.026                           | 2.59  |

|                                               |                 |               |               |
|-----------------------------------------------|-----------------|---------------|---------------|
| <i>Rhamnus virgatus</i>                       | 266.67          | 0.050         | 5.78          |
| <i>Rosa brunonii</i>                          | 1866.67         | 7.373         | 55.85         |
| <i>Sageretia thea</i>                         | 66.67           | 0.031         | 2.31          |
| <i>Salix denticulata</i>                      | 66.67           | 0.371         | 3.89          |
| <i>Sarcococca saligna</i>                     | 900.00          | 0.038         | 14.61         |
| <i>Schisandra grandiflora</i>                 | 33.33           | 0.002         | 1.87          |
| <i>Skimmia laureola</i>                       | 166.67          | 0.201         | 4.01          |
| <i>Solanum myriacanthum</i>                   | 66.67           | 0.002         | 2.18          |
| <i>Spiraea canescens</i>                      | 66.67           | 0.006         | 2.20          |
| <i>Strobilanthes atropurpureus</i>            | 933.33          | 0.055         | 16.55         |
| <i>Viburnum cotinifolium</i>                  | 433.33          | 0.147         | 12.43         |
| <i>Wikstroemia canescens</i>                  | 166.67          | 0.032         | 4.79          |
| <b>Total</b>                                  | <b>11000.00</b> | <b>21.562</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (2300-2800 m)</b> |                 |               |               |
| <i>Berberis aristata</i>                      | 566.67          | 3.297         | 27.83         |
| <i>Berberis lycium</i>                        | 133.33          | 1.191         | 9.14          |
| <i>Buddleja crispa</i>                        | 566.67          | 0.309         | 13.99         |
| <i>Clematis barbellata</i>                    | 33.33           | 0.002         | 1.83          |
| <i>Coriaria nepalensis</i>                    | 533.33          | 0.574         | 14.96         |
| <i>Cotoneaster bacillaris</i>                 | 400.00          | 0.330         | 12.13         |
| <i>Daphne papyracea</i>                       | 666.67          | 0.111         | 15.57         |
| <i>Desmodium elegans</i>                      | 100.00          | 0.069         | 2.96          |
| <i>Deutzia compacta</i>                       | 133.33          | 0.045         | 3.23          |
| <i>Deutzia staminea</i>                       | 166.67          | 0.511         | 8.89          |
| <i>Hypericum oblongifolium</i>                | 366.67          | 2.863         | 20.52         |
| <i>Indigofera atropurpurea</i>                | 400.00          | 0.017         | 11.94         |
| <i>Indigofera dosua</i>                       | 166.67          | 0.001         | 4.04          |
| <i>Jasminum humile</i>                        | 933.33          | 3.709         | 32.20         |
| <i>Jasminum officinale</i>                    | 400.00          | 1.763         | 13.81         |
| <i>Lespedeza stenocarpa</i>                   | 33.33           | 0.006         | 1.43          |
| <i>Lonicera quinquelocularis</i>              | 33.33           | 0.006         | 1.43          |
| <i>Prinsepia utilis</i>                       | 33.33           | 0.006         | 2.70          |
| <i>Pteracanthus urticifolius</i>              | 166.67          | 0.007         | 3.43          |
| <i>Rabdosia rugosa</i>                        | 100.00          | 0.002         | 4.05          |
| <i>Ribes emodense</i>                         | 166.67          | 0.004         | 4.84          |
| <i>Rosa mycophylla</i>                        | 266.67          | 0.789         | 8.64          |
| <i>Rubus macilentus</i>                       | 333.33          | 1.683         | 14.29         |
| <i>Sageretia thea</i>                         | 66.67           | 0.043         | 9.58          |
| <i>Salix denticulata</i>                      | 366.67          | 1.616         | 12.66         |
| <i>Sarcococca saligna</i>                     | 866.67          | 0.078         | 13.47         |
| <i>Schisandra grandiflora</i>                 | 166.67          | 0.001         | 1.43          |
| <i>Spiraea bella</i>                          | 233.33          | 0.008         | 2.65          |
| <i>Strobilanthes dalhousianus</i>             | 100.00          | 0.001         | 6.90          |

|                                               |                |               |               |
|-----------------------------------------------|----------------|---------------|---------------|
| <i>Thamnocalamus spathiflorus</i>             | 33.33          | 0.004         | 3.27          |
| <i>Viburnum foetida</i>                       | 254.55         | 0.160         | 5.25          |
| <i>Wikstroemia canescens</i>                  | 433.33         | 0.180         | 10.96         |
| <b>Total</b>                                  | <b>9221.20</b> | <b>19.387</b> | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (2800-3300 m)</b> |                |               |               |
| <i>Berberis aristata</i>                      | 166.67         | 1.321         | 15.74         |
| <i>Berberis lycium</i>                        | 300.00         | 1.438         | 14.16         |
| <i>Clematis buchananiana</i>                  | 133.33         | 0.011         | 7.39          |
| <i>Cotoneaster microphylla</i>                | 1500.00        | 1.477         | 39.13         |
| <i>Deutzia compacta</i>                       | 600.00         | 0.953         | 21.24         |
| <i>Elaeagnus parvifolia</i>                   | 66.67          | 0.035         | 2.91          |
| <i>Lespedeza gerardiana</i>                   | 1033.33        | 0.226         | 21.08         |
| <i>Lonicera quinquelocularis</i>              | 200.00         | 0.060         | 4.61          |
| <i>Parthenocissus himalayana</i>              | 400.00         | 0.103         | 11.05         |
| <i>Pteracanthus urticifolius</i>              | 266.67         | 0.058         | 7.69          |
| <i>Rabdosia rugosa</i>                        | 66.67          | 0.016         | 2.79          |
| <i>Rhamnus virgatus</i>                       | 100.00         | 0.038         | 3.32          |
| <i>Rosa macrophylla</i>                       | 133.33         | 0.431         | 6.10          |
| <i>Rosa sericea</i>                           | 200.00         | 1.519         | 15.80         |
| <i>Rubus biflorus</i>                         | 933.33         | 4.048         | 47.41         |
| <i>Rubus hypargyryus</i>                      | 166.67         | 0.893         | 9.29          |
| <i>Rubus macilentus</i>                       | 100.00         | 0.474         | 5.97          |
| <i>Salix denticulata</i>                      | 433.33         | 1.599         | 22.46         |
| <i>Skimmia laureola</i>                       | 633.33         | 0.681         | 18.44         |
| <i>Strobilanthes atropurpureus</i>            | 100.00         | 0.007         | 3.13          |
| <i>Thamnocalamus spathiflorus</i>             | 66.67          | 0.154         | 3.64          |
| <i>Viburnum cotinifolium</i>                  | 500.00         | 0.894         | 16.65         |
| <b>Total</b>                                  | <b>8100.00</b> | <b>16.437</b> | <b>300.00</b> |

At E<sub>1</sub>, *Rosa brunonii* was the dominant species with IVI of 55.85 followed by *Agave cantula* as co-dominant species with IVI of 49.68, *Berberis aristata* with IVI of 47.43 was an associate species, while least IVI was recorded for *Schisandra grandiflora* (1.87) signifying it as the rare species. At E<sub>2</sub> *Jasminum humile* was the dominant shrub species with highest IVI of 32.20, *Berberis aristata* with an IVI of 27.83 was co-dominant and *Hypericum oblongifolium* was associate species with IVI of 20.52. *Schisandra grandiflora* was rare species with IVI of 1.43. At E<sub>3</sub> *Rubus biflorus* was the dominant shrub with highest IVI of 47.41, while *Cotoneaster microphylla* (IVI = 39.13) and *Salix denticulata* (IVI = 22.46) were co-dominant and associate shrub species, respectively. However *Rabdosia rugosa* with an importance value index of 2.79 was rare shrub species at E<sub>3</sub> (Table 19).

In Deodar forests 58 shrub species were recorded at different elevations (Table 20). The total density and basal area of shrubs showed declining trend along elevation as:  $E_1 > E_2 > E_3$ . Among the three elevations, at  $E_1$  total density (9766.67 plants/ha) and basal area (16.968 m<sup>2</sup>/ha) of shrubs was highest. 28 shrub species were present in Deodar forests at  $E_1$ . At  $E_2$ , total density of shrubs was 8966.67 plants/ha and basal area was 14.642 m<sup>2</sup>/ha. At  $E_2$  like  $E_1$ , 28 shrub species were recorded. While the lowest density and basal area of shrubs was recorded at  $E_3$  i.e. 6800.00 plants/ha and 9.720 m<sup>2</sup>/ha with 20 shrub species. The density (plants/ha) and basal area (m<sup>2</sup>/ha) of shrubs at  $E_1$  ranged from 66.67 plants/ha to 1200.00 plants/ha and 0.001 m<sup>2</sup>/ha to 4.324 m<sup>2</sup>/ha, respectively, at  $E_2$  they varied from 66.67 plants/ha to 900.00 plants/ha and 0.003 m<sup>2</sup>/ha to 2.852 m<sup>2</sup>/ha, respectively and  $E_3$  their values fluctuated from 66.67 plants/ha to 866.67 plants/ha and 0.005 m<sup>2</sup>/ha to 1.974 m<sup>2</sup>/ha, respectively (Table 20).

At elevation  $E_1$ , maximum density of an individual shrub was recorded for *Sarcococca saligna* (1200.00 plant/ha) followed by *Lespedeza juncea* (966.67 plant/ha) while least density (66.67 plant /ha) was recorded for *Berberis lycium*, *Elaeagnus parvifolia*, *Euphorbia royleana* and *Rubus ellipticus*. Highest basal area was recorded for *Prinsepia utilis* (4.324 m<sup>2</sup>/ha) followed by *Jasminum officinale* (1.875 m<sup>2</sup>/ha), while the least basal area was observed for *Clematis grata* (0.001 m<sup>2</sup>/ha). At elevation  $E_2$ , highest density (900.00 plant/ha) was recorded for *Solanum myriacanthum*, followed by *Viburnum cotinifolium* (833.33 plant/ha), while lowest density of 66.67 plant/ha was exhibited by *Berberis lycium*. Highest basal area was observed for *Viburnum cotinifolium* (2.852 m<sup>2</sup>/ha) followed by 1.300 m<sup>2</sup>/ha for *Rubus biflorus* while lowest basal area of 0.003 m<sup>2</sup>/ha was recorded for *Spiraea canescens*. At elevation  $E_3$ , *Viburnum cotinifolium* exhibited highest shrub density (866.67 plant/ha), followed by *Elaeagnus parvifolia* (600.00 plant /ha). Whereas lowest density was recorded for *Rubus foliolosus* (66.67 plant /ha). At  $E_3$  highest basal area was observed for *Rubus biflorus* (1.974 m<sup>2</sup>/ha), followed by *Rosa macrophylla* as 1.777 m<sup>2</sup>/ha while lowest basal area was recorded for *Spiraea canescens* as 0.005 m<sup>2</sup>/ha (Table 20).

At elevation  $E_1$ , it emerged from the result that *Prinsepia utilis* was the dominant shrub species with IVI of 41.19. Whereas, *Hypericum oblongifolium* and *Viburnum cotinifolium* showed IVI values of 25.78 and 24.57, respectively and thus can be considered as co- dominant species, while *Jasminum officinale*, *Lespedeza gerardiana* and *Sarcococca saligna* exhibited slightly less IVI (21.47, 20.34 and 20.26, respectively), thus can be called



as associate species. At elevation E<sub>2</sub>, dominant shrub species was *Viburnum cotinifolium* (IVI = 37.86), co-dominant shrub species were *Rubus biflorus* (IVI = 20.88) and *Solanum myriacanthum* (IVI = 19.56) and, associate shrub species were: *Myrsine africana*, *Buddleja crispa* and *Lonicera angustifolia* with their respective IVI values as: 16.54, 15.71 and 14.80, respectively. At elevation E<sub>3</sub>, highest IVI was recorded as 38.01 for *Viburnum cotinifolium* which was the dominant shrub species. *Rosa macrophylla* and *Rubus biflorus* showed almost similar IVI (30.19 and 28.29, respectively) values were and the co-dominant species and, *Elaeagnus parvifolia* and *Taxillus vestitus* had IVI values of 22.42 and 20.65, respectively can be considered as associate shrub species. Whereas least IVI exhibited by *Rubus ellipticus* (IVI of 2.61 at E<sub>1</sub>), *Lespedeza gerardiana* (IVI of 3.08 at E<sub>2</sub>) and *Rubus foliolosus* (IVI of 3.66) at E<sub>3</sub>, showing these are the rare shrub species in Deodar forests (Table 20).

**Table 20: Density, basal area, and importance value index of shrubs in Deodar (*Cedrus deodara*) forests at different elevations**

| Shrub Species                                 | Density<br>(plants/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI   |
|-----------------------------------------------|------------------------|------------------------------------|-------|
| <b>Elevation - E<sub>1</sub> (900-1800 m)</b> |                        |                                    |       |
| <i>Asparagus adscendens</i>                   | 500.00                 | 0.011                              | 11.34 |
| <i>Berberis lycium</i>                        | 66.67                  | 0.204                              | 3.43  |
| <i>Boehmeria platyphylla</i>                  | 300.00                 | 0.025                              | 4.76  |
| <i>Buddleja asiatica</i>                      | 300.00                 | 0.169                              | 7.14  |
| <i>Clematis grata</i>                         | 133.33                 | 0.001                              | 2.91  |
| <i>Desmodium concinnum</i>                    | 100.00                 | 0.007                              | 2.61  |
| <i>Desmodium elegans</i>                      | 100.00                 | 0.294                              | 4.29  |
| <i>Dodonaea viscosa</i>                       | 266.67                 | 0.659                              | 12.77 |
| <i>Elaeagnus parvifolia</i>                   | 66.67                  | 0.371                              | 4.41  |
| <i>Euphorbia royleana</i>                     | 66.67                  | 0.736                              | 6.56  |
| <i>Hypericum oblongifolium</i>                | 900.00                 | 1.766                              | 25.78 |
| <i>Indigofera atropurpurea</i>                | 233.33                 | 0.006                              | 5.50  |
| <i>Indigofera heterantha</i>                  | 200.00                 | 0.007                              | 5.17  |
| <i>Jasminum officinale</i>                    | 566.67                 | 1.875                              | 21.47 |
| <i>Lespedeza juncea</i>                       | 966.67                 | 0.466                              | 20.34 |
| <i>Meriandra strobilifera</i>                 | 333.33                 | 0.038                              | 6.72  |
| <i>Myrsine africana</i>                       | 300.00                 | 1.737                              | 16.39 |
| <i>Osyris quadripartite</i>                   | 366.67                 | 1.218                              | 14.01 |
| <i>Prinsepia utilis</i>                       | 933.33                 | 4.324                              | 41.19 |
| <i>Rabdosia rugosa</i>                        | 166.67                 | 0.016                              | 4.88  |
| <i>Randia tetrasperma</i>                     | 133.33                 | 0.287                              | 4.60  |
| <i>Rhamnus virgatus</i>                       | 166.67                 | 0.021                              | 3.37  |
| <i>Rubus ellipticus</i>                       | 66.67                  | 0.064                              | 2.60  |

|                                                |                |               |               |
|------------------------------------------------|----------------|---------------|---------------|
| <i>Sageretia thea</i>                          | 200.00         | 0.313         | 8.51          |
| <i>Sarcococca saligna</i>                      | 1200.00        | 0.048         | 20.26         |
| <i>Viburnum cotinifolium</i>                   | 833.33         | 1.417         | 24.57         |
| <i>Woodfordia fruticosa</i>                    | 200.00         | 0.323         | 7.03          |
| <i>Zanthoxylum armatum</i>                     | 100.00         | 0.564         | 7.42          |
| <b>Total</b>                                   | <b>9766.67</b> | <b>16.968</b> | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (1800-2700 m)</b> |                |               |               |
| <i>Berberis aristata</i>                       | 100.00         | 0.559         | 6.45          |
| <i>Berberis lycium</i>                         | 66.67          | 0.492         | 5.62          |
| <i>Buddleja crispa</i>                         | 466.67         | 0.650         | 15.71         |
| <i>Clematis grata</i>                          | 266.67         | 0.012         | 6.09          |
| <i>Coriaria nepalensis</i>                     | 166.67         | 0.147         | 4.38          |
| <i>Cotoneaster bacillaris</i>                  | 200.00         | 0.912         | 9.98          |
| <i>Daphne papyracea</i>                        | 233.33         | 0.004         | 4.15          |
| <i>Debregeasia salicifolia</i>                 | 333.33         | 0.713         | 11.62         |
| <i>Desmodium elegans</i>                       | 133.33         | 0.032         | 3.22          |
| <i>Deutzia compacta</i>                        | 400.00         | 1.135         | 16.76         |
| <i>Elaeagnus parvifolia</i>                    | 233.33         | 0.832         | 11.31         |
| <i>Indigofera dosua</i>                        | 300.00         | 0.005         | 6.41          |
| <i>Jasminum humile</i>                         | 233.33         | 0.871         | 11.58         |
| <i>Jasminum officinale</i>                     | 366.67         | 0.723         | 12.06         |
| <i>Lespedeza gerardiana</i>                    | 133.33         | 0.011         | 3.08          |
| <i>Lonicera angustifolia</i>                   | 466.67         | 0.296         | 14.80         |
| <i>Myrsine africana</i>                        | 400.00         | 1.102         | 16.54         |
| <i>Prinsepia utilis</i>                        | 100.00         | 0.324         | 4.84          |
| <i>Rhamnus virgatus</i>                        | 433.33         | 0.070         | 9.85          |
| <i>Rosa brunonii</i>                           | 166.67         | 0.353         | 5.78          |
| <i>Rosa macrophylla</i>                        | 333.33         | 0.986         | 13.48         |
| <i>Rubus biflorus</i>                          | 533.33         | 1.300         | 20.88         |
| <i>Sarcococca saligna</i>                      | 333.33         | 0.019         | 6.88          |
| <i>Skimmia laureola</i>                        | 300.00         | 0.128         | 7.25          |
| <i>Solanum myriacanthum</i>                    | 900.00         | 0.063         | 19.56         |
| <i>Spiraea canescens</i>                       | 200.00         | 0.003         | 5.28          |
| <i>Viburnum cotinifolium</i>                   | 833.33         | 2.852         | 37.86         |
| <i>Wikstroemia canescens</i>                   | 333.33         | 0.048         | 8.59          |
| <b>Total</b>                                   | <b>8966.67</b> | <b>14.642</b> | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (2700-3600 m)</b> |                |               |               |
| <i>Berberis aristata</i>                       | 100.00         | 0.457         | 7.96          |
| <i>Berberis lycium</i>                         | 300.00         | 0.649         | 14.66         |
| <i>Clematis grata</i>                          | 266.67         | 0.030         | 9.58          |
| <i>Cotoneaster microphylla</i>                 | 300.00         | 0.165         | 9.68          |
| <i>Deutzia compacta</i>                        | 400.00         | 0.311         | 14.44         |
| <i>Elaeagnus parvifolia</i>                    | 600.00         | 0.454         | 22.42         |
| <i>Lonicera quinquelocularis</i>               | 366.67         | 0.039         | 12.94         |

|                                    |                |              |               |
|------------------------------------|----------------|--------------|---------------|
| <i>Pteracanthus urticifolius</i>   | 233.33         | 0.087        | 11.46         |
| <i>Ribes emodense</i>              | 400.00         | 0.089        | 12.16         |
| <i>Rosa macrophylla</i>            | 566.67         | 1.777        | 30.19         |
| <i>Rubus biflorus</i>              | 300.00         | 1.974        | 28.29         |
| <i>Rubus foliolosus</i>            | 66.67          | 0.087        | 3.66          |
| <i>Schisandra grandiflora</i>      | 133.33         | 0.085        | 8.20          |
| <i>Scurrula elata</i>              | 233.33         | 0.131        | 8.35          |
| <i>Skimmia laureola</i>            | 166.67         | 0.131        | 7.37          |
| <i>Spiraea canescens</i>           | 466.67         | 0.005        | 14.06         |
| <i>Strobilanthes atropurpureus</i> | 300.00         | 0.020        | 8.19          |
| <i>Taxillus vestitus</i>           | 533.33         | 0.724        | 20.65         |
| <i>Thamnocalamus spathiflorus</i>  | 200.00         | 1.092        | 17.75         |
| <i>Viburnum cotinifolium</i>       | 866.67         | 1.414        | 38.01         |
| <b>Total</b>                       | <b>6800.00</b> | <b>9.720</b> | <b>300.00</b> |

In western mixed coniferous forests 54 shrub species were recorded at different elevations (Table 21). Among three different elevations, at E<sub>1</sub>, 37 shrub species with highest total density (11000.00 plants/ha) and basal area (18.111 m<sup>2</sup>/ha) was recorded that declined at E<sub>2</sub> with density (10400.00 plants/ha) and basal area (15.293 m<sup>2</sup>/ha) for 37 shrub species. While the lowest density and basal area of shrubs was recorded at E<sub>3</sub> i.e. 8333.33 (plants/ha) and 14.463 m<sup>2</sup>/ha with 15 shrub species.

Maximum density of an individual shrub at E<sub>1</sub> was exhibited by *Sarcococca saligna* (1600.000 plants/ha) followed by *Berberis lycium* (1033.33 plants/ha) and *Prinsepia utilis* (933.33 plants/ha). While very low density was exhibited by *Rubus ellipticus* and *Clematis montana*, with 33.33 plants/ha each. Maximum and minimum basal area at E<sub>1</sub> was observed for *Berberis lycium* (4.482 m<sup>2</sup>) and *Clematis montana* (0.002 m<sup>2</sup>) respectively. At E<sub>2</sub>, highest density and basal area was exhibited by *Inula cuspidate* (1066.67 plants/ha) and *Hypericum dyeri* (3.238 m<sup>2</sup>/ha) respectively. Whereas minimum density (66.67 plants/ha) and basal area (0.001 m<sup>2</sup>/ha) was observed for *Hedera nepalensis* and *Strobilanthes dalhousianus* respectively. At elevation E<sub>3</sub>, *Strobilanthes atropurpureus* exhibited highest shrub density per hectare (1400.00 plant/ha), followed by *Taxillus vestitus* (1300.00 plant /ha). Whereas lowest density was recorded for *Clematis montana* (33.33 plant /ha). At E<sub>3</sub> highest basal area was observed for *Clematis montana* (4.659 m<sup>2</sup>/ha), followed by *Viburnum nervosum* basal area as 3.981 m<sup>2</sup>/ha while lowest basal area was recorded for *Clematis montana* as 0.004 m<sup>2</sup>/ha (Table 21).

The dominant shrub species of western mixed coniferous forests at E<sub>1</sub> was *Berberis lycium* having the highest IVI of 42.20, followed by *Prinsepia utilis* as the co-dominant species having IVI of 31.55. At E<sub>2</sub>, *Hypericum dyeri* was the dominant shrub species with IVI of 30.68 followed by *Cotoneaster bacillaris* (19.91) which was co-dominant, whereas *Inula cuspidata* (IVI = 18.82) was associate species. At E<sub>3</sub>, *Viburnum nervosum* was the dominant species (IVI as 54.35), *Berberis aristata* was the co-dominant species (IVI = 52.16) and *Taxillus vestitus* was the associate species (IVI = 36.52). Whereas least IVI was recorded for *Clematis montana* (IVI = 1.93 at E<sub>1</sub>), *Hedera nepalensis* (IVI of 2.02 at E<sub>2</sub>) and *Clematis montana* (IVI of 2.75) at E<sub>3</sub>, confirming the rarity of these species in western mixed coniferous forests (Table 21).

**Table 21: Density, basal area, and Importance value index (IVI) of shrubs in western mixed coniferous forests at different elevations**

| Shrub Species                                  | Density (plants/ha) | Basal area (m <sup>2</sup> /ha) | IVI   |
|------------------------------------------------|---------------------|---------------------------------|-------|
| <b>Elevation - E<sub>1</sub> (1200-2100 m)</b> |                     |                                 |       |
| <i>Andrachne cordifolia</i>                    | 133.33              | 0.097                           | 3.36  |
| <i>Berberis lycium</i>                         | 1033.33             | 4.482                           | 42.20 |
| <i>Buddleja crispa</i>                         | 233.33              | 0.201                           | 4.84  |
| <i>Clematis buchananiana</i>                   | 66.67               | 0.003                           | 2.24  |
| <i>Clematis montana</i>                        | 33.33               | 0.002                           | 1.93  |
| <i>Coriaria nepalensis</i>                     | 133.33              | 0.132                           | 3.55  |
| <i>Cotinus coggygia</i>                        | 133.33              | 0.034                           | 3.01  |
| <i>Cotoneaster microphylla</i>                 | 400.00              | 0.392                           | 9.03  |
| <i>Daphne papyracea</i>                        | 166.67              | 0.021                           | 3.24  |
| <i>Debregeasia salicifolia</i>                 | 133.33              | 0.386                           | 4.95  |
| <i>Desmodium elegans</i>                       | 200.00              | 0.090                           | 3.93  |
| <i>Elaeagnus parvifolia</i>                    | 133.33              | 0.090                           | 3.32  |
| <i>Hedera nepalensis</i>                       | 66.67               | 0.002                           | 2.23  |
| <i>Hypericum dyeri</i>                         | 466.67              | 2.226                           | 19.76 |
| <i>Indigofera atropurpurea</i>                 | 133.33              | 0.009                           | 2.87  |
| <i>Indigofera heterantha</i>                   | 133.33              | 0.007                           | 2.86  |
| <i>Inula cuspidata</i>                         | 133.33              | 0.011                           | 2.89  |
| <i>Jasminum humile</i>                         | 133.33              | 0.455                           | 5.34  |
| <i>Jasminum officinale</i>                     | 133.33              | 0.474                           | 5.44  |
| <i>Lеспедежа juncea</i>                        | 133.33              | 0.041                           | 3.05  |
| <i>Lonicera quinquelocularis</i>               | 100.00              | 0.017                           | 2.61  |
| <i>Prinsepia utilis</i>                        | 833.33              | 3.173                           | 31.55 |
| <i>Rabdosia rugosa</i>                         | 166.67              | 0.017                           | 3.22  |
| <i>Rhamnus virgatus</i>                        | 200.00              | 0.076                           | 3.85  |
| <i>Rosa brunonii</i>                           | 100.00              | 0.297                           | 4.16  |

|                                                |                 |               |               |
|------------------------------------------------|-----------------|---------------|---------------|
| <i>Rosa macrophylla</i>                        | 166.67          | 0.735         | 7.18          |
| <i>Rubus ellipticus</i>                        | 33.33           | 0.157         | 2.78          |
| <i>Rubus macilentus</i>                        | 100.00          | 0.368         | 4.55          |
| <i>Salix denticulata</i>                       | 100.00          | 0.215         | 3.71          |
| <i>Sarcococca saligna</i>                      | 1600.00         | 0.099         | 24.77         |
| <i>Skimmia laureola</i>                        | 866.67          | 0.258         | 18.98         |
| <i>Sorbaria tomentosa</i>                      | 133.33          | 0.115         | 3.46          |
| <i>Strobilanthes dalhousianus</i>              | 233.33          | 0.012         | 3.80          |
| <i>Taxillus vestitus</i>                       | 133.33          | 0.032         | 3.00          |
| <i>Thamnocalamus spathiflorus</i>              | 166.67          | 0.939         | 8.31          |
| <i>Viburnum cotinifolium</i>                   | 1433.33         | 1.006         | 26.65         |
| <i>Zanthoxylum armatum</i>                     | 500.00          | 1.442         | 17.34         |
| <b>Total</b>                                   | <b>11000.00</b> | <b>18.111</b> | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (2100-3000 m)</b> |                 |               |               |
| <i>Andrachne cordifolia</i>                    | 366.67          | 0.077         | 6.70          |
| <i>Berberis aristata</i>                       | 266.67          | 1.075         | 12.26         |
| <i>Buddleja crispa</i>                         | 300.00          | 0.048         | 7.20          |
| <i>Clematis barbellata</i>                     | 333.33          | 0.033         | 6.09          |
| <i>Coriaria nepalensis</i>                     | 133.33          | 0.069         | 3.07          |
| <i>Cotoneaster bacillaris</i>                  | 766.67          | 0.695         | 19.91         |
| <i>Cotoneaster microphylla</i>                 | 133.33          | 0.183         | 3.81          |
| <i>Daphne papyracea</i>                        | 566.67          | 0.058         | 12.49         |
| <i>Deutzia compacta</i>                        | 100.00          | 0.098         | 2.93          |
| <i>Elaeagnus parvifolia</i>                    | 200.00          | 0.083         | 5.13          |
| <i>Elsholtzia fruticosa</i>                    | 133.33          | 0.058         | 3.00          |
| <i>Hedera nepalensis</i>                       | 66.67           | 0.006         | 2.02          |
| <i>Hypericum dyeri</i>                         | 433.33          | 3.238         | 30.68         |
| <i>Inula cuspidata</i>                         | 1066.67         | 0.289         | 18.82         |
| <i>Lespedeza gerardiana</i>                    | 100.00          | 0.002         | 2.31          |
| <i>Lonicera angustifolia</i>                   | 100.00          | 0.017         | 2.41          |
| <i>Lonicera quinquelocularis</i>               | 133.33          | 0.033         | 2.83          |
| <i>Pteracanthus urticifolius</i>               | 833.33          | 0.170         | 13.13         |
| <i>Rhamnus virgatus</i>                        | 500.00          | 0.231         | 10.32         |
| <i>Ribes emodense</i>                          | 100.00          | 0.003         | 2.32          |
| <i>Rosa macrophylla</i>                        | 166.67          | 1.511         | 12.82         |
| <i>Rosa sericea</i>                            | 233.33          | 0.912         | 10.87         |
| <i>Rubus biflorus</i>                          | 100.00          | 0.277         | 4.10          |
| <i>Rubus macilentus</i>                        | 100.00          | 0.422         | 5.05          |
| <i>Salix denticulata</i>                       | 300.00          | 1.666         | 16.45         |
| <i>Scurrula elata</i>                          | 100.00          | 0.038         | 2.55          |
| <i>Skimmia laureola</i>                        | 233.33          | 0.025         | 5.07          |
| <i>Spiraea bella</i>                           | 100.00          | 0.006         | 2.33          |
| <i>Strobilanthes atropurpureus</i>             | 166.67          | 0.016         | 3.04          |
| <i>Strobilanthes dalhousianus</i>              | 133.33          | 0.001         | 2.62          |

|                                                |                 |               |               |
|------------------------------------------------|-----------------|---------------|---------------|
| <i>Taxillus vestitus</i>                       | 566.67          | 0.397         | 12.04         |
| <i>Thamnocalamus spathiflorus</i>              | 233.33          | 1.186         | 12.66         |
| <i>Viburnum cotinifolium</i>                   | 133.33          | 0.180         | 3.79          |
| <i>Viburnum foetens</i>                        | 566.67          | 0.622         | 14.85         |
| <i>Viburnum nervosum</i>                       | 333.33          | 0.523         | 10.63         |
| <i>Wikstroemia canescens</i>                   | 166.67          | 0.475         | 7.38          |
| <i>Zanthoxylum armatum</i>                     | 133.33          | 0.569         | 6.34          |
| <b>Total</b>                                   | <b>10400.00</b> | <b>15.293</b> | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (3000-3900 m)</b> |                 |               |               |
| <i>Berberis aristata</i>                       | 500.00          | 4.659         | 52.16         |
| <i>Clematis montana</i>                        | 33.33           | 0.004         | 2.75          |
| <i>Cotoneaster microphylla</i>                 | 166.67          | 0.264         | 6.15          |
| <i>Deutzia compacta</i>                        | 233.33          | 0.586         | 9.18          |
| <i>Lonicera quinquelocularis</i>               | 500.00          | 0.518         | 16.56         |
| <i>Pteracanthus urticifolius</i>               | 166.67          | 0.025         | 4.50          |
| <i>Ribes emodense</i>                          | 566.67          | 0.323         | 16.01         |
| <i>Salix denticulata</i>                       | 200.00          | 1.062         | 12.07         |
| <i>Scurrula elata</i>                          | 166.67          | 0.090         | 4.95          |
| <i>Spiraea bella</i>                           | 1033.33         | 0.272         | 25.91         |
| <i>Strobilanthes atropurpureus</i>             | 1400.00         | 0.108         | 29.17         |
| <i>Strobilanthes dalhousianus</i>              | 733.33          | 0.090         | 16.40         |
| <i>Taxillus vestitus</i>                       | 1300.00         | 1.344         | 36.52         |
| <i>Thamnocalamus spathiflorus</i>              | 66.67           | 1.139         | 13.33         |
| <i>Viburnum nervosum</i>                       | 1266.67         | 3.981         | 54.35         |
| <b>Total</b>                                   | <b>8333.33</b>  | <b>14.463</b> | <b>300.00</b> |

A perusal of the data presented in Table 22 reveals that in moist temperate lower deciduous forests 56 shrub species were recorded at different elevations. Elevation E<sub>2</sub> and E<sub>3</sub> nurtured 31 shrub species each while E<sub>1</sub> had 26 shrubs. Among three elevations, at E<sub>1</sub> highest shrub density (11900.00 plants/ha) and basal area (18.996 m<sup>2</sup>/ha) was recorded followed by E<sub>2</sub> with shrub density as 10533.33 plants/ha with basal area of 16.445 m<sup>2</sup>/ha. While the lowest values for density (8600.00 plants/ha) and basal area (13.087 m<sup>2</sup>/ha) of shrubs was recorded at elevation E<sub>3</sub> (Table 22).

At elevation E<sub>1</sub>, maximum density (1533.33 plants/ha) of an individual shrub was recorded for *Viburnum mullaha* followed by *Cotoneaster bacillaris* (1400.00 plants/ha) while very low density (33.33 plants/ha) was recorded by *Clematis buchananiana*. At elevation E<sub>1</sub> highest basal area was recorded for *Rubus macilentus* (3.120 m<sup>2</sup>/ha), while the least basal area was observed for *Clematis buchananiana* (0.001 m<sup>2</sup>/ha). *Viburnum mullaha* was dominant shrub species at E<sub>1</sub> with highest IVI of 29.62 and *Cotoneaster bacillaris* was co-

dominant species with IVI 26.98. Least IVI was recorded for *Clematis buchananiana* (IVI = 2.17) making it rare species (Table 22).

At elevation E<sub>2</sub>, highest density (1200.00 plants/ha) was recorded for *Strobilanthes atropurpureus* followed by *Sarcococca saligna* (966.67 plants/ha), while lowest density of 33.33 plants/ha was recorded for *Thamnocalamus spathiflorus*. At E<sub>2</sub>, lowest basal area (0.002 m<sup>2</sup>/ha) was recorded for *Clematis buchananiana*, while highest basal area was observed for *Berberis lycium* (5.493 m<sup>2</sup>/ha). *Berberis lycium* was dominant shrub species at E<sub>2</sub> (IVI = 49.00) and *Hypericum dyeri* was co-dominant species (IVI = 29.05). Whereas *Clematis buchananiana* was rare species with least IVI as 2.18 (Table 22).

At elevation E<sub>3</sub> *Strobilanthes atropurpureus* recorded highest density per hectare (1000.00 plants/ha), followed by *Cotoneaster microphylla* (833.33 plants/ha). Whereas lowest shrub density was recorded for *Lonicera angustifolia* (33.33 plants/ha). At E<sub>3</sub> highest basal area was observed for *Berberis lycium* (3.354 m<sup>2</sup>/ha), which was followed by *Myrsine africana* (1.594 m<sup>2</sup>/ha). While lowest basal area was recorded for *Hedera nepalensis* (0.004 m<sup>2</sup>/ha). At E<sub>3</sub> *Berberis lycium* was observed as dominant shrub species with highest IVI of 43.53, followed by *Myrsine africana* (26.18) making it co-dominant. *Lonicera angustifolia* was recorded as rare species with an importance value index of 1.99 (Table 22).

**Table 22: Density, basal area, and importance value index (IVI) of shrubs in moist temperate lower deciduous forests at different elevations**

| Shrub species                                  | Density (plants/ha) | Basal area (m <sup>2</sup> /ha) | IVI   |
|------------------------------------------------|---------------------|---------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (10000-1800 m)</b> |                     |                                 |       |
| <i>Andrachne cordifolia</i>                    | 100.00              | 0.057                           | 3.02  |
| <i>Argyrobium flaccidum</i>                    | 966.67              | 0.432                           | 14.17 |
| <i>Berberis lycium</i>                         | 200.00              | 0.830                           | 9.82  |
| <i>Boehmeria platyphylla</i>                   | 166.67              | 0.427                           | 5.54  |
| <i>Buddleja asiatica</i>                       | 466.67              | 0.422                           | 11.81 |
| <i>Clematis buchananiana</i>                   | 33.33               | 0.001                           | 2.17  |
| <i>Cotoneaster bacillaris</i>                  | 1400.00             | 1.098                           | 26.98 |
| <i>Daphne papyracea</i>                        | 600.00              | 0.102                           | 13.13 |
| <i>Desmodium elegans</i>                       | 133.33              | 0.176                           | 3.93  |
| <i>Elsholtzia fruticosa</i>                    | 166.67              | 0.672                           | 6.83  |
| <i>Euphorbia royleana</i>                      | 400.00              | 2.380                           | 19.66 |
| <i>Indigofera atropurpurea</i>                 | 1166.67             | 0.093                           | 15.95 |
| <i>Jasminum officinale</i>                     | 133.33              | 1.245                           | 9.56  |
| <i>Lespedeza stenocarpa</i>                    | 1366.67             | 0.298                           | 20.60 |

|                                               |                 |               |               |
|-----------------------------------------------|-----------------|---------------|---------------|
| <i>Lonicera quinquelocularis</i>              | 66.67           | 0.032         | 2.62          |
| <i>Myrsine africana</i>                       | 266.67          | 1.307         | 11.01         |
| <i>Pteracanthus urticifolius</i>              | 633.33          | 0.099         | 9.62          |
| <i>Rhamnus virgatus</i>                       | 333.33          | 0.085         | 7.02          |
| <i>Rosa brunonii</i>                          | 400.00          | 2.395         | 21.63         |
| <i>Rubus ellipticus</i>                       | 200.00          | 0.793         | 7.74          |
| <i>Rubus macilentus</i>                       | 433.33          | 3.120         | 25.73         |
| <i>Sageretia thea</i>                         | 100.00          | 0.111         | 3.31          |
| <i>Salix denticulate</i>                      | 200.00          | 0.564         | 6.54          |
| <i>Sarcococca saligna</i>                     | 333.33          | 0.035         | 4.87          |
| <i>Viburnum mullaha</i>                       | 1533.33         | 1.387         | 29.62         |
| <i>Zanthoxylum armatum</i>                    | 100.00          | 0.834         | 7.12          |
| <b>Total</b>                                  | <b>11900.00</b> | <b>18.996</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (1800-2400 m)</b> |                 |               |               |
| <i>Berberis lycium</i>                        | 833.33          | 5.493         | 49.00         |
| <i>Buddleja asiatica</i>                      | 133.33          | 0.157         | 3.76          |
| <i>Clematis buchananiana</i>                  | 66.67           | 0.002         | 2.18          |
| <i>Clematis montana</i>                       | 133.33          | 0.004         | 2.83          |
| <i>Coriaria nepalensis</i>                    | 666.67          | 0.533         | 17.26         |
| <i>Cotoneaster bacillaris</i>                 | 333.33          | 0.306         | 6.56          |
| <i>Cotoneaster microphylla</i>                | 133.33          | 0.120         | 3.53          |
| <i>Daphne papyracea</i>                       | 600.00          | 0.124         | 12.60         |
| <i>Elsholtzia fruticosa</i>                   | 266.67          | 0.561         | 7.48          |
| <i>Hedera nepalensis</i>                      | 66.67           | 0.064         | 2.56          |
| <i>Hypericum dyeri</i>                        | 733.33          | 2.874         | 29.05         |
| <i>Indigofera atropurpurea</i>                | 266.67          | 0.011         | 5.67          |
| <i>Indigofera dosua</i>                       | 133.33          | 0.007         | 2.85          |
| <i>Lonicera angustifolia</i>                  | 766.67          | 0.203         | 14.66         |
| <i>Rabdosia rugosa</i>                        | 400.00          | 0.053         | 7.19          |
| <i>Rhamnus virgatus</i>                       | 66.67           | 0.011         | 3.78          |
| <i>Ribes emodense</i>                         | 166.67          | 0.017         | 4.77          |
| <i>Rosa brunonii</i>                          | 366.67          | 1.271         | 12.75         |
| <i>Rosa macrophylla</i>                       | 166.67          | 0.452         | 5.87          |
| <i>Rosa sericea</i>                           | 200.00          | 1.034         | 9.72          |
| <i>Rubus foliolosus</i>                       | 66.67           | 0.182         | 3.28          |
| <i>Rubus hypargyryus</i>                      | 300.00          | 1.406         | 14.47         |
| <i>Sageretia thea</i>                         | 100.00          | 0.214         | 3.79          |
| <i>Salix denticulate</i>                      | 66.67           | 0.165         | 3.17          |
| <i>Sarcococca saligna</i>                     | 966.67          | 0.103         | 17.50         |
| <i>Schisandra grandiflora</i>                 | 233.33          | 0.121         | 6.03          |
| <i>Spiraea bella</i>                          | 66.67           | 0.042         | 3.97          |
| <i>Spiraea canescens</i>                      | 100.00          | 0.015         | 2.58          |
| <i>Strobilanthes atropurpureus</i>            | 1200.00         | 0.091         | 19.64         |



|                                               |                 |               |               |
|-----------------------------------------------|-----------------|---------------|---------------|
| <i>Thamnocalamus spathiflorus</i>             | 33.33           | 0.112         | 2.53          |
| <i>Viburnum cotinifolium</i>                  | 900.00          | 0.701         | 18.96         |
| <b>Total</b>                                  | <b>10533.33</b> | <b>16.445</b> | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (2400-2700 m)</b> |                 |               |               |
| <i>Berberis aristata</i>                      | 233.33          | 0.791         | 11.88         |
| <i>Berberis lycium</i>                        | 733.33          | 3.354         | 43.53         |
| <i>Clematis barbellata</i>                    | 166.67          | 0.009         | 5.13          |
| <i>Cotoneaster bacillaris</i>                 | 100.00          | 0.097         | 3.47          |
| <i>Cotoneaster microphylla</i>                | 833.33          | 0.723         | 23.03         |
| <i>Elaeagnus parvifolia</i>                   | 600.00          | 0.445         | 16.63         |
| <i>Hedera nepalensis</i>                      | 66.67           | 0.004         | 2.37          |
| <i>Lespedeza juncea</i>                       | 233.33          | 0.030         | 6.07          |
| <i>Lonicera angustifolia</i>                  | 33.33           | 0.005         | 1.99          |
| <i>Lonicera quinquelocularis</i>              | 400.00          | 0.073         | 9.90          |
| <i>Myrsine africana</i>                       | 666.67          | 1.594         | 26.18         |
| <i>Pteracanthus urticifolius</i>              | 133.33          | 0.031         | 3.35          |
| <i>Rhamnus virgatus</i>                       | 200.00          | 0.060         | 5.91          |
| <i>Ribes emodense</i>                         | 666.67          | 0.158         | 15.21         |
| <i>Rosa macrophylla</i>                       | 300.00          | 1.593         | 18.78         |
| <i>Rosa sericea</i>                           | 166.67          | 0.537         | 9.16          |
| <i>Rubus biflorus</i>                         | 133.33          | 0.426         | 6.37          |
| <i>Rubus foliolosus</i>                       | 100.00          | 0.247         | 4.61          |
| <i>Rubus hypargyryus</i>                      | 200.00          | 0.601         | 10.05         |
| <i>Salix denticulate</i>                      | 200.00          | 0.695         | 10.76         |
| <i>Skimmia laureola</i>                       | 66.67           | 0.005         | 2.38          |
| <i>Sorbaria tomentosa</i>                     | 133.33          | 0.090         | 5.36          |
| <i>Spiraea bella</i>                          | 266.67          | 0.054         | 5.07          |
| <i>Spiraea canescens</i>                      | 66.67           | 0.018         | 2.47          |
| <i>Strobilanthes atropurpureus</i>            | 1000.00         | 0.056         | 18.31         |
| <i>Strobilanthes dalhousianus</i>             | 66.67           | 0.005         | 2.37          |
| <i>Thamnocalamus spathiflorus</i>             | 100.00          | 0.428         | 5.99          |
| <i>Viburnum cotinifolium</i>                  | 133.33          | 0.158         | 5.88          |
| <i>Viburnum foetens</i>                       | 100.00          | 0.109         | 3.55          |
| <i>Viburnum mullaha</i>                       | 400.00          | 0.512         | 10.13         |
| <i>Viburnum nervosum</i>                      | 100.00          | 0.182         | 4.11          |
| <b>Total</b>                                  | <b>8600.00</b>  | <b>13.087</b> | <b>300.00</b> |

A perusal of the data presented in Table 23 reveals that 56 shrub species were present in Kail forests at different elevations. Maximum number of species were recorded at E<sub>2</sub> (37) followed by E<sub>1</sub> (33) and E<sub>3</sub> (32). Among three elevations, at E<sub>1</sub> highest density (10300.00 plants/ha) and basal area (16.801 m<sup>2</sup>/ha) of shrubs was recorded followed by E<sub>2</sub> with density

as 8866.67 plants/ha and basal area as 14.577 m<sup>2</sup>/ha. While the lowest values for density (8066.67 plants/ha) and basal area (12.866 m<sup>2</sup>/ha) of shrubs was recorded at elevation E<sub>3</sub>.

At elevation E<sub>1</sub>, maximum density (1500.00 plants/ha) of an individual shrub was recorded for *Sarcococca saligna* followed by *Pteracanthus urticifolius* (1400.000 plants/ha) and *Hypericum dyeri* (966.66 plants/ha). While very low density was recorded for *Clematis montana* and *Salix denticulata* with each 33.33 plants/ha. At E<sub>1</sub> highest basal area was recorded for *Hypericum dyeri* (2.847 m<sup>2</sup>/ha), followed by *Zanthoxylum armatum* (1.885 m<sup>2</sup>/ha) while the least value of basal area was observed for *Clematis montana* (0.001 m<sup>2</sup>/ha). *Hypericum dyeri* was dominant shrub species at E<sub>1</sub> with highest IVI (33.00), *Myrsine africana* was co-dominant species with IVI = 24.06 and *Pteracanthus urticifolius* was recorded as associate species with IVI=22.01. However, with least IVI, *Clematis montana* (IVI = 1.66) along with other 20 species were considered as rare (IVI < 10) (Table 23)

At elevation E<sub>2</sub>, highest density (1033.33 plants/ha) was recorded for *Myrsine africana*, which was followed *Coriaria nepalensis* (933.33 plants/ha), while lowest density of 33.33 plants/ha were recorded for *Buddleja asiatica*, *Clematis spp* and *Indigofera dosua*. Lowest basal area (0.001 m<sup>2</sup>/ha) was recorded for *Indigofera dosua*, while highest value of basal area was observed for *Berberis aristata* (2.504 m<sup>2</sup>/ha). *Viburnum foetens* was dominant shrub species at E<sub>2</sub> with highest IVI (45.40), *Myrsine africana* (IVI=31.13) was co-dominant shrub and *Berberis aristata* (IVI = 23.65) was associate species. However, *Clematis montana* and *Indigofera dosua* showed least (IVI=1.41) to be the rare shrub species along with other 29 species in this forest (Table 23).

At elevation E<sub>3</sub>, *Cotoneaster bacillaris* recorded highest density (1400.000 plants/ha), followed by *Viburnum cotinifolium* (600 plants/ha). Whereas, lowest density was recorded for *Hedera nepalensis* (33.33 plants/ha). Highest basal area (2.072 m<sup>2</sup>/ha) was recorded in *Rubus hypargyrus* which was followed by *Myrsine africana* (1.825 m<sup>2</sup>/ha), while lowest basal area was recorded for *Clematis Montana* (0.006 m<sup>2</sup>/ha). *Cotoneaster bacillaris* was dominant shrub species (IVI=32.54), *Rubus hypargyrus* was co-dominant (IVI=32.54) and *Myrsine africana* was associate species (IVI = 20.93). Whereas, *Clematis montana* showed least (IVI=2.66) and was rare species along with other 23 species (Table 23).

**Table 23: Density, basal area, and importance value index (IVI) of shrubs in Kail (*Pinus wallichiana*) forests at different elevations**

| Shrub species                                 | Density (plants/ha) | Basal Area (m <sup>2</sup> /ha) | IVI           |
|-----------------------------------------------|---------------------|---------------------------------|---------------|
| <b>Elevation- E<sub>1</sub> (1400-2100 m)</b> |                     |                                 |               |
| <i>Andrachne cordifolia</i>                   | 266.67              | 0.237                           | 6.67          |
| <i>Berberis aristata</i>                      | 166.67              | 1.499                           | 13.21         |
| <i>Berberis lycium</i>                        | 100.00              | 1.781                           | 15.57         |
| <i>Boehmeria platyphylla</i>                  | 100.00              | 0.014                           | 2.39          |
| <i>Buddleja asiatica</i>                      | 66.67               | 0.674                           | 5.99          |
| <i>Clematis buchananiana</i>                  | 100.00              | 0.018                           | 3.75          |
| <i>Clematis montana</i>                       | 33.33               | 0.001                           | 1.66          |
| <i>Coriaria nepalensis</i>                    | 200.00              | 0.014                           | 4.69          |
| <i>Cotoneaster bacillaris</i>                 | 333.33              | 0.093                           | 7.79          |
| <i>Cotoneaster microphylla</i>                | 100.00              | 0.949                           | 7.95          |
| <i>Daphne papyracea</i>                       | 466.67              | 0.251                           | 11.36         |
| <i>Desmodium elegans</i>                      | 466.67              | 0.372                           | 10.74         |
| <i>Elaeagnus parvifolia</i>                   | 233.33              | 0.417                           | 7.41          |
| <i>Elsholtzia fruticosa</i>                   | 66.67               | 0.004                           | 2.00          |
| <i>Hedera nepalensis</i>                      | 66.67               | 0.002                           | 1.99          |
| <i>Hypericum dyeri</i>                        | 966.67              | 2.847                           | 33.00         |
| <i>Indigofera atropurpurea</i>                | 600.00              | 0.035                           | 11.37         |
| <i>Indigofera dosua</i>                       | 133.33              | 0.010                           | 4.02          |
| <i>Inula cuspidata</i>                        | 100.00              | 0.030                           | 2.48          |
| <i>Jasminum officinale</i>                    | 66.67               | 0.588                           | 5.48          |
| <i>Lespedeza stenocarpa</i>                   | 66.67               | 0.002                           | 1.99          |
| <i>Lonicera quinquelocularis</i>              | 333.33              | 0.068                           | 4.98          |
| <i>Myrsine africana</i>                       | 666.67              | 1.835                           | 24.06         |
| <i>Osyris quadripartita</i>                   | 166.67              | 0.219                           | 5.59          |
| <i>Pteracanthus urticifolius</i>              | 1400.00             | 0.071                           | 22.01         |
| <i>Rabdosia rugosa</i>                        | 466.67              | 0.036                           | 7.41          |
| <i>Rosa brunonii</i>                          | 200.00              | 1.106                           | 11.19         |
| <i>Rubus ellipticus</i>                       | 300.00              | 1.257                           | 15.73         |
| <i>Sageretia thea</i>                         | 133.33              | 0.079                           | 3.10          |
| <i>Salix denticulata</i>                      | 33.33               | 0.044                           | 1.92          |
| <i>Sarcococca saligna</i>                     | 1500.00             | 0.083                           | 21.72         |
| <i>Viburnum cotinifolium</i>                  | 266.67              | 0.282                           | 6.93          |
| <i>Zanthoxylum armatum</i>                    | 133.33              | 1.885                           | 13.84         |
| <b>Total</b>                                  | <b>10300.00</b>     | <b>16.801</b>                   | <b>300.00</b> |
| <b>Elevation-E<sub>2</sub> (2100-2800 m)</b>  |                     |                                 |               |
| <i>Andrachne cordifolia</i>                   | 66.67               | 0.006                           | 1.82          |
| <i>Berberis aristata</i>                      | 300.00              | 2.504                           | 23.65         |
| <i>Berberis lycium</i>                        | 166.67              | 0.869                           | 9.90          |
| <i>Buddleja asiatica</i>                      | 33.33               | 0.009                           | 1.47          |
| <i>Buddleja crispa</i>                        | 100.00              | 0.034                           | 2.39          |
| <i>Clematis barbellata</i>                    | 33.33               | 0.002                           | 1.42          |
| <i>Clematis montana</i>                       | 33.33               | 0.001                           | 1.41          |
| <i>Coriaria nepalensis</i>                    | 933.33              | 0.659                           | 21.23         |

|                                              |                |               |               |
|----------------------------------------------|----------------|---------------|---------------|
| <i>Cotoneaster microphylla</i>               | 166.67         | 0.292         | 4.91          |
| <i>Daphne papyracea</i>                      | 866.67         | 0.084         | 15.51         |
| <i>Debregeasia salicifolia</i>               | 133.33         | 0.276         | 4.43          |
| <i>Elaeagnus parvifolia</i>                  | 133.33         | 0.081         | 3.09          |
| <i>Elsholtzia fruticosa</i>                  | 66.67          | 0.043         | 2.08          |
| <i>Hedera nepalensis</i>                     | 100.00         | 0.006         | 2.20          |
| <i>Hypericum dyeri</i>                       | 433.33         | 1.192         | 14.09         |
| <i>Indigofera dosua</i>                      | 33.33          | 0.001         | 1.41          |
| <i>Lespedeza juncea</i>                      | 100.00         | 0.016         | 2.27          |
| <i>Lonicera angustifolia</i>                 | 133.33         | 0.082         | 3.10          |
| <i>Myrsine africana</i>                      | 1033.33        | 2.234         | 32.13         |
| <i>Pteracanthus urticifolius</i>             | 266.67         | 0.021         | 7.28          |
| <i>Rabdosia rugosa</i>                       | 166.67         | 0.007         | 2.96          |
| <i>Rhamnus virgatus</i>                      | 100.00         | 0.213         | 3.62          |
| <i>Ribes emodense</i>                        | 166.67         | 0.016         | 3.02          |
| <i>Rosa brunonii</i>                         | 66.67          | 0.771         | 7.07          |
| <i>Rosa macrophylla</i>                      | 66.67          | 0.765         | 7.03          |
| <i>Rosa sericea</i>                          | 100.00         | 0.210         | 3.60          |
| <i>Rubus foliolosus</i>                      | 333.33         | 1.002         | 14.75         |
| <i>Salix denticulata</i>                     | 133.33         | 1.026         | 9.57          |
| <i>Sarcococca saligna</i>                    | 466.67         | 0.016         | 9.49          |
| <i>Skimmia laureola</i>                      | 133.33         | 0.015         | 2.64          |
| <i>Sorbaria tomentosa</i>                    | 133.33         | 0.086         | 3.13          |
| <i>Spiraea bella</i>                         | 166.67         | 0.013         | 3.00          |
| <i>Spiraea canescens</i>                     | 66.67          | 0.006         | 1.82          |
| <i>Strobilanthes dalhousianus</i>            | 133.33         | 0.001         | 5.63          |
| <i>Strobilanthes atropurpureus</i>           | 433.33         | 0.016         | 8.09          |
| <i>Thamnocalamus spathiflorus</i>            | 233.33         | 1.417         | 13.38         |
| <i>Viburnum foetens</i>                      | 833.33         | 0.589         | 45.40         |
| <b>Total</b>                                 | <b>8866.67</b> | <b>14.577</b> | <b>300.00</b> |
| <b>Elevation-E<sub>3</sub> (2800-3600 m)</b> |                |               |               |
| <i>Berberis aristata</i>                     | 100.00         | 0.475         | 6.72          |
| <i>Berberis lycium</i>                       | 100.00         | 0.481         | 6.76          |
| <i>Clematis barbellata</i>                   | 100.00         | 0.010         | 3.10          |
| <i>Clematis montana</i>                      | 66.67          | 0.006         | 2.66          |
| <i>Cotoneaster bacillaris</i>                | 1400.00        | 0.804         | 32.54         |
| <i>Cotoneaster microphylla</i>               | 333.33         | 0.204         | 7.50          |
| <i>Elaeagnus parvifolia</i>                  | 166.67         | 0.099         | 4.62          |
| <i>Hedera nepalensis</i>                     | 33.33          | 0.391         | 5.24          |
| <i>Lespedeza juncea</i>                      | 100.00         | 0.006         | 4.86          |
| <i>Lonicera angustifolia</i>                 | 300.00         | 0.023         | 9.25          |
| <i>Lonicera quinquelocularis</i>             | 166.67         | 0.652         | 8.92          |
| <i>Myrsine africana</i>                      | 400.00         | 1.825         | 20.93         |
| <i>Pteracanthus urticifolius</i>             | 100.00         | 0.007         | 3.08          |
| <i>Rhamnus virgatus</i>                      | 500.00         | 0.162         | 14.60         |
| <i>Ribes emodense</i>                        | 200.00         | 0.061         | 4.74          |
| <i>Rosa macrophylla</i>                      | 200.00         | 0.674         | 9.51          |
| <i>Rosa sericea</i>                          | 200.00         | 0.930         | 11.50         |

|                                    |                |               |               |
|------------------------------------|----------------|---------------|---------------|
| <i>Rubus biflorus</i>              | 66.67          | 0.185         | 4.05          |
| <i>Rubus foliolosus</i>            | 66.67          | 0.771         | 8.60          |
| <i>Rubus hypargyryus</i>           | 466.67         | 2.072         | 30.82         |
| <i>Salix denticulata</i>           | 100.00         | 0.675         | 8.27          |
| <i>Skimmia laureola</i>            | 400.00         | 0.792         | 18.26         |
| <i>Sorbaria tomentosa</i>          | 100.00         | 0.066         | 3.54          |
| <i>Spiraea bella</i>               | 566.67         | 0.050         | 14.56         |
| <i>Spiraea canescens</i>           | 133.33         | 0.017         | 3.57          |
| <i>Strobilanthes atropurpureus</i> | 200.00         | 0.015         | 4.38          |
| <i>Strobilanthes dalhousianus</i>  | 166.67         | 0.524         | 7.92          |
| <i>Thamnocalamus spathiflorus</i>  | 266.67         | 0.302         | 9.22          |
| <i>Viburnum cotinifolium</i>       | 600.00         | 0.352         | 17.32         |
| <i>Viburnum foetens</i>            | 100.00         | 0.009         | 3.09          |
| <i>Viburnum mullaha</i>            | 233.33         | 0.138         | 5.75          |
| <i>Viburnum nervosum</i>           | 133.33         | 0.088         | 4.12          |
| <b>Total</b>                       | <b>8066.67</b> | <b>12.866</b> | <b>300.00</b> |

A perusal of the data presented in Table 24 reveals that in Kharsu Oak forests 41 shrub species were present at different elevations. Maximum number of species were recorded at E<sub>1</sub> (30) which was followed by E<sub>2</sub> (26) and E<sub>3</sub> (10). Among three elevations, at E<sub>1</sub> highest shrub density (9866.67.00 plants/ha) and basal area (19.209 m<sup>2</sup>/ha) was recorded which was followed by E<sub>2</sub> with shrub density as 7969.00 plants/ha and basal area as 17.417 m<sup>2</sup>/ha. While the lowest values for density (6799.98 plants/ha) and basal area (15.454 m<sup>2</sup>/ha) of shrubs was recorded at elevation E<sub>3</sub>.

At elevation E<sub>1</sub>, maximum density (1833.33 plants/ha) of an individual shrub was recorded for *Strobilanthes atropurpureus* followed by *Myrsine africana* (1766.67 plants/ha). While very low density (33.33 plants /ha) was recorded for *Rabdosia rugosa*, *Rubus biflorus* and *Salix denticulata* each. Highest basal area was recorded for *Myrsine africana* (4.834 m<sup>2</sup>/ha), while the least value of basal area was observed for *Rabdosia rugosa* (0.005 m<sup>2</sup>/ha). *Myrsine africana* was dominant shrub species at E<sub>1</sub> with IVI of 53.75. Whereas, *Berberis lycium*, *Prinsepia utilis* and *Sarcococca saligna* were the co-dominant species with IVI of 27.32, 27.24 and 25.31, respectively and least IVI was recorded for *Rubus biflorus* (1.82) confirming its rarity (Table 24).

At elevation E<sub>2</sub>, highest density of 966.67 plants/ha was recorded for *Strobilanthes atropurpureus*, which was followed *Cotoneaster bacillaris* (666.67 plants/ha), while lowest density of 66.67 plants/ha was recorded for *Skimmia laureola*. Lowest basal area (0.011 m<sup>2</sup>/ha) was recorded for *Indigofera dosua*, while highest basal area was observed in *Berberis*

*aristata* (2.805 m<sup>2</sup>/ha). *Berberis aristata* was the dominant shrub species at E<sub>2</sub> with highest IVI of 27.84 and *Rosa sericea* with an IVI of 23.80 was co-dominant shrub. *Skimmia laureola* was rare species with IVI of 2.77 (Table 24).

At elevation E<sub>3</sub>, *Ribes emodense* exhibited highest shrub density (1233.33 plants/ha), followed by *Viburnum mullaha* (1200.00 plants/ha). Whereas lowest shrub density was recorded for *Salix denticulata* (233.33 plants/ha). At E<sub>3</sub> highest basal area was recorded for *Berberis aristata* (5.215 m<sup>2</sup>/ha), which was followed by *Rosa sericea* (3.113 m<sup>2</sup>/ha). While, lowest basal area was recorded for *Spiraea bella* (0.124m<sup>2</sup>/ha). *Berberis aristata* was the dominant shrub with highest IVI of 62.12, while *Viburnum mullaha* was co-dominant shrub (IVI=39.39) and *Salix denticulata* with an importance value index of 13.65 was rare shrub (Table 24).

**Table 24: Density, basal area, and importance value index (IVI) of shrubs in Kharsu Oak (*Q. semecarpifolia*) forests at different elevations**

| Shrub species                                 | Density (plants/ha) | Basal area (m <sup>2</sup> /ha) | IVI   |
|-----------------------------------------------|---------------------|---------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (2300-2800 m)</b> |                     |                                 |       |
| <i>Berberis aristata</i>                      | 100.00              | 0.309                           | 4.03  |
| <i>Berberis lycium</i>                        | 300.00              | 3.569                           | 27.32 |
| <i>Buddleja crispa</i>                        | 100.00              | 0.242                           | 3.68  |
| <i>Cotoneaster bacillaris</i>                 | 100.00              | 0.085                           | 2.86  |
| <i>Cotoneaster microphylla</i>                | 300.00              | 0.324                           | 7.48  |
| <i>Daphne papyracea</i>                       | 266.67              | 0.047                           | 7.20  |
| <i>Desmodium elegans</i>                      | 133.33              | 0.114                           | 3.33  |
| <i>Deutzia compacta</i>                       | 133.33              | 0.144                           | 4.96  |
| <i>Elaeagnus parvifolia</i>                   | 200.00              | 0.258                           | 4.72  |
| <i>Elsholtzia fruticosa</i>                   | 100.00              | 0.031                           | 2.58  |
| <i>Hypericum dyeri</i>                        | 200.00              | 0.308                           | 6.45  |
| <i>Indigofera atropurpurea</i>                | 300.00              | 0.053                           | 9.56  |
| <i>Indigofera dosua</i>                       | 100.00              | 0.006                           | 2.46  |
| <i>Lespedeza juncea</i>                       | 100.00              | 0.185                           | 4.86  |
| <i>Myrsine africana</i>                       | 1766.67             | 4.834                           | 53.75 |
| <i>Prinsepia utilis</i>                       | 600.00              | 3.005                           | 27.24 |
| <i>Pteracanthus urticifolius</i>              | 300.00              | 0.173                           | 9.64  |
| <i>Rabdosia rugosa</i>                        | 33.33               | 0.005                           | 1.82  |
| <i>Rhamnus virgatus</i>                       | 66.67               | 0.017                           | 2.19  |
| <i>Rosa macrophylla</i>                       | 366.67              | 2.205                           | 20.85 |
| <i>Rubus biflorus</i>                         | 33.33               | 0.130                           | 2.46  |
| <i>Salix denticulata</i>                      | 33.33               | 0.257                           | 3.13  |
| <i>Sarcococca saligna</i>                     | 1433.33             | 0.545                           | 25.31 |

|                                               |                |               |               |
|-----------------------------------------------|----------------|---------------|---------------|
| <i>Skimmia laureola</i>                       | 300.00         | 0.483         | 13.79         |
| <i>Sorbaria tomentosa</i>                     | 200.00         | 0.248         | 4.66          |
| <i>Spiraea bella</i>                          | 66.67          | 0.015         | 2.18          |
| <i>Strobilanthes atropurpureus</i>            | 1833.33        | 0.197         | 25.84         |
| <i>Thamnocalamus spathiflorus</i>             | 66.67          | 0.887         | 6.72          |
| <i>Viburnum cotinifolium</i>                  | 166.67         | 0.189         | 4.04          |
| <i>Viburnum foetens</i>                       | 166.67         | 0.346         | 4.86          |
| <b>Total</b>                                  | <b>9866.67</b> | <b>19.209</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (2800-3200 m)</b> |                |               |               |
| <i>Berberis aristata</i>                      | 300.00         | 2.805         | 27.84         |
| <i>Cotoneaster bacillaris</i>                 | 666.67         | 0.540         | 16.33         |
| <i>Cotoneaster microphylla</i>                | 300.33         | 0.510         | 15.79         |
| <i>Deutzia compacta</i>                       | 200.00         | 0.178         | 5.18          |
| <i>Deutzia staminea</i>                       | 200.00         | 0.174         | 5.16          |
| <i>Elaeagnus parvifolia</i>                   | 100.00         | 0.072         | 3.46          |
| <i>Indigofera dosua</i>                       | 133.33         | 0.011         | 3.48          |
| <i>Indigofera heterantha</i>                  | 466.66         | 0.054         | 14.72         |
| <i>Lespedeza gerardiana</i>                   | 100.00         | 0.037         | 3.26          |
| <i>Lonicera quinquelocularis</i>              | 100.00         | 0.040         | 3.27          |
| <i>Pteracanthus urticifolius</i>              | 300.00         | 0.058         | 7.54          |
| <i>Ribes emodense</i>                         | 266.67         | 0.047         | 7.10          |
| <i>Rosa macrophylla</i>                       | 466.67         | 2.288         | 22.20         |
| <i>Rosa sericea</i>                           | 533.33         | 2.771         | 23.80         |
| <i>Rubus biflorus</i>                         | 300.00         | 1.639         | 14.69         |
| <i>Rubus foliolosus</i>                       | 233.33         | 0.718         | 8.66          |
| <i>Rubus hypargyryus</i>                      | 333.33         | 1.794         | 17.88         |
| <i>Salix denticulata</i>                      | 266.67         | 1.205         | 13.75         |
| <i>Skimmia laureola</i>                       | 66.67          | 0.017         | 2.77          |
| <i>Sorbaria tomentosa</i>                     | 133.33         | 0.125         | 4.13          |
| <i>Spiraea bella</i>                          | 466.67         | 0.219         | 12.25         |
| <i>Strobilanthes atropurpureus</i>            | 966.67         | 0.076         | 22.80         |
| <i>Thamnocalamus spathiflorus</i>             | 333.33         | 1.137         | 14.10         |
| <i>Viburnum cotinifolium</i>                  | 166.67         | 0.247         | 5.21          |
| <i>Viburnum foetens</i>                       | 300.00         | 0.494         | 16.87         |
| <i>Wikstroemia canescens</i>                  | 266.67         | 0.163         | 7.77          |
| <b>Total</b>                                  | <b>7967.00</b> | <b>17.417</b> | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (3200-3600 m)</b> |                |               |               |
| <i>Berberis aristata</i>                      | 733.33         | 5.215         | 62.12         |
| <i>Cotoneaster microphylla</i>                | 1066.67        | 0.981         | 31.13         |
| <i>Deutzia compacta</i>                       | 433.33         | 1.035         | 19.69         |
| <i>Lonicera quinquelocularis</i>              | 433.33         | 0.187         | 26.51         |
| <i>Ribes emodense</i>                         | 1233.33        | 0.404         | 29.54         |
| <i>Rosa macrophylla</i>                       | 433.33         | 2.129         | 26.00         |
| <i>Rosa sericea</i>                           | 600.00         | 3.113         | 36.73         |

|                          |                |               |               |
|--------------------------|----------------|---------------|---------------|
| <i>Salix denticulata</i> | 233.33         | 0.961         | 13.65         |
| <i>Spiraea bella</i>     | 433.33         | 0.124         | 15.25         |
| <i>Viburnum mullaha</i>  | 1200.00        | 1.305         | 39.39         |
| <b>Total</b>             | <b>6799.98</b> | <b>15.454</b> | <b>300.00</b> |

In upper Oak-Fir forest 43 shrub species were recorded at different elevations (Table 25). Among three elevations, highest total shrub density (9200.00 plants/ha) and basal area (16.241 m<sup>2</sup>) with 35 shrub species was recorded at E<sub>1</sub> which decreased to 9000.00 plants/ha (density) and 15.200 m<sup>2</sup> (basal area) at E<sub>2</sub> with 26 shrub species. While the lowest density and basal area of shrubs was reported at E<sub>3</sub> i.e. 8633.33 plants/ha and 14.007 m<sup>2</sup>/ha with 9 shrub species.

At elevation E<sub>1</sub>, maximum density (800 plants/ha) of an individual shrub was recorded for *Strobilanthes atropurpureus* followed by *Daphne papyracea* (633.33 plants/ha). While very low density (66.67 plants /ha) was recorded for *Ribes emodense*. Highest basal area was recorded for *Berberis lycium* (2.397 m<sup>2</sup>/ha), followed by *Hypericum dyeri* ( 2.026 m<sup>2</sup>/ha) while the least value of basal area (0.011 m<sup>2</sup>/ha) was observed for *Indigofera dosua* and *Indigofera heterantha*. *Berberis lycium* was dominant shrub species at E<sub>1</sub> with IVI of 23.20. Whereas, *Rubus biflorus* was the co-dominant species with IVI of 21.86. *Hypericum dyeri* was associate species (IVI = 20.94), whereas and least IVI was recorded for *Ribes emodense* (2.23) confirming its rarity (Table 25).

At elevation E<sub>2</sub>, highest density of 1033.33 plants/ha was recorded for *Wikstroemia canescens*, which was followed by *Viburnum foetens* (800.00 plants/ha), while lowest density of 33.33 plants/ha was recorded for *Cotoneaster bacillaris*. Lowest basal area (0.001 m<sup>2</sup>/ha) was recorded for *Lespedeza gerardiana*, while highest basal area was observed in *Rosa sericea* (3.556 m<sup>2</sup>/ha) followed by *Rubus hypargyrus* (3.289 m<sup>2</sup>/ha). *Rosa sericea* was the dominant shrub species at E<sub>2</sub> with highest IVI of 40.90 and *Rubus hypargyrus* with an IVI of 35.94 was co-dominant shrub. *Lespedeza gerardiana* was rare species with IVI of 2.10 (Table 25).

At elevation E<sub>3</sub>, *Ribes emodense* exhibited highest shrub density (2400 plants/ha), followed by *Viburnum mullaha* (1533.33 plants/ha). Whereas lowest shrub density (233.33 plants/ha) was recorded for *Lonicera quinquelocularis* and *Spiraea bella*. At E<sub>3</sub> highest basal area was recorded for *Berberis aristata* (4.919m<sup>2</sup>/ha), which was followed by *Rosa sericea* (3.079 m<sup>2</sup>/ha). While, lowest basal area was recorded for *Lonicera quinquelocularis* (0.06 m<sup>2</sup>/ha). *Berberis aristata* was the dominant shrub with highest IVI of 69.96 while *Ribes*



*emodense* was co-dominant shrub (IVI=45.37) and *Spiraea bella* with an importance value index of 6.33 was rare shrub (Table 25).

**Table 25: Density, basal area, and importance value index (IVI) of shrubs in upper Oak-Fir forests at different elevations**

| Shrub species                                  | Density<br>(plants/ha) | Basal area<br>(m <sup>2</sup> /ha) | IVI           |
|------------------------------------------------|------------------------|------------------------------------|---------------|
| <b>Elevation - E<sub>1</sub> (2100-2600 m)</b> |                        |                                    |               |
| <i>Andrachne cordifolia</i>                    | 300.00                 | 0.113                              | 8.06          |
| <i>Argyrobium flaccidum</i>                    | 133.33                 | 0.069                              | 4.61          |
| <i>Berberis aristata</i>                       | 100.00                 | 0.372                              | 4.75          |
| <i>Berberis lycium</i>                         | 400.00                 | 2.397                              | 23.2          |
| <i>Buddleja crispa</i>                         | 366.67                 | 0.535                              | 11.39         |
| <i>Cotoneaster bacillaris</i>                  | 300.00                 | 0.263                              | 8.99          |
| <i>Cotoneaster microphylla</i>                 | 133.33                 | 0.086                              | 4.72          |
| <i>Daphne papyracea</i>                        | 633.33                 | 0.086                              | 11.53         |
| <i>Desmodium elegans</i>                       | 133.33                 | 0.099                              | 3.43          |
| <i>Deutzia compacta</i>                        | 133.33                 | 0.262                              | 4.43          |
| <i>Deutzia staminea</i>                        | 566.67                 | 1.045                              | 18.07         |
| <i>Elaeagnus parvifolia</i>                    | 100.00                 | 0.056                              | 2.80          |
| <i>Elsholtzia fruticosa</i>                    | 100.00                 | 0.201                              | 3.70          |
| <i>Hypericum dyeri</i>                         | 400.00                 | 2.026                              | 20.94         |
| <i>Indigofera atropurpurea</i>                 | 400.00                 | 0.021                              | 5.85          |
| <i>Indigofera dosua</i>                        | 166.67                 | 0.011                              | 4.61          |
| <i>Indigofera heterantha</i>                   | 400.00                 | 0.011                              | 9.89          |
| <i>Jasminum officinale</i>                     | 166.67                 | 0.579                              | 6.74          |
| <i>Lespedeza juncea</i>                        | 400.00                 | 0.153                              | 8.03          |
| <i>Myrsine africana</i>                        | 366.67                 | 1.028                              | 14.43         |
| <i>Prinsepia utilis</i>                        | 233.33                 | 1.137                              | 12.28         |
| <i>Pteracanthus urticifolius</i>               | 133.33                 | 0.061                              | 4.56          |
| <i>Rabdosia rugosa</i>                         | 166.67                 | 0.051                              | 4.86          |
| <i>Rhamnus virgatus</i>                        | 266.67                 | 0.089                              | 7.55          |
| <i>Ribes emodense</i>                          | 66.67                  | 0.022                              | 2.23          |
| <i>Rosa macrophylla</i>                        | 200.00                 | 0.664                              | 9.00          |
| <i>Rubus biflorus</i>                          | 366.67                 | 2.013                              | 21.86         |
| <i>Rubus hypargyryus</i>                       | 166.67                 | 1.389                              | 13.11         |
| <i>Salix denticulata</i>                       | 133.33                 | 0.384                              | 5.19          |
| <i>Sarcococca saligna</i>                      | 233.33                 | 0.028                              | 4.08          |
| <i>Skimmia laureola</i>                        | 233.33                 | 0.094                              | 5.858         |
| <i>Spiraea bella</i>                           | 100.00                 | 0.019                              | 2.58          |
| <i>Strobilanthes atropurpureus</i>             | 800.00                 | 0.047                              | 11.73         |
| <i>Viburnum foetens</i>                        | 300.00                 | 0.708                              | 11.73         |
| <i>Wikstroemia canescens</i>                   | 100.00                 | 0.123                              | 3.22          |
| <b>Total</b>                                   | <b>9200.00</b>         | <b>16.241</b>                      | <b>300.00</b> |

| <b>Elevation – E<sub>2</sub> (2600-3100 m)</b> |                |               |               |
|------------------------------------------------|----------------|---------------|---------------|
| <i>Berberis aristata</i>                       | 233.33         | 0.937         | 12.21         |
| <i>Cotoneaster bacillaris</i>                  | 200.00         | 0.029         | 4.13          |
| <i>Cotoneaster microphylla</i>                 | 600.00         | 0.463         | 14.88         |
| <i>Deutzia compacta</i>                        | 266.66         | 0.054         | 5.04          |
| <i>Deutzia staminea</i>                        | 133.33         | 0.021         | 5.07          |
| <i>Elaeagnus parvifolia</i>                    | 600.00         | 0.073         | 12.32         |
| <i>Indigofera dosua</i>                        | 333.33         | 0.018         | 5.55          |
| <i>Indigofera heterantha</i>                   | 266.66         | 0.003         | 6.43          |
| <i>Lespedeza gerardiana</i>                    | 33.33          | 0.001         | 2.10          |
| <i>Lonicera quinquelocularis</i>               | 66.66          | 0.003         | 2.48          |
| <i>Pteracanthus urticifolius</i>               | 400.00         | 0.031         | 11.55         |
| <i>Ribes emodense</i>                          | 66.66          | 0.008         | 2.52          |
| <i>Rosa macrophylla</i>                        | 200.00         | 0.959         | 10.25         |
| <i>Rosa sericea</i>                            | 800.00         | 3.556         | 40.90         |
| <i>Rubus biflorus</i>                          | 166.66         | 0.593         | 7.48          |
| <i>Rubus foliolosus</i>                        | 300.00         | 1.251         | 13.29         |
| <i>Rubus hypargyryus</i>                       | 666.66         | 3.289         | 35.94         |
| <i>Salix denticulata</i>                       | 300.00         | 1.696         | 19.67         |
| <i>Skimmia laureola</i>                        | 400.00         | 0.026         | 11.52         |
| <i>Sorbaria tomentosa</i>                      | 1033.33        | 0.825         | 25.53         |
| <i>Spiraea bella</i>                           | 400.00         | 0.031         | 9.82          |
| <i>Strobilanthes atropurpureus</i>             | 166.66         | 0.007         | 3.62          |
| <i>Thamnocalamus spathiflorus</i>              | 66.66          | 0.199         | 3.77          |
| <i>Viburnum cotinifolium</i>                   | 566.66         | 0.557         | 13.41         |
| <i>Viburnum foetens</i>                        | 100.00         | 0.024         | 4.72          |
| <i>Wikstroemia canescens</i>                   | 633.33         | 0.545         | 15.80         |
| <b>Total</b>                                   | <b>9000.00</b> | <b>15.200</b> | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (3100-3500 m)</b> |                |               |               |
| <i>Berberis aristata</i>                       | 966.67         | 4.919         | 63.96         |
| <i>Cotoneaster microphylla</i>                 | 666.67         | 0.561         | 17.61         |
| <i>Deutzia compacta</i>                        | 1200.00        | 1.297         | 40.81         |
| <i>Lonicera quinquelocularis</i>               | 233.33         | 0.066         | 9.06          |
| <i>Ribes emodense</i>                          | 2400.00        | 0.401         | 45.37         |
| <i>Rosa macrophylla</i>                        | 700.00         | 2.183         | 35.46         |
| <i>Rosa sericea</i>                            | 700.00         | 3.079         | 41.86         |
| <i>Spiraea bella</i>                           | 233.33         | 0.097         | 6.33          |
| <i>Viburnum mullaha</i>                        | 1533.33        | 1.404         | 39.55         |
| <b>Total</b>                                   | <b>8633.33</b> | <b>14.007</b> | <b>300.00</b> |

A perusal of the data presented in Table 26 reveals that in upper moist temperate deciduous forests 41 shrub species were present at different elevations. Maximum number of species were recorded from E<sub>1</sub> (29) followed by E<sub>2</sub> (26) and E<sub>3</sub> (10). Among three elevations, at E<sub>1</sub> highest shrub density (8200.00 plants/ha) and basal area (16.330 m<sup>2</sup>/ha) was recorded

that decreased at E<sub>2</sub> with shrub density as 7500.00 plants/ha and basal area of 14.305 m<sup>2</sup>/ha. While the lowest shrubs density (7500 plants/ha) and basal area (13.687 m<sup>2</sup>/ha) was recorded at elevation E<sub>3</sub>.

At elevation E<sub>1</sub>, maximum density (933.33 plants/ha) and basal area (4.022 m<sup>2</sup>/ha) of an individual shrub was recorded for *Prinsepia utilis* followed by *Myrsine africana* (density as 866.67 plants/ha and basal area as 1.877 m<sup>2</sup>/ha). While least density (33.33 plants/ha) was recorded for *Viburnum foetens* while lowest basal area (0.006 m<sup>2</sup>/ha) was exhibited by *Lespedeza juncea*. At elevation E<sub>2</sub>, *Berberis aristata* displayed highest density and basal area as 733.33 plants/ha and 4.313 m<sup>2</sup>/ha respectively. Minimum density and basal area was exhibited by *Indigofera dosua* as 33.33 plants/ha and 0.007 m<sup>2</sup>/ha respectively. At elevation E<sub>3</sub>, *Rosa macrophylla* showed highest density and basal area with 1333.33 plants/ha and 4.585 m<sup>2</sup>/ha respectively. Least density (33.33 plants/ha) and basal area (0.207m<sup>2</sup>/ha) was recorded for *Rosa sericea* (Table 26).

*Prinsepia utilis* was dominant shrub species at E<sub>1</sub> with highest IVI of 41.87, *Myrsine africana* was co-dominant shrub with IVI of 27.32 and *Rosa macrophylla* was an associate species with an IVI of 23.95. Whereas *Viburnum foetens* was rare species with least IVI of 2.48. At E<sub>2</sub>, *Berberis aristata* was dominant species with IVI of 51.93, while *Rosa sericea* and *Indigofera heterantha* were co-dominant and associate species with IVI of 30.93 and 15.29 respectively. However *Indigofera dosua* was rare species with an importance value index of (3.38). At E<sub>3</sub>, *Rosa macrophylla* was the dominant shrub species with highest IVI of 60.09, co-dominant shrub was *Viburnum mullaha* with an IVI as 49.67 and *Berberis aristata* was an associate species with IVI of 32.04 whereas *Rosa sericea* was rare species with least value for IVI as 8.34 (Table 26).

**Table 26: Density, basal area, and importance value index (IVI) of shrubs in upper moist temperate deciduous forests at different elevations**

| Shrub Species                                  | Density (plants/ha) | Basal area (m <sup>2</sup> /ha) | IVI   |
|------------------------------------------------|---------------------|---------------------------------|-------|
| <b>Elevation - E<sub>1</sub> (1700-2300 m)</b> |                     |                                 |       |
| <i>Andrachne cordifolia</i>                    | 66.67               | 0.027                           | 2.64  |
| <i>Argyrolobium flaccidum</i>                  | 66.67               | 0.051                           | 2.79  |
| <i>Berberis lycium</i>                         | 333.33              | 0.681                           | 11.57 |
| <i>Buddleja crispa</i>                         | 100.00              | 0.008                           | 2.93  |
| <i>Cotoneaster bacillaris</i>                  | 233.33              | 0.198                           | 7.39  |
| <i>Daphne papyracea</i>                        | 66.67               | 0.010                           | 2.54  |
| <i>Deutzia staminea</i>                        | 133.33              | 0.104                           | 3.93  |

|                                                |                |               |               |
|------------------------------------------------|----------------|---------------|---------------|
| <i>Indigofera atropurpurea</i>                 | 533.33         | 0.032         | 13.37         |
| <i>Jasminum officinale</i>                     | 266.67         | 0.759         | 11.23         |
| <i>Lespedeza gerardiana</i>                    | 333.33         | 0.132         | 9.87          |
| <i>Lespedeza juncea</i>                        | 133.33         | 0.006         | 3.33          |
| <i>Myrsine africana</i>                        | 866.67         | 1.877         | 27.32         |
| <i>Prinsepia utilis</i>                        | 933.33         | 4.022         | 41.87         |
| <i>Pteracanthus urticifolius</i>               | 200.00         | 0.011         | 5.84          |
| <i>Rabdosia rugosa</i>                         | 366.67         | 0.038         | 9.71          |
| <i>Rhamnus virgatus</i>                        | 166.67         | 0.027         | 3.87          |
| <i>Ribes emodense</i>                          | 400.00         | 0.013         | 9.96          |
| <i>Rosa macrophylla</i>                        | 400.00         | 2.569         | 23.95         |
| <i>Rubus foliolosus</i>                        | 166.67         | 0.771         | 8.42          |
| <i>Rubus hypargyryus</i>                       | 333.33         | 1.272         | 13.52         |
| <i>Salix denticulata</i>                       | 166.67         | 1.617         | 16.94         |
| <i>Sarcococca saligna</i>                      | 133.33         | 0.006         | 3.33          |
| <i>Skimmia laureola</i>                        | 266.67         | 0.039         | 8.49          |
| <i>Sorbaria tomentosa</i>                      | 66.67          | 0.063         | 2.86          |
| <i>Spiraea bella</i>                           | 100.00         | 0.008         | 2.93          |
| <i>Strobilanthes atropurpureus</i>             | 733.33         | 0.010         | 22.34         |
| <i>Thamnocalamus spathiflorus</i>              | 366.67         | 1.786         | 19.30         |
| <i>Viburnum foetens</i>                        | 33.33          | 0.067         | 2.48          |
| <i>Wikstroemia canescens</i>                   | 233.33         | 0.127         | 5.29          |
| <b>Total</b>                                   | <b>8200.00</b> | <b>16.330</b> | <b>300.00</b> |
| <b>Elevation – E<sub>2</sub> (2300-2900 m)</b> |                |               |               |
| <i>Berberis aristata</i>                       | 733.33         | 4.313         | 51.93         |
| <i>Cotoneaster bacillaris</i>                  | 433.33         | 0.379         | 14.43         |
| <i>Cotoneaster microphylla</i>                 | 133.33         | 0.111         | 4.55          |
| <i>Deutzia compacta</i>                        | 100.00         | 0.194         | 4.69          |
| <i>Deutzia staminea</i>                        | 100.00         | 0.141         | 4.32          |
| <i>Elaeagnus parvifolia</i>                    | 300.00         | 0.124         | 8.87          |
| <i>Indigofera dosua</i>                        | 33.33          | 0.007         | 3.38          |
| <i>Indigofera heterantha</i>                   | 533.33         | 0.026         | 15.29         |
| <i>Lespedeza gerardiana</i>                    | 233.33         | 0.026         | 5.29          |
| <i>Lonicera quinquelocularis</i>               | 300.00         | 0.063         | 8.44          |
| <i>Lotus corniculatus</i>                      | 533.33         | 0.136         | 12.06         |
| <i>Ribes emodense</i>                          | 233.33         | 0.044         | 5.42          |
| <i>Rosa macrophylla</i>                        | 300.00         | 1.237         | 16.65         |
| <i>Rosa sericea</i>                            | 500.00         | 2.619         | 30.97         |
| <i>Rubus biflorus</i>                          | 100.00         | 0.109         | 4.10          |
| <i>Rubus foliolosus</i>                        | 133.33         | 0.461         | 9.00          |
| <i>Rubus hypargyryus</i>                       | 200.00         | 1.008         | 11.71         |
| <i>Salix denticulata</i>                       | 133.33         | 0.980         | 10.63         |
| <i>Skimmia laureola</i>                        | 166.67         | 0.035         | 4.47          |
| <i>Sorbaria tomentosa</i>                      | 400.00         | 0.209         | 10.80         |

|                                                 |                |               |               |
|-------------------------------------------------|----------------|---------------|---------------|
| <i>Spiraea bella</i>                            | 533.33         | 0.077         | 13.65         |
| <i>Strobilanthes atropurpureus</i>              | 200.00         | 0.016         | 4.78          |
| <i>Thamnocalamus spathiflorus</i>               | 300.00         | 1.031         | 17.21         |
| <i>Viburnum cotinifolium</i>                    | 400.00         | 0.598         | 13.52         |
| <i>Viburnum foetens</i>                         | 166.67         | 0.242         | 5.91          |
| <i>Wikstroemia canescens</i>                    | 233.33         | 0.119         | 7.94          |
| <b>Total</b>                                    | <b>7433.33</b> | <b>14.305</b> | <b>300.00</b> |
| <b>Elevation – E<sub>3</sub> (2900 -3500 m)</b> |                |               |               |
| <i>Berberis aristata</i>                        | 433.33         | 2.542         | 32.04         |
| <i>Cotoneaster microphylla</i>                  | 666.67         | 0.598         | 26.08         |
| <i>Deutzia compacta</i>                         | 733.33         | 1.441         | 28.00         |
| <i>Lonicera quinquelocularis</i>                | 333.33         | 0.209         | 17.99         |
| <i>Ribes emodense</i>                           | 866.67         | 0.379         | 20.78         |
| <i>Rosa macrophylla</i>                         | 1333.33        | 4.585         | 60.10         |
| <i>Rosa sericea</i>                             | 33.33          | 0.207         | 8.34          |
| <i>Salix denticulata</i>                        | 333.33         | 1.192         | 20.84         |
| <i>Spiraea bella</i>                            | 999.99         | 0.229         | 36.17         |
| <i>Viburnum mullaha</i>                         | 1033.33        | 2.306         | 49.67         |
| <b>Total</b>                                    | <b>6766.65</b> | <b>13.687</b> | <b>300.00</b> |

On perusal of Table 27 it becomes clear that forest type coupled with particular elevation unveiled difference in shrub species and particularly their functional attributes i.e. density and basal area. The difference in shrub density was evident with maximum shrub density in moist temperate lower deciduous forests (10344.44 plants/ha) followed by western mixed coniferous forests (9911.11 plants/ha), Moru Oak forests (9440.40 plants/ha), Kail forests (9077.78 plants/ha), Kharsu Oak forests (9077.78 plants/ha), upper Oak-Fir forests (8944.44 plants/ha), Ban Oak forests (8922.11 plants/ha), Deodar forests (8511.11 plants/ha) and moist temperate upper deciduous forests (7466.66 plants/ha). Likewise the basal area of shrubs in different forests ranged from 191.289 to 135.767 m<sup>2</sup>/ha with maximum values in Moru Oak forests (191.289 cm<sup>2</sup>/ha ) followed by Ban Oak forests (188.449 m<sup>2</sup>/ha), Kharsu Oak forests (173.599 m<sup>2</sup>/ha), moist temperate lower deciduous forests (171.760 m<sup>2</sup>/ha), western mixed coniferous forests (159.555 m<sup>2</sup>/ha), upper Oak-Fir forests (151.490 m<sup>2</sup>/ha), moist temperate upper deciduous forests (147.742 m<sup>2</sup>/ha), Kail forests (147.480 m<sup>2</sup>/ha) and Deodar forests (135.766 m<sup>2</sup>/ha). Such difference in growth characteristics of shrubs under different forests can be related to difference in gap opening in forests due to tree characteristics, density, disturbance or management leading changes in micro habitat favoring different shrub species (Thomas *et al.* 1999), which becomes more directional when coupled with type and rate of decomposition of tree leaf litter (Lebret *et al.* 2001).

Comparable range of shrub density in forests of Himalayan region have been recorded by other workers (Kumar 2012; Verma and Kapoor 2013; Verma 2014; Sharma *et al.* 2014, Dar and Sundarapandian 2016; Thokchom and Yadava 2017). However, it is evident from the results in the present study that density of shrubs is higher than shrub density of 850-5380 plants ha<sup>-1</sup> reported by Raturi (2012), Saha and saxena (1990), Negi *et al.*(2008) and Rawal and Pangtey (1994b) in chir pine forest of Himalaya. Shrub density ranging from 720-2801 plants/ha was recorded in mixed forests by Kumar and Bhatt (2006), Chandra *et al.* (2010), Gairola *et al.* (2008). Other workers like, Guleria *et al.* (1999); Gupta *et al.* (2000); Sharma and Gupta (2005); Gupta *et al.* (2009); Masoodi (2010); Siddiqui *et al.* (2009); Dangwal *et al.* (2012); Farooq (2012); Sharma (2012); Mahato (2013) and Singh (2014) who worked on different vegetations of Himalayan region also reported less density of shrubs in their findings.

**Table 27: Change in density (plants/ha) and basal area (m<sup>2</sup>/ha) of shrubs among forests (F) and elevations (E)**

| Forest Types (F) | Density (plants/ha) at different elevations (E) |                |                | Mean            | Basal area (m <sup>2</sup> /ha) at different elevations (E) |                |                | Mean          |
|------------------|-------------------------------------------------|----------------|----------------|-----------------|-------------------------------------------------------------|----------------|----------------|---------------|
|                  | E <sub>1</sub>                                  | E <sub>2</sub> | E <sub>3</sub> |                 | E <sub>1</sub>                                              | E <sub>2</sub> | E <sub>3</sub> |               |
| <b>FT-1</b>      | 10000.00                                        | 8433.00        | 8333.33        | <b>8922.11</b>  | 21.232                                                      | 19.187         | 16.116         | <b>18.845</b> |
| <b>FT-2</b>      | 11000.00                                        | 9221.20        | 8100.00        | <b>9440.40</b>  | 21.562                                                      | 19.387         | 16.437         | <b>19.129</b> |
| <b>FT-3</b>      | 9766.67                                         | 8966.67        | 6800.00        | <b>8511.11</b>  | 16.968                                                      | 14.642         | 9.120          | <b>13.577</b> |
| <b>FT-4</b>      | 11000.00                                        | 10400.00       | 8333.33        | <b>9911.11</b>  | 18.111                                                      | 15.293         | 14.463         | <b>15.956</b> |
| <b>FT-5</b>      | 11900.00                                        | 10533.33       | 8600.00        | <b>10344.44</b> | 18.996                                                      | 16.445         | 13.087         | <b>16.176</b> |
| <b>FT-6</b>      | 10300.00                                        | 8866.67        | 8066.67        | <b>9077.78</b>  | 16.801                                                      | 14.577         | 12.866         | <b>14.748</b> |
| <b>FT-7</b>      | 9866.67                                         | 7967.00        | 6799.98        | <b>8211.22</b>  | 19.209                                                      | 17.417         | 15.454         | <b>17.360</b> |
| <b>FT-8</b>      | 9200.00                                         | 9000.00        | 8633.33        | <b>8944.44</b>  | 16.241                                                      | 15.200         | 14.007         | <b>15.149</b> |
| <b>FT-9</b>      | 8200.00                                         | 7433.33        | 6766.65        | <b>7466.66</b>  | 16.330                                                      | 14.305         | 13.687         | <b>14.774</b> |
| <b>Mean</b>      | <b>10137.04</b>                                 | <b>8980.13</b> | <b>7825.92</b> |                 | <b>18.383</b>                                               | <b>16.273</b>  | <b>13.915</b>  |               |
|                  | C.D. 0.05                                       |                |                |                 | C.D. 0.05                                                   |                |                |               |
|                  |                                                 | C.D.           | SE (d)         |                 |                                                             | C.D.           | SE (d)         |               |
|                  | F                                               | 377.47         | 187.57         |                 | F                                                           | 1.08           | 0.54           |               |
|                  | E                                               | 217.93         | 108.30         |                 | E                                                           | 0.62           | 0.31           |               |
|                  | F X E                                           | 635.80         | 324.89         |                 | F X E                                                       | 1.87           | 0.93           |               |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different.

Elevation exerted influence on density and basal area of shrub species (Table 27). Maximum mean density of shrub species was recorded at E<sub>1</sub> (10207.40 plants/ha) followed by E<sub>2</sub> (9087.50 plants/ha) and E<sub>3</sub> (7937.03 plants/ha). While, the maximum mean basal area

of shrubs was recorded at E<sub>1</sub> (183.883 m<sup>2</sup>/ha), followed by E<sub>2</sub> (162.725 m<sup>2</sup>/ha) and E<sub>3</sub> (139.153 m<sup>2</sup>/ha). Perhaps, the difference in growth parameters along elevation can be related to varying micro-climate under overgrowing canopy of trees, which is governed by density of the trees. The change in environmental factors along the elevation as contended by Jamwal and Uniyal (2008), Sevgi and Tecimen (2008), Bhat (2012) and Gupta and Sharma (2015) might have influenced shrubs growth and development accordingly. Several ecological and physiological constraints such as reduced growing season (Korner 2003; Korner 1998b), slope & aspect (Yuan *et al.* 2014) and low temperature with increasing elevation in mountain ecosystems are responsible for reduced growth at high elevation (Korner 1998a), can be accounted for decreased population and growth of shrubs at higher elevations.

It is also evident that among all the shrub species only few species showed better distribution and growth characteristics than others thereby revealed different importance value index (Tables 10-14). These were: in Ban Oak forests (*Berberis lycium* and *Zanthoxylum armatum*); in Moru Oak forests (*Rosa brunonii* and *Agave cantula*); in Deodar forests (*Prinsepia utilis* and *Viburnum cotinifolium*); in western mixed coniferous forests (*Viburnum cotinifolium* and *Berberis lycium*); in moist temperate lower deciduous forests (*Berberis lycium* and *Cotoneaster bacillaris*); in Kail forests (*Viburnum foetens* and *Hypericum dyeri*); in Kharsu Oak forests (*Myrsine africana* and *Berberis aristata*); in upper Oak-Fir forests (*Berberis aristata* and *Rosa sericea*) and in moist temperate upper deciduous forests (*Berberis aristata* and *Rosa macrophylla*). The dominance of few species over their peer group can be ascertained to the suitability of specific ecological niche which have favored the germination, establishment and dominance of these species. The dominance of few species in different forest types has also been reported by Pielou (1966), Ram *et al.* (2004), Uniyal *et al.* (2010), Kumar and Ram (2005), Rawat and Chandra (2014), and Iqbal *et al.* (2014).

#### 4.4.3 Phytosociology of forbs

The herbaceous flora in Ban Oak forests at different elevations was comprised of 104 forb species (Table 28). More number of forb species (58) were recorded at E<sub>1</sub> as compared to E<sub>2</sub> (54) and E<sub>3</sub> (51). Among three elevations, highest forb density (221333.34 plants/ha) and basal area (118.065 cm<sup>2</sup>/m<sup>2</sup>) occurred at E<sub>1</sub> followed by E<sub>2</sub> with forb density as 198333.33 plants/ha with basal area of 90.345 cm<sup>2</sup>/m<sup>2</sup>. While the lowest density (178333.33 plants/ha) and basal area (87.951 cm<sup>2</sup>/m<sup>2</sup>) of forbs was recorded at elevation E<sub>3</sub> (Table 28).

Among different forbs species at E<sub>1</sub> highest density (19666.67 plants/ha) and basal area (22.587 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Iris nepalensis* and *Primula denticulata*, respectively. Whereas, lowest plant density of 1666.67 plants/ha at E<sub>1</sub> was observed for each of the following species viz., *Anemone obtusiloba*, *Angelica glauca*, *Dioscorea deltoidea*, *Erigeron bellidioides* and *Geranium lucidum*. Lowest value of basal area in forbs was recorded for *Dioscorea deltoidea* as 0.137 cm<sup>2</sup>/m<sup>2</sup>. At E<sub>2</sub>, highest density and basal area was recorded in *Leucas lanata* (13333.33 plants/ha) and *Fragaria nubicola* (12.392 cm<sup>2</sup>/m<sup>2</sup>), respectively. Minimum density (1666.67 plants/ha) at E<sub>2</sub>, was observed in *Amaranthus blitum*, *Arabis amplexicaulis*, *Artemisia roxburghiana*, *Duchesnea indica*, *Urtica dioica*, *Trifolium repens*, *Swertia cordata*, *Stellaria media*, *Scutellaria scandens*, *Salvia lanata*, *Primula floribunda*, *Plectranthus japonicas*, *Impatiens scabrida*, *Geranium lucidum*, *Gerbera gossypina* and *Fagopyrum dibotrys*. Minimum basal area of 0.216 cm<sup>2</sup>/m<sup>2</sup> was recorded for *Artemisia roxburghiana* at E<sub>2</sub>. Maximum density at E<sub>3</sub> was recorded in *Verbascum thapsus* and *Androsace rotundifolia* each with 11666.67 plants/ha while, highest basal area (14.176 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Verbascum thapsus* followed by *Trifolium repens* (13.302 cm<sup>2</sup>/m<sup>2</sup>). Lowest density of 1666.67 plants/ha existed in each: *Vicatia coniifolia*, *Urtica dioica*, *Thymus linearis*, *Rumex nepalensis*, *Ranunculus laetus*, *Rosularia rosulata*, *Ranunculus hirtellus*, *Primula petiolaris*, *Potentilla nepalensis*, *Nepeta laevigata*, *Phragmites communis*, *Erigeron multicaulis*, *Dicliptera bupleuroides*, *Chenopodium opulifolium*, *Astilbe rivularis*, *Androsace sarmentosa* and *Arisaema flavum*, whereas minimum basal area was recorded in *Androsace sarmentosa* as 0.037 cm<sup>2</sup>/m<sup>2</sup> (Table 28).

Among forbs, *Verbascum thapsus* was dominant plant at E<sub>1</sub> with IVI of 33.56, whereas *Primula denticulata* was co-dominant and *Iris nepalensis* was associate species with IVI of 27.34 and 20.50, respectively. At E<sub>2</sub>, *Fragaria nubicola* was the dominant species (IVI as 19.61) and *Urtica ardens* (IVI as 16.16) was co-dominant and *Leucas lanata* (IVI as 15.85) was associate species. At E<sub>3</sub>, *Verbascum Thapsus* was the dominant species with IVI of 29.42, *Trifolium repens* and *Bupleurum hamiltonii* were the co-dominant and associate species with IVI of 23.37 and 14.22 respectively. Lowest IVI of 2.09 in all the three elevations was observed in *Dioscorea deltoidea*, symbolising it as the rare species in Ban Oak forests (Table 28).



**Table 28: Density basal area, and importance value index (IVI) of forbs in Ban Oak (*Q. leucotrichophora*) forests at different elevations.**

| Forb Species                      | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|-----------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation-E1 (700 -1300 m)</b> |                     |                                               |       |
| <i>Adiantum venustum</i>          | 1666.67             | 0.145                                         | 2.10  |
| <i>Ainsliaea aptera</i>           | 5000.00             | 1.215                                         | 4.52  |
| <i>Ajuga bracteosa</i>            | 5000.00             | 4.016                                         | 6.89  |
| <i>Anaphalis contorta</i>         | 15000.00            | 5.445                                         | 16.31 |
| <i>Androsace lanuginosa</i>       | 3333.33             | 0.582                                         | 3.23  |
| <i>Androsace sarmentosa</i>       | 3333.33             | 0.347                                         | 3.03  |
| <i>Anemone obtusiloba</i>         | 1666.67             | 0.685                                         | 2.56  |
| <i>Angelica glauca</i>            | 1666.67             | 0.386                                         | 2.30  |
| <i>Arabis amplexicaulis</i>       | 3333.33             | 0.851                                         | 3.46  |
| <i>Artemisia roxburghiana</i>     | 10000.00            | 1.495                                         | 10.69 |
| <i>Bergenia stracheyi</i>         | 8333.33             | 1.710                                         | 7.68  |
| <i>Bistorta amplexicaulis</i>     | 3333.33             | 0.123                                         | 2.84  |
| <i>Bupleurum falcatum</i>         | 3333.33             | 1.059                                         | 3.63  |
| <i>Carex breviculmis</i>          | 3333.33             | 0.390                                         | 3.06  |
| <i>Carex cardiolepis</i>          | 3333.33             | 0.737                                         | 3.36  |
| <i>Chenopodium opulifolium</i>    | 3333.33             | 1.071                                         | 3.64  |
| <i>Clinopodium vulgare</i>        | 3333.33             | 0.910                                         | 3.51  |
| <i>Corydalis govaniana</i>        | 3333.33             | 0.497                                         | 3.16  |
| <i>Dioscorea deltoidea</i>        | 1666.67             | 0.137                                         | 2.09  |
| <i>Erigeron bellidioides</i>      | 1666.67             | 0.326                                         | 2.25  |
| <i>Fagopyrum dibotrys</i>         | 3333.33             | 0.380                                         | 3.06  |
| <i>Galium aparine</i>             | 3333.33             | 0.318                                         | 3.00  |
| <i>Geranium lucidum</i>           | 1666.67             | 0.468                                         | 2.37  |
| <i>Gypsophila cerastioides</i>    | 1666.67             | 0.943                                         | 2.78  |
| <i>Halenia elliptica</i>          | 5000.00             | 2.107                                         | 6.50  |
| <i>Impatiens scabrida</i>         | 3333.33             | 0.601                                         | 3.24  |
| <i>Iris nepalensis</i>            | 19666.67            | 5.727                                         | 20.50 |
| <i>Lotus corniculatus</i>         | 5000.00             | 0.796                                         | 4.17  |
| <i>Nepeta laevigata</i>           | 5000.00             | 3.510                                         | 8.90  |
| <i>Pedicularis hoffmeisteri</i>   | 1666.67             | 0.734                                         | 2.60  |
| <i>Phragmites communis</i>        | 1666.67             | 0.428                                         | 2.34  |
| <i>Plantago depressa</i>          | 1666.67             | 5.894                                         | 6.97  |
| <i>Plectranthus japonicus</i>     | 3333.33             | 1.625                                         | 4.11  |
| <i>Podophyllum hexandrum</i>      | 1666.67             | 0.472                                         | 2.38  |
| <i>Polygonatum cirrhifolium</i>   | 1666.67             | 2.226                                         | 3.86  |
| <i>Polygonatum multiflorum</i>    | 1666.67             | 2.586                                         | 4.17  |
| <i>Potentilla argrophylla</i>     | 1666.67             | 1.923                                         | 3.61  |
| <i>Potentilla atrosanguinea</i>   | 3333.33             | 0.515                                         | 3.17  |
| <i>Primula denticulata</i>        | 10000.00            | 22.587                                        | 27.34 |
| <i>Primula petiolaris</i>         | 1666.67             | 0.791                                         | 2.65  |
| <i>Pteris cretica</i>             | 1666.67             | 0.739                                         | 2.60  |
| <i>Ranunculus hirtellus</i>       | 1666.67             | 1.371                                         | 3.14  |
| <i>Roscoeia purpurea</i>          | 1666.67             | 2.096                                         | 3.75  |

|                                              |                  |                |               |
|----------------------------------------------|------------------|----------------|---------------|
| <i>Salvia nubicola</i>                       | 3333.33          | 2.945          | 5.23          |
| <i>Scrophularia himalensis</i>               | 1666.67          | 1.326          | 3.10          |
| <i>Selaginella kraussiana</i>                | 1666.67          | 1.366          | 3.13          |
| <i>Senecio chrysanthemoides</i>              | 1666.67          | 1.365          | 3.13          |
| <i>Sibbaldia cuneata</i>                     | 3333.33          | 1.005          | 3.59          |
| <i>Silene griffithii</i>                     | 1666.67          | 0.551          | 2.44          |
| <i>Silene vulgaris</i>                       | 1666.67          | 0.441          | 2.35          |
| <i>Smilacina purpurea</i>                    | 1666.67          | 0.347          | 2.27          |
| <i>Stellaria media</i>                       | 3333.33          | 2.296          | 4.68          |
| <i>Thymus linearis</i>                       | 3333.33          | 1.313          | 3.85          |
| <i>Urtica ardens</i>                         | 1666.67          | 0.852          | 2.70          |
| <i>Valeriana jatamansi</i>                   | 3333.33          | 2.815          | 5.12          |
| <i>Valeriana pyrolaefolia</i>                | 3333.33          | 1.104          | 3.67          |
| <i>Verbascum thapsus</i>                     | 18333.33         | 18.269         | 33.56         |
| <i>Vicatia coniifolia</i>                    | 3333.33          | 1.106          | 3.67          |
| <b>Total</b>                                 | <b>221333.34</b> | <b>118.065</b> | <b>300.00</b> |
| <b>Elevation-E<sub>2</sub> (1300-1900 m)</b> |                  |                |               |
| <i>Achyranthes aspera</i>                    | 3333.33          | 0.484          | 3.48          |
| <i>Achyranthes bidentata</i>                 | 5000.00          | 2.509          | 6.56          |
| <i>Ajuga bracteosa</i>                       | 6666.67          | 1.599          | 7.67          |
| <i>Ajuga parviflora</i>                      | 1666.67          | 1.624          | 3.91          |
| <i>Amaranthus blitum</i>                     | 1666.67          | 1.057          | 3.29          |
| <i>Androsace lanuginosa</i>                  | 3333.33          | 0.311          | 3.29          |
| <i>Arabis amplexicaulis</i>                  | 1666.67          | 0.263          | 2.41          |
| <i>Arisaema flavum</i>                       | 3333.33          | 0.380          | 3.37          |
| <i>Artemisia roxburghiana</i>                | 1666.67          | 0.216          | 2.35          |
| <i>Aster molliusculus</i>                    | 10000.00         | 1.049          | 12.12         |
| <i>Atylosia scarabaeoides</i>                | 1666.67          | 0.670          | 2.86          |
| <i>Bidens biternata</i>                      | 3333.33          | 0.744          | 3.77          |
| <i>Bistorta amplexicaulis</i>                | 3333.33          | 1.426          | 5.81          |
| <i>Clinopodium vulgare</i>                   | 1666.67          | 0.553          | 2.73          |
| <i>Cyathula tomentosa</i>                    | 3333.33          | 1.205          | 5.56          |
| <i>Datura stramonium</i>                     | 8333.33          | 2.140          | 9.10          |
| <i>Dicliptera bupleuroides</i>               | 3333.33          | 0.264          | 3.24          |
| <i>Dioscorea deltoidea</i>                   | 3333.33          | 0.093          | 3.05          |
| <i>Duchesnea indica</i>                      | 1666.67          | 0.567          | 2.74          |
| <i>Echinops niveus</i>                       | 1666.67          | 0.285          | 2.43          |
| <i>Fagopyrum dibotrys</i>                    | 1666.67          | 0.564          | 2.74          |
| <i>Fragaria nubicola</i>                     | 6666.67          | 12.392         | 19.61         |
| <i>Galium aparine</i>                        | 3333.33          | 2.041          | 6.49          |
| <i>Geranium lucidum</i>                      | 1666.67          | 0.251          | 2.39          |
| <i>Gerbera gossypina</i>                     | 1666.67          | 0.457          | 2.62          |
| <i>Habenaria intermedia</i>                  | 3333.33          | 0.399          | 3.39          |
| <i>Heracleum candicans</i>                   | 3333.33          | 0.816          | 3.85          |
| <i>Impatiens scabrida</i>                    | 1666.67          | 1.055          | 3.28          |
| <i>Iris nepalensis</i>                       | 3333.33          | 1.678          | 4.81          |
| <i>Leucas lanata</i>                         | 13333.33         | 3.664          | 15.85         |
| <i>Micromeria biflora</i>                    | 3333.33          | 1.427          | 4.53          |

|                                              |                  |               |               |
|----------------------------------------------|------------------|---------------|---------------|
| <i>Oenothera rosea</i>                       | 8333.33          | 5.113         | 13.67         |
| <i>Phragmites communis</i>                   | 3333.33          | 1.344         | 4.44          |
| <i>Plantago depressa</i>                     | 5000.00          | 2.023         | 7.30          |
| <i>Plantago erosa</i>                        | 5000.00          | 1.078         | 6.26          |
| <i>Plectranthus japonicus</i>                | 1666.67          | 0.835         | 3.04          |
| <i>Polygonatum multiflorum</i>               | 3333.33          | 2.223         | 5.41          |
| <i>Potentilla argyrophylla</i>               | 3333.33          | 1.162         | 4.23          |
| <i>Primula floribunda</i>                    | 1666.67          | 0.690         | 2.88          |
| <i>Pteris cretica</i>                        | 3333.33          | 2.863         | 7.40          |
| <i>Rumex nepalensis</i>                      | 3333.33          | 0.737         | 3.76          |
| <i>Salvia lanata</i>                         | 1666.67          | 0.646         | 2.83          |
| <i>Scutellaria scandens</i>                  | 1666.67          | 0.781         | 2.98          |
| <i>Silene vulgaris</i>                       | 8333.33          | 4.129         | 12.58         |
| <i>Stellaria media</i>                       | 1666.67          | 0.345         | 2.50          |
| <i>Swertia cordata</i>                       | 1666.67          | 0.377         | 2.53          |
| <i>Thalictrum foliolosum</i>                 | 3333.33          | 1.269         | 4.35          |
| <i>Themeda anathera</i>                      | 6666.67          | 5.272         | 13.02         |
| <i>Trifolium repens</i>                      | 1666.67          | 4.356         | 6.94          |
| <i>Urtica ardens</i>                         | 6666.67          | 8.114         | 16.16         |
| <i>Urtica dioica</i>                         | 1666.67          | 0.317         | 2.47          |
| <i>Valeriana jatamansi</i>                   | 3333.33          | 0.745         | 3.77          |
| <i>Verbascum thapsus</i>                     | 5000.00          | 2.246         | 7.55          |
| <i>Viola canescens</i>                       | 3333.33          | 1.497         | 4.61          |
| <b>Total</b>                                 | <b>198333.33</b> | <b>90.345</b> | <b>300.00</b> |
| <b>Elevation-E<sub>3</sub> (1900-2500 m)</b> |                  |               |               |
| <i>Anaphalis contorta</i>                    | 3333.33          | 0.215         | 3.23          |
| <i>Androsace rotundifolia</i>                | 11666.67         | 0.984         | 12.15         |
| <i>Androsace sarmentosa</i>                  | 1666.67          | 0.037         | 2.10          |
| <i>Arisaema flavum</i>                       | 1666.67          | 0.163         | 2.25          |
| <i>Artemisia indica</i>                      | 6666.67          | 1.078         | 9.48          |
| <i>Astilbe rivularis</i>                     | 1666.67          | 0.317         | 2.42          |
| <i>Bupleurum hamiltonii</i>                  | 10000.00         | 2.622         | 14.22         |
| <i>Carex breviculmis</i>                     | 1666.67          | 0.629         | 2.78          |
| <i>Carex remota</i>                          | 3333.33          | 0.629         | 4.84          |
| <i>Chenopodium opulifolium</i>               | 1666.67          | 0.345         | 2.46          |
| <i>Corydalis govaniana</i>                   | 5000.00          | 1.799         | 7.10          |
| <i>Crepis sancta</i>                         | 10000.00         | 1.518         | 11.83         |
| <i>Dicliptera bupleuroides</i>               | 1666.67          | 0.417         | 2.54          |
| <i>Dioscorea deltoidea</i>                   | 3333.33          | 1.219         | 5.51          |
| <i>Erigeron bellidioides</i>                 | 5000.00          | 1.245         | 6.47          |
| <i>Erigeron multicaulis</i>                  | 1666.67          | 0.498         | 2.63          |
| <i>Fagopyrum dibotrys</i>                    | 5000.00          | 1.202         | 6.42          |
| <i>Fragaria nubicola</i>                     | 5000.00          | 1.305         | 6.53          |
| <i>Galium asperuloides</i>                   | 3333.33          | 0.176         | 3.19          |
| <i>Geranium lucidum</i>                      | 1666.67          | 0.068         | 2.14          |
| <i>Gypsophila cerastioides</i>               | 1666.67          | 0.680         | 2.84          |
| <i>Halenia elliptica</i>                     | 1666.67          | 0.238         | 2.33          |
| <i>Iris nepalensis</i>                       | 1666.67          | 0.850         | 3.03          |

|                                 |                  |               |               |
|---------------------------------|------------------|---------------|---------------|
| <i>Lamium album</i>             | 1666.67          | 0.533         | 2.67          |
| <i>Lotus corniculatus</i>       | 5000.00          | 2.826         | 8.26          |
| <i>Myriactis nepalensis</i>     | 5000.00          | 0.882         | 6.05          |
| <i>Nepeta laevigata</i>         | 1666.67          | 0.391         | 2.51          |
| <i>Phragmites communis</i>      | 1666.67          | 1.679         | 3.97          |
| <i>Polygala abyssinica</i>      | 3333.33          | 0.388         | 3.43          |
| <i>Polygonatum cirrhifolium</i> | 3333.33          | 2.013         | 5.28          |
| <i>Polygonatum multiflorum</i>  | 3333.33          | 0.249         | 5.54          |
| <i>Potentilla argyrophylla</i>  | 3333.33          | 0.927         | 5.18          |
| <i>Potentilla nepalensis</i>    | 1666.67          | 1.298         | 3.54          |
| <i>Primula petiolaris</i>       | 1666.67          | 1.320         | 3.56          |
| <i>Ranunculus hirtellus</i>     | 1666.67          | 2.293         | 4.67          |
| <i>Rosularia rosulata</i>       | 1666.67          | 2.287         | 4.66          |
| <i>Ranunculus laetus</i>        | 1666.67          | 3.620         | 6.18          |
| <i>Rumex nepalensis</i>         | 1666.67          | 0.244         | 2.34          |
| <i>Salvia nubicola</i>          | 10000.00         | 2.559         | 13.01         |
| <i>Scrophularia himalensis</i>  | 1666.67          | 0.331         | 2.44          |
| <i>Smilax glaucophylla</i>      | 3333.33          | 0.282         | 4.24          |
| <i>Stellaria media</i>          | 1666.67          | 1.027         | 3.23          |
| <i>Swertia cordata</i>          | 3333.33          | 4.073         | 8.76          |
| <i>Thymus linearis</i>          | 1666.67          | 1.401         | 3.66          |
| <i>Trifolium repens</i>         | 6666.67          | 13.302        | 23.37         |
| <i>Urtica ardens</i>            | 1666.67          | 3.895         | 6.49          |
| <i>Urtica dioica</i>            | 1666.67          | 1.992         | 4.33          |
| <i>Valeriana jatamansi</i>      | 1666.67          | 0.669         | 2.82          |
| <i>Valeriana pyrolaefolia</i>   | 3333.33          | 2.781         | 7.29          |
| <i>Verbascum thapsus</i>        | 11666.67         | 14.176        | 29.42         |
| <i>Vicatia coniiifolia</i>      | 1666.67          | 2.279         | 4.65          |
| <b>Total</b>                    | <b>178333.33</b> | <b>87.951</b> | <b>300.01</b> |

The herbaceous flora in Moru Oak forests at different elevations was comprised of 95 species (Table 29). Maximum number of species existed at E<sub>2</sub> (50) followed by E<sub>1</sub> (49) and least were reported from E<sub>3</sub> (44). Among three elevations, at E<sub>1</sub> highest density (275837.33 plant/ha) and highest basal area (49.684 cm<sup>2</sup>/m<sup>2</sup>) was recorded followed at E<sub>2</sub> with density as 221989.00 plant/ha with their total basal area as 40.845 cm<sup>2</sup>/m<sup>2</sup>. While the lowest density (186311.67 plants/ha) and basal area (35.897 cm<sup>2</sup>/m<sup>2</sup>) was recorded at elevation E<sub>3</sub> (Table 29).

At E<sub>1</sub>, maximum density (15000.00 plants/ha) and basal area (5.126 cm<sup>2</sup>/m<sup>2</sup>) of an individual forb was recorded for *Stellaria media* followed by *Fragaria nubicola* and *Anaphalis contorta* with density as 13333.33 plants/ha each and basal area as 2.801 cm<sup>2</sup>/m<sup>2</sup> and 1.319 cm<sup>2</sup>/m<sup>2</sup> respectively. While least density (1666.67 plants/ha) was existed in *Bergenia ciliate*, *Androsace rotundifolia* and *Podophyllum hexandrum* each, while the least basal area was observed for *Adiantum venustum* (0.041 cm<sup>2</sup>/m<sup>2</sup>) at E<sub>1</sub>. At E<sub>2</sub> highest density

(13333.33 plants/ha) and basal area (3.441 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Primula denticulate*, followed *Potentilla leschenaultiana* (basal area as 2.270 cm<sup>2</sup>/m<sup>2</sup>), *Heracleum candicans* (basal area as 1.795 cm<sup>2</sup>/m<sup>2</sup>) and *Anaphalis contorta* (basal area as 1.669 cm<sup>2</sup>/m<sup>2</sup>) each with density of 11666.67 plants/ha while lowest plant density of 1666.67 plants/ha was observed for each of the species viz. *Rumex nepalensis*, *Scrophularia himalensis*, *Roscoeia purpurea*, *Rosularia rosulata*, *Fagopyrum dibotrys*, *Crepis sancta*, *Carex breviculmis* and *Ajuga bracteosa*. Whereas Lowest value of basal area (0.109 cm<sup>2</sup>/m<sup>2</sup>) in forbs was recorded for was recorded for *Artemisia roxburghiana*. At E<sub>3</sub> *Viola canescens* exhibited highest density (13333.33 plants/ha) and basal area (5.126 cm<sup>2</sup>/m<sup>2</sup>), followed by *Bidens biternata* (2.993 cm<sup>2</sup>/m<sup>2</sup>) and *Primula floribunda* (2.690 cm<sup>2</sup>/m<sup>2</sup>) with density as 10000.00 plants/ha each. Whereas minimum density was observed for *Valeriana jatamansi*, *Urtica dioica*, *Silene vulgaris*, *Plectranthus japonicas*, *Myriactis nepalensis*, *Lotus corniculatus*, *Girardinia diversifolia*, *Habenaria intermedia*, *Leucas lanata*, *Datura stramonium*, *Dicliptera bupleuroides*, *Atylosia scarabaeoides*, *Arabis amplexicaulis*, *Agrimonia pilosa* and *Ajuga parviflora* as 1666.67 plants/ha. Lowest basal area was recorded for *Achyranthes aspera* (0.087 cm<sup>2</sup>/m<sup>2</sup>) at E<sub>3</sub> (Table 29).

*Erigeron bellidioides* was dominant forb species at E<sub>1</sub> with highest IVI of 26.02, whereas co-dominance was reported from *Stellaria media* (20.35). Very low IVI of 1.48 recorded *Adiantum venustum* suggests that it's a rare species in this forest. At E<sub>2</sub> *Vicatia coniiifolia* was dominant forb species with highest IVI of 31.96, co-dominant species was *Potentilla leschenaultiana* with an IVI of 16.75. Whereas, *Artemisia roxburghiana* was rare species with least IVI of 1.97. At E<sub>3</sub>, *Viola canescens* was dominant forb species with highest IVI of 19.89 and *Valeriana jatamansi* was co-dominant species with an IVI of 3.74. Whereas, *Achyranthes aspera* was rare species with an importance value index of 1.89 (Table 29).

**Table 29: Density, basal area, and importance value index (IVI) of forbs in Moru Oak (*Q. floribunda*) forests at different elevations**

| Forb Species                                  | Density (Plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|-----------------------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (1800-2300 m)</b> |                     |                                               |       |
| <i>Adiantum venustum</i>                      | 3333.33             | 0.041                                         | 1.48  |
| <i>Agrimonia pilosa</i>                       | 3333.33             | 0.082                                         | 1.78  |
| <i>Ainsliaea aptera</i>                       | 3333.33             | 0.655                                         | 4.35  |
| <i>Ajuga bracteosa</i>                        | 6666.67             | 0.967                                         | 6.86  |
| <i>Anaphalis contorta</i>                     | 13333.33            | 1.319                                         | 11.31 |
| <i>Androsace lanuginosa</i>                   | 5000.00             | 1.358                                         | 6.09  |
| <i>Androsace rotundifolia</i>                 | 1666.67             | 0.522                                         | 3.79  |

|                                               |                  |               |               |
|-----------------------------------------------|------------------|---------------|---------------|
| <i>Arabis amplexicaulis</i>                   | 4235.00          | 0.395         | 2.88          |
| <i>Bergenia ciliata</i>                       | 1666.67          | 0.412         | 2.90          |
| <i>Bergenia stracheyi</i>                     | 6666.67          | 0.870         | 5.88          |
| <i>Bistorta amplexicaulis</i>                 | 5000.00          | 0.684         | 5.34          |
| <i>Bupleurum falcatum</i>                     | 5000.00          | 0.829         | 5.82          |
| <i>Carex cardiolepis</i>                      | 3333.33          | 0.296         | 2.71          |
| <i>Carex remota</i>                           | 3333.33          | 0.296         | 2.71          |
| <i>Chenopodium opulifolium</i>                | 4000.00          | 0.582         | 3.88          |
| <i>Clinopodium vulgare</i>                    | 5000.00          | 1.083         | 6.58          |
| <i>Corydalis govaniana</i>                    | 6666.67          | 1.829         | 8.97          |
| <i>Dioscorea deltoidea</i>                    | 10000.00         | 0.798         | 7.18          |
| <i>Erigeron bellidioides</i>                  | 5000.00          | 1.255         | 26.02         |
| <i>Fragaria nubicola</i>                      | 13333.33         | 2.801         | 16.55         |
| <i>Gypsophila cerastioides</i>                | 6666.67          | 1.672         | 7.54          |
| <i>Halenia elliptica</i>                      | 3333.33          | 0.498         | 3.04          |
| <i>Heracleum candicans</i>                    | 6666.67          | 0.760         | 5.35          |
| <i>Iris nepalensis</i>                        | 3333.33          | 0.451         | 2.62          |
| <i>Lotus corniculatus</i>                     | 3333.33          | 0.393         | 2.87          |
| <i>Origanum vulgare</i>                       | 3333.33          | 0.812         | 4.26          |
| <i>Pedicularis hoffmeisteri</i>               | 3333.33          | 0.421         | 4.09          |
| <i>Plantago depressa</i>                      | 6666.67          | 0.876         | 4.72          |
| <i>Plectranthus japonicus</i>                 | 3333.33          | 2.092         | 7.05          |
| <i>Podophyllum hexandrum</i>                  | 1666.67          | 0.699         | 2.67          |
| <i>Polygonatum cirrhifolium</i>               | 3333.33          | 0.601         | 3.56          |
| <i>Polygonatum verticillatum</i>              | 3333.33          | 1.302         | 6.59          |
| <i>Potentilla argyrophylla</i>                | 8333.33          | 1.663         | 10.58         |
| <i>Potentilla leschenaultiana</i>             | 6666.67          | 1.405         | 7.46          |
| <i>Primula denticulata</i>                    | 8333.33          | 1.560         | 9.59          |
| <i>Primula petiolaris</i>                     | 3333.33          | 0.508         | 2.71          |
| <i>Roscoeia purpurea</i>                      | 3333.33          | 0.297         | 2.72          |
| <i>Rumex nepalensis</i>                       | 5000.00          | 0.275         | 3.51          |
| <i>Salvia nubicola</i>                        | 3333.33          | 0.490         | 3.38          |
| <i>Scrophularia himalensis</i>                | 6666.67          | 2.187         | 9.09          |
| <i>Selaginella kraussiana</i>                 | 8333.33          | 1.431         | 9.38          |
| <i>Selinum candollii</i>                      | 6666.67          | 1.186         | 6.75          |
| <i>Senecio chrysanthemoides</i>               | 3333.33          | 0.436         | 2.94          |
| <i>Sibbaldia cuneata</i>                      | 3333.33          | 0.870         | 4.00          |
| <i>Silene griffithii</i>                      | 10000.00         | 2.290         | 10.78         |
| <i>Stellaria media</i>                        | 15000.00         | 5.126         | 20.35         |
| <i>Urtica dioica</i>                          | 11111.00         | 0.495         | 2.34          |
| <i>Valeriana jatamansi</i>                    | 8956.00          | 1.251         | 4.27          |
| <i>Valeriana pyrolaefolia</i>                 | 5869.00          | 0.565         | 2.68          |
| <b>Total</b>                                  | <b>275837.33</b> | <b>49.684</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (2300-2800 m)</b> |                  |               |               |
| <i>Ainsliaea aptera</i>                       | 3333.33          | 0.168         | 2.49          |
| <i>Ajuga bracteosa</i>                        | 1666.67          | 0.197         | 2.55          |
| <i>Anaphalis contorta</i>                     | 11666.67         | 1.669         | 11.09         |
| <i>Androsace lanuginosa</i>                   | 3333.33          | 0.320         | 3.59          |

|                                   |                  |               |               |
|-----------------------------------|------------------|---------------|---------------|
| <i>Androsace rotundifolia</i>     | 3333.33          | 0.291         | 3.53          |
| <i>Arisaema flavum</i>            | 3333.33          | 0.373         | 3.70          |
| <i>Artemisia indica</i>           | 3333.33          | 0.391         | 3.36          |
| <i>Artemisia roxburghiana</i>     | 3333.33          | 0.109         | 1.97          |
| <i>Bergenia ciliata</i>           | 3333.33          | 0.628         | 4.38          |
| <i>Bupleurum falcatum</i>         | 5000.00          | 0.511         | 3.61          |
| <i>Carex breviculmis</i>          | 1666.67          | 1.051         | 5.55          |
| <i>Carex remota</i>               | 5000.00          | 0.327         | 3.60          |
| <i>Chenopodium opulifolium</i>    | 3333.33          | 0.254         | 2.93          |
| <i>Crepis sancta</i>              | 1666.67          | 0.224         | 2.61          |
| <i>Dioscorea deltoidea</i>        | 3333.33          | 0.783         | 5.49          |
| <i>Erigeron multicaulis</i>       | 3333.33          | 0.239         | 3.03          |
| <i>Fagopyrum dibotrys</i>         | 1666.67          | 0.255         | 3.06          |
| <i>Galium asperuloides</i>        | 1989.00          | 1.445         | 12.07         |
| <i>Girardinia diversifolia</i>    | 5000.00          | 0.491         | 3.96          |
| <i>Habenaria intermedia</i>       | 3333.33          | 0.642         | 4.28          |
| <i>Heracleum candicans</i>        | 11666.67         | 1.795         | 12.94         |
| <i>Lamium album</i>               | 8333.33          | 0.841         | 10.44         |
| <i>Myriactis nepalensis</i>       | 3333.33          | 0.284         | 3.12          |
| <i>Origanum vulgare</i>           | 5000.00          | 0.584         | 4.03          |
| <i>Phragmites communis</i>        | 5000.00          | 0.529         | 3.65          |
| <i>Plantago erosa</i>             | 3333.33          | 1.179         | 6.09          |
| <i>Polygala abyssinica</i>        | 3333.33          | 0.491         | 3.57          |
| <i>Polygonatum multiflorum</i>    | 3333.33          | 0.537         | 3.67          |
| <i>Polygonatum verticillatum</i>  | 5000.00          | 0.696         | 6.14          |
| <i>Potentilla faragarioides</i>   | 3333.33          | 0.745         | 4.12          |
| <i>Potentilla leschenaultiana</i> | 11666.67         | 2.270         | 16.75         |
| <i>Primula denticulata</i>        | 13333.33         | 3.441         | 15.99         |
| <i>Primula petiolaris</i>         | 3333.33          | 0.912         | 4.87          |
| <i>Pteris cretica</i>             | 3333.33          | 1.509         | 6.28          |
| <i>Ranunculus laetus</i>          | 3333.33          | 1.639         | 6.56          |
| <i>Roscoeia purpurea</i>          | 1666.67          | 0.274         | 2.72          |
| <i>Rosularia rosulata</i>         | 1666.67          | 0.622         | 4.11          |
| <i>Rumex nepalensis</i>           | 1666.67          | 0.368         | 2.92          |
| <i>Salvia nubicola</i>            | 3333.33          | 0.402         | 3.38          |
| <i>Scrophularia himalensis</i>    | 1666.67          | 0.517         | 3.63          |
| <i>Senecio nudicaulis</i>         | 5000.00          | 1.049         | 7.16          |
| <i>Silene griffithii</i>          | 5000.00          | 0.332         | 3.23          |
| <i>Smilax vaginata</i>            | 5000.00          | 0.368         | 3.30          |
| <i>Stellaria media</i>            | 3333.33          | 0.425         | 3.43          |
| <i>Swertia cordata</i>            | 3333.33          | 0.864         | 5.02          |
| <i>Thalictrum foliolosum</i>      | 8333.33          | 2.066         | 12.89         |
| <i>Trifolium pratense</i>         | 3333.33          | 0.724         | 4.33          |
| <i>Thymus linearis</i>            | 8333.33          | 2.294         | 12.61         |
| <i>Valeriana pyrolaefolia</i>     | 3333.33          | 0.690         | 4.26          |
| <i>Vicatia coniiifolia</i>        | 8333.33          | 2.034         | 31.96         |
| <b>Total</b>                      | <b>221989.00</b> | <b>40.845</b> | <b>300.00</b> |

| Elevation- E <sub>3</sub> (2800-3300) |                  |               |               |
|---------------------------------------|------------------|---------------|---------------|
| <i>Achyranthes aspera</i>             | 3333.33          | 0.087         | 1.89          |
| <i>Agrimonia pilosa</i>               | 1666.67          | 0.100         | 1.93          |
| <i>Ajuga parviflora</i>               | 1666.67          | 0.106         | 1.94          |
| <i>Apluda mutica</i>                  | 3333.33          | 0.703         | 7.08          |
| <i>Arabis amplexicaulis</i>           | 1666.67          | 0.330         | 3.23          |
| <i>Arctium lappa</i>                  | 3333.33          | 0.593         | 6.77          |
| <i>Arisaema flavum</i>                | 1666.67          | 0.110         | 1.95          |
| <i>Artemisia indica</i>               | 3333.33          | 0.267         | 2.89          |
| <i>Aster molliusculus</i>             | 3333.33          | 0.965         | 7.14          |
| <i>Atylosia scarabaeoides</i>         | 1666.67          | 0.155         | 2.08          |
| <i>Bergenia ciliata</i>               | 5000.00          | 0.399         | 4.90          |
| <i>Bidens biternata</i>               | 10000.00         | 2.993         | 12.88         |
| <i>Bupleurum falcatum</i>             | 3333.33          | 0.179         | 2.15          |
| <i>Cheilanthes albomarginata</i>      | 5000.00          | 1.234         | 10.20         |
| <i>Clinopodium vulgare</i>            | 3333.33          | 0.123         | 1.82          |
| <i>Datura stramonium</i>              | 1666.67          | 0.295         | 3.30          |
| <i>Dicliptera bupleuroides</i>        | 1666.67          | 0.179         | 2.31          |
| <i>Dioscorea deltoidea</i>            | 6666.67          | 0.610         | 6.15          |
| <i>Echinops niveus</i>                | 8333.33          | 1.873         | 15.45         |
| <i>Erigeron multicaulis</i>           | 3333.33          | 0.282         | 2.77          |
| <i>Fragaria nubicola</i>              | 3333.33          | 0.310         | 3.17          |
| <i>Galium aparine</i>                 | 6666.67          | 0.595         | 7.93          |
| <i>Girardinia diversifolia</i>        | 1666.67          | 0.489         | 4.17          |
| <i>Habenaria intermedia</i>           | 1666.67          | 0.162         | 2.10          |
| <i>Leucas lanata</i>                  | 1666.67          | 0.168         | 2.11          |
| <i>Lotus corniculatus</i>             | 1666.67          | 0.163         | 2.60          |
| <i>Micromeria biflora</i>             | 6666.67          | 0.511         | 6.04          |
| <i>Myriactis nepalensis</i>           | 1666.67          | 0.256         | 2.86          |
| <i>Plantago erosa</i>                 | 8333.33          | 1.496         | 14.23         |
| <i>Plectranthus japonicus</i>         | 1666.67          | 0.776         | 5.30          |
| <i>Polygala abyssinica</i>            | 3333.33          | 0.589         | 4.12          |
| <i>Potentilla argyrophylla</i>        | 8333.33          | 1.101         | 11.15         |
| <i>Primula floribunda</i>             | 10000.00         | 2.690         | 20.21         |
| <i>Pteris cretica</i>                 | 3333.33          | 1.013         | 8.10          |
| <i>Roscoea purpurea</i>               | 8989.00          | 2.258         | 17.18         |
| <i>Rumex nepalensis</i>               | 5000.00          | 0.941         | 7.90          |
| <i>Saccharum filifolium</i>           | 5000.00          | 1.476         | 10.39         |
| <i>Silene vulgaris</i>                | 1666.67          | 0.378         | 3.20          |
| <i>Smilax glaucophylla</i>            | 6666.67          | 0.661         | 5.80          |
| <i>Thalictrum foliolosum</i>          | 5656.00          | 1.774         | 32.11         |
| <i>Trifolium pratense</i>             | 3333.33          | 0.294         | 2.96          |
| <i>Urtica dioica</i>                  | 1666.67          | 0.513         | 3.91          |
| <i>Valeriana jatamansi</i>            | 1666.67          | 0.574         | 3.74          |
| <i>Viola canescens</i>                | 13333.33         | 5.126         | 19.89         |
| <b>Total</b>                          | <b>186311.67</b> | <b>35.897</b> | <b>300.00</b> |



A perusal of Table 30 reveals that a total of 78 species of forbs were recorded in Deodar forests at different elevations. Among all the elevation zones, E<sub>1</sub> showed maximum total density (258333.33 plants/ha) and basal area (123.975 cm<sup>2</sup>/m<sup>2</sup>) of herbs having 51 species, which was followed by E<sub>2</sub> with density as 236666.66 plants/ha and basal area as 110.601 cm<sup>2</sup>/m<sup>2</sup> having 41 species. While the lowest density and basal area were recorded from E<sub>3</sub> i.e. 195000.00 plants/ha and 105.296 cm<sup>2</sup>/m<sup>2</sup> having 33 forb species.

Among different species, maximum density (13333.33 plants/ha) and basal area (6.344 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Dicliptera bupleuroides* and *Artemisia roxburghiana* respectively at E<sub>1</sub>, whereas lowest value of density (1666.67 plants/ha) was recorded for *Fumaria indica*, *Pteris cretica*, *Silene vulgaris* and others. At E<sub>2</sub>, maximum density (20000 plants/ha) and basal area (10.223 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Androsace rotundifolia*. Whereas *Thymus linearis* and *Potentilla nepalensis* showed lowest density (1666.67 plants/ha) and basal area (0.417 cm<sup>2</sup>/m<sup>2</sup>) respectively. At E<sub>3</sub>, maximum density was shown by *Ajuga bracteosa* (16666.67 plants/ha), followed by *Agrimonia pilosa* (11666.67 plants/ha). Lowest basal area of 0.434 cm<sup>2</sup>/m<sup>2</sup> was observed in *Galinsoga parviflora* (Table 30).

At E<sub>1</sub>, *Dicliptera bupleuroides* (IVI of 12.53), *Artemisia roxburghiana* (IVI of 11.63) and *Primula petiolaris* (IVI of 11.04) were the dominant, co-dominant and associate species. At E<sub>2</sub>, *Androsace rotundifolia* was dominant species with IVI of 22.93, followed by *Impatiens scabrida* with IVI of 14.55 as the co-dominant species and *Valeriana jatamansi* with IVI of 12.24 as the associate species. At elevation E<sub>3</sub>, dominant species was *Ajuga bracteosa* with IVI of 24.52, while *Dichanthium annulatum* and *Verbascum thapsus* as co-dominant (IVI as 19.01) and associate species (IVI as 18.28). Lowest IVI was recorded for *Silene vulgaris* (IVI as 2.28 at E<sub>1</sub>), *Potentilla nepalensis* (IVI as 3.55 at E<sub>2</sub>) and *Polygonum nepalense* (IVI as 2.69 at E<sub>3</sub>), indicating them as the rare species in Deodar forests (Table 30).

**Table 30: Density, basal area, and importance value index (IVI) of forbs in Deodar (*Cedrus deodara*) forests at different elevations**

| Forb Species                                | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI  |
|---------------------------------------------|---------------------|-----------------------------------------------|------|
| <b>Elevation-E<sub>1</sub> (900-1800 m)</b> |                     |                                               |      |
| <i>Adiantum venustum</i>                    | 5000.00             | 2.647                                         | 5.39 |
| <i>Agrimonia pilosa</i>                     | 3333.33             | 2.017                                         | 4.24 |
| <i>Ainsliaea aptera</i>                     | 8333.33             | 0.972                                         | 5.32 |
| <i>Ajuga bracteosa</i>                      | 8333.33             | 2.024                                         | 7.50 |

|                                   |          |       |       |
|-----------------------------------|----------|-------|-------|
| <i>Anaphalis busua</i>            | 3333.33  | 1.553 | 3.87  |
| <i>Anemone vitifolia</i>          | 5000.00  | 3.825 | 6.34  |
| <i>Angelica glauca</i>            | 3333.33  | 0.936 | 3.37  |
| <i>Artemisia roxburghiana</i>     | 10000.00 | 6.344 | 11.63 |
| <i>Carex cardiolepis</i>          | 6666.67  | 1.610 | 6.53  |
| <i>Cheilanthes dalhousiae</i>     | 3333.33  | 2.170 | 4.37  |
| <i>Chenopodium opulifolium</i>    | 3333.33  | 2.101 | 4.31  |
| <i>Corydalis govaniana</i>        | 5000.00  | 3.160 | 7.14  |
| <i>Delphinium denudatum</i>       | 5000.00  | 3.208 | 5.84  |
| <i>Dicliptera bupleuroides</i>    | 13333.33 | 2.568 | 12.53 |
| <i>Eriophorum comosum</i>         | 3333.33  | 1.445 | 3.78  |
| <i>Fagopyrum dibotry</i>          | 8333.33  | 4.926 | 9.85  |
| <i>Fragaria nubicola</i>          | 6666.67  | 0.741 | 5.83  |
| <i>Fumaria indica</i>             | 1666.67  | 2.678 | 4.13  |
| <i>Galium aparine</i>             | 5000.00  | 1.674 | 4.61  |
| <i>Girardinia diversifolia</i>    | 8333.33  | 3.819 | 7.62  |
| <i>Impatiens scabrida</i>         | 6666.67  | 3.657 | 8.18  |
| <i>Iris nepalensis</i>            | 3333.33  | 1.346 | 3.70  |
| <i>Malvastrum coromandelianum</i> | 3333.33  | 3.376 | 5.34  |
| <i>Oxalis corniculata</i>         | 5000.00  | 1.073 | 4.12  |
| <i>Pennisetum flaccidum</i>       | 3333.33  | 2.876 | 4.93  |
| <i>Phragmites communis</i>        | 3333.33  | 2.432 | 4.58  |
| <i>Plantago depressa</i>          | 3333.33  | 0.961 | 3.39  |
| <i>Polygala abyssinica</i>        | 6666.67  | 2.506 | 7.25  |
| <i>Polygonatum multiflorum</i>    | 3333.33  | 2.059 | 4.28  |
| <i>Polygonum nepalense</i>        | 8333.33  | 2.582 | 7.95  |
| <i>Potentilla fragarioides</i>    | 3333.33  | 2.463 | 4.60  |
| <i>Primula petiolaris</i>         | 10000.00 | 3.166 | 11.04 |
| <i>Pteris cretica</i>             | 1666.67  | 0.605 | 2.46  |
| <i>Ranunculus hirtellus</i>       | 3333.33  | 1.006 | 3.43  |
| <i>Roscoea purpurea</i>           | 5000.00  | 3.965 | 7.79  |
| <i>Rubia cordifolia</i>           | 6666.67  | 5.616 | 9.76  |
| <i>Rumex nepalensis</i>           | 6666.67  | 4.476 | 8.84  |
| <i>Salvia nubicola</i>            | 6666.67  | 2.984 | 7.64  |
| <i>Scutellaria scandens</i>       | 1666.67  | 2.191 | 3.74  |
| <i>Selinum candollii</i>          | 3333.33  | 1.931 | 4.17  |
| <i>Silene vulgaris</i>            | 1666.67  | 0.379 | 2.28  |
| <i>Smilax aspera</i>              | 3333.33  | 0.236 | 2.81  |
| <i>Thalictrum foliolosum</i>      | 3333.33  | 1.667 | 3.96  |
| <i>Themeda anathera</i>           | 1666.67  | 1.685 | 3.33  |
| <i>Thymus linearis</i>            | 5000.00  | 2.683 | 6.75  |
| <i>Trifolium repens</i>           | 8333.33  | 3.201 | 9.79  |
| <i>Urtica ardens</i>              | 3333.33  | 1.221 | 3.60  |
| <i>Urtica dioica</i>              | 1666.67  | 4.080 | 5.27  |

|                                               |                  |                |               |
|-----------------------------------------------|------------------|----------------|---------------|
| <i>Valeriana jatamansi</i>                    | 6666.67          | 1.855          | 6.73          |
| <i>Verbascum thapsus</i>                      | 5000.00          | 4.494          | 8.21          |
| <i>Viola canescens</i>                        | 6666.67          | 0.784          | 5.86          |
| <b>Total</b>                                  | <b>258333.33</b> | <b>123.975</b> | <b>300.00</b> |
| <b>Elevation-E<sub>2</sub> (18000-2700 m)</b> |                  |                |               |
| <i>Adiantum venustum</i>                      | 3333.33          | 1.876          | 4.87          |
| <i>Agrimonia pilosa</i>                       | 5000.00          | 1.021          | 4.79          |
| <i>Ainsliaea aptera</i>                       | 3333.33          | 1.165          | 4.23          |
| <i>Ajuga bracteosa</i>                        | 5000.00          | 1.240          | 4.99          |
| <i>Androsace rotundifolia</i>                 | 20000.00         | 10.223         | 22.93         |
| <i>Anemone vitifolia</i>                      | 5000.00          | 2.209          | 5.87          |
| <i>Angelica glauca</i>                        | 11666.67         | 3.159          | 11.29         |
| <i>Artemisia vestita</i>                      | 3333.33          | 0.818          | 3.91          |
| <i>Bergenia stracheyi</i>                     | 3333.33          | 1.028          | 4.10          |
| <i>Bistorta amplexicaulis</i>                 | 3333.33          | 2.146          | 5.12          |
| <i>Bromus mollis</i>                          | 8333.33          | 2.816          | 9.59          |
| <i>Carex cardiolepis</i>                      | 10000.00         | 2.576          | 10.07         |
| <i>Eriophorum comosum</i>                     | 6666.67          | 4.942          | 10.82         |
| <i>Fagopyrum dibotry</i>                      | 5000.00          | 1.874          | 5.56          |
| <i>Fragaria nubicola</i>                      | 10000.00         | 2.701          | 10.18         |
| <i>Galium aparine</i>                         | 3333.33          | 0.464          | 3.59          |
| <i>Halenia elliptica</i>                      | 3333.33          | 2.073          | 5.05          |
| <i>Impatiens scabrida</i>                     | 10000.00         | 7.539          | 14.55         |
| <i>Iris nepalensis</i>                        | 8333.33          | 2.380          | 9.20          |
| <i>Malva verticillata</i>                     | 5000.00          | 3.002          | 6.58          |
| <i>Pedicularis hoffmeisteri</i>               | 3333.33          | 3.246          | 6.11          |
| <i>Pennisetum flaccidum</i>                   | 8333.33          | 3.359          | 10.08         |
| <i>Phragmites communis</i>                    | 5000.00          | 2.943          | 6.53          |
| <i>Plantago depressa</i>                      | 3333.33          | 0.905          | 3.99          |
| <i>Polygonatum multiflorum</i>                | 3333.33          | 3.536          | 6.37          |
| <i>Polygonum nepalense</i>                    | 6666.67          | 3.113          | 9.16          |
| <i>Potentilla nepalensis</i>                  | 3333.33          | 0.417          | 3.55          |
| <i>Primula petiolaris</i>                     | 8333.33          | 3.495          | 10.20         |
| <i>Pteris cretica</i>                         | 3333.33          | 0.529          | 3.65          |
| <i>Ranunculus hirtellus</i>                   | 3333.33          | 2.954          | 5.85          |
| <i>Rumex nepalensis</i>                       | 8333.33          | 2.808          | 9.58          |
| <i>Salvia nubicola</i>                        | 8333.33          | 3.507          | 10.21         |
| <i>Scirpus roylei</i>                         | 5000.00          | 1.041          | 4.81          |
| <i>Silene griffithii</i>                      | 3333.33          | 1.821          | 4.82          |
| <i>Silene vulgaris</i>                        | 3333.33          | 2.312          | 5.27          |
| <i>Smilacina purpurea</i>                     | 3333.33          | 0.860          | 3.95          |
| <i>Thalictrum foliolosum</i>                  | 3333.33          | 1.184          | 4.94          |
| <i>Thymus linearis</i>                        | 1666.67          | 3.066          | 5.25          |
| <i>Urtica ardens</i>                          | 5000.00          | 6.527          | 10.46         |

|                                              |                  |                |               |
|----------------------------------------------|------------------|----------------|---------------|
| <i>Valeriana jatamansi</i>                   | 8333.33          | 5.753          | 12.24         |
| <i>Verbascum thapsus</i>                     | 5000.00          | 1.974          | 5.65          |
| <b>Total</b>                                 | <b>236666.66</b> | <b>110.601</b> | <b>300.00</b> |
| <b>Elevation-E<sub>3</sub> (2700-3600 m)</b> |                  |                |               |
| <i>Achyranthes bidentata</i>                 | 3333.33          | 1.245          | 4.18          |
| <i>Agrimonia pilosa</i>                      | 11666.67         | 5.774          | 15.32         |
| <i>Ajuga bracteosa</i>                       | 16666.67         | 10.027         | 24.52         |
| <i>Anaphalis busua</i>                       | 8333.33          | 3.524          | 11.51         |
| <i>Apluda mutica</i>                         | 10000.00         | 3.745          | 12.56         |
| <i>Artemisia vestita</i>                     | 5000.00          | 2.772          | 7.80          |
| <i>Bergenia ciliata</i>                      | 6666.67          | 3.012          | 8.86          |
| <i>Cheilanthes albomarginata</i>             | 1666.67          | 1.340          | 3.44          |
| <i>Cheilanthes brevifrons</i>                | 1666.67          | 0.877          | 3.00          |
| <i>Chenopodium ambrosioides</i>              | 6666.67          | 7.684          | 13.30         |
| <i>Cissampelos pareira</i>                   | 3333.33          | 0.380          | 4.69          |
| <i>Cynodon dactylon</i>                      | 6666.67          | 0.811          | 6.77          |
| <i>Dichanthium annulatum</i>                 | 13333.33         | 5.972          | 19.01         |
| <i>Digitaria sanguinalis</i>                 | 10000.00         | 4.324          | 13.11         |
| <i>Dryopteris caroli</i>                     | 1666.67          | 1.321          | 3.42          |
| <i>Echinochloa crusgalli</i>                 | 5000.00          | 4.332          | 9.28          |
| <i>Eriophorum comosum</i>                    | 3333.33          | 1.835          | 6.08          |
| <i>Fumaria indica</i>                        | 1666.67          | 0.958          | 3.08          |
| <i>Galinsoga parviflora</i>                  | 3333.33          | 0.434          | 3.41          |
| <i>Galium aparine</i>                        | 5000.00          | 0.559          | 5.70          |
| <i>Girardinia diversifolia</i>               | 6666.67          | 5.785          | 12.83         |
| <i>Malvastrum coromandelianum</i>            | 8333.33          | 5.904          | 13.77         |
| <i>Oxalis corniculata</i>                    | 5000.00          | 1.021          | 6.14          |
| <i>Phalaris paradoxa</i>                     | 1666.67          | 1.420          | 3.51          |
| <i>Plantago depressa</i>                     | 6666.67          | 2.816          | 10.01         |
| <i>Polygala abyssinica</i>                   | 8333.33          | 3.044          | 11.06         |
| <i>Polygonum nepalense</i>                   | 1666.67          | 0.548          | 2.69          |
| <i>Rumex nepalensis</i>                      | 3333.33          | 3.443          | 7.60          |
| <i>Thalictrum foliolosum</i>                 | 6666.67          | 3.259          | 7.76          |
| <i>Themeda anathera</i>                      | 3333.33          | 0.600          | 3.57          |
| <i>Urtica dioica</i>                         | 3333.33          | 5.902          | 14.27         |
| <i>Verbascum thapsus</i>                     | 10000.00         | 8.370          | 18.28         |
| <i>Viola canescens</i>                       | 5000.00          | 2.258          | 9.48          |
| <b>Total</b>                                 | <b>195000.00</b> | <b>105.296</b> | <b>300.00</b> |

A perusal of Table 5 reveals that a total of 103 species of forbs were recorded in western mixed coniferous forests at different elevations (Table 31). Among three elevations, E<sub>1</sub> exhibited maximum total density (278333.33 plants/ha) and basal area (97.732 cm<sup>2</sup>/m<sup>2</sup>) for 67 species, followed by E<sub>2</sub> with density and basal area of herbs as 258333.33 plants/ha and

71.942 cm<sup>2</sup>/m<sup>2</sup>, respectively having 60 species. While the lowest density and basal area was recorded in E<sub>3</sub> i.e. 236666.67 plants/ha and 61.836 cm<sup>2</sup>/m<sup>2</sup> with 54 forb species.

Among forbs maximum density (18333.33 plants/ha) and basal area (6.766 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Fragaria nubicola* at E<sub>1</sub>, whereas lowest density (1666.67 plants/ha) was observed in *Urtica ardens*, *Trifolium repens*, *Sonchus asper*, *Ranunculus laetus* *Polystichum neolobatum*, *Phragmites communis*, *Nepeta laevigata* and *Duchesnea indica*. At E<sub>2</sub>, *Viola canescens* exhibited maximum density (18333.33 plants/ha) and basal area (4.257 cm<sup>2</sup>/m<sup>2</sup>). Whereas each of *Salvia nubicola*, *Polygonatum cirrhifolium* and *Plantago erosa* exhibited lowest density (1666.67 plants/ha). While lowest basal area (0.202 cm<sup>2</sup>/m<sup>2</sup>) was observed for *Dioscorea melanophyma*. At E<sub>3</sub>, maximum density (15000.00 plants/ha) and basal area (6.147 cm<sup>2</sup>/m<sup>2</sup>) exhibited in *Thalictrum foliolosum* and *Plantago erosa*, respectively. Lowest density (1666.67 plants/ha) was observed in *Aquilegia fragrans*, *Carex remota*, *Gypsophila cerastioides*, *Bistorta amplexicaulis*, *Corydalis govaniana*, *Fagopyrum dibotrys*, *Phragmites communis*, *Podophyllum hexandrum*, *Polygonatum cirrhifolium*, *Polygonum nepalense*, *Primula denticulate*, *Roscoea purpurea*, *Salvia nubicola*, *Rumex nepalensis*, *Senecio chrysanthemoides*, *Stellaria media* and *Thymus linearis*, whereas least basal area of 0.094 cm<sup>2</sup>/m<sup>2</sup> was observed in *Podophyllum hexandrum* (Table 31).

Among all the species, *Fragaria nubicola* showed highest IVI of 20.29, followed by *Artemisia vestita* with IVI of 15.28 and *Viola canescens* with IVI of 13.34 indicating them as dominant, co-dominant and associate species in western mixed coniferous forests. At E<sub>1</sub>, *Fragaria nubicola* (IVI of 20.29), *Artemisia vestita* (IVI of 15.28) and *Galium aparine* (IVI of 12.55) constituted the dominant, co-dominant and associate species. At E<sub>2</sub>, *Viola canescens* was the dominant species with IVI of 13.34, followed by *Plectranthus japonicus* with IVI of 12.38 as the co-dominant species and *Nepeta laevigata* with IVI of 10.65 as the associate species. At elevation E<sub>3</sub>, dominant species was *Thalictrum foliolosum* with IVI of 17.79, where *Plantago erosa* and *Carduus nutans* were co-dominant (IVI as 15.58) and associate species (IVI as 14.87). Lowest IVI was noted for *Trifolium repens* (IVI as 2.22 at E<sub>1</sub>), *Astilbe rivularis* (IVI as 2.73 at E<sub>2</sub>) and *Podophyllum hexandrum* (IVI as 1.80 at E<sub>3</sub>), indicating them as the rare species in western mixed coniferous forests (Table 31).

**Table 31: Density, basal area, and importance value index (IVI) of forbs in western mixed coniferous forests at different elevations**

| Forb Species                                 | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|----------------------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation-E<sub>1</sub> (1200-2100 m)</b> |                     |                                               |       |
| <i>Achyranthes bidentata</i>                 | 3333.33             | 0.425                                         | 2.76  |
| <i>Agrimonia pilosa</i>                      | 3333.33             | 0.827                                         | 3.17  |
| <i>Ajuga bracteosa</i>                       | 3333.33             | 0.950                                         | 3.30  |
| <i>Androsace lanuginosa</i>                  | 3333.33             | 1.452                                         | 3.81  |
| <i>Apluda mutica</i>                         | 3333.33             | 0.842                                         | 3.19  |
| <i>Arisaema flavum</i>                       | 3333.33             | 1.354                                         | 3.71  |
| <i>Artemisia indica</i>                      | 3333.33             | 1.870                                         | 4.24  |
| <i>Artemisia roxburghiana</i>                | 3333.33             | 1.364                                         | 3.72  |
| <i>Artemisia vestita</i>                     | 15000.00            | 4.144                                         | 15.28 |
| <i>Asplenium dalhousiae</i>                  | 3333.33             | 3.212                                         | 5.61  |
| <i>Astilbe rivularis</i>                     | 3333.33             | 0.920                                         | 3.27  |
| <i>Bergenia ciliata</i>                      | 3333.33             | 0.865                                         | 3.21  |
| <i>Bupleurum falcatum</i>                    | 3333.33             | 0.780                                         | 3.13  |
| <i>Capillipedium assimile</i>                | 3333.33             | 0.681                                         | 3.02  |
| <i>Cirsium wallichii</i>                     | 3333.33             | 4.228                                         | 6.65  |
| <i>Cynoglossum glochidiatum</i>              | 3333.33             | 0.726                                         | 3.07  |
| <i>Dioscorea deltoidea</i>                   | 3333.33             | 0.222                                         | 2.55  |
| <i>Dioscorea melanophyllum</i>               | 5000.00             | 0.276                                         | 3.20  |
| <i>Duchesnea indica</i>                      | 1666.67             | 1.062                                         | 2.82  |
| <i>Erigeron bellidioides</i>                 | 3333.33             | 1.664                                         | 4.03  |
| <i>Erigeron multicaulis</i>                  | 3333.33             | 0.378                                         | 2.71  |
| <i>Eriophorum comosum</i>                    | 5000.00             | 0.806                                         | 3.75  |
| <i>Fagopyrum dibotrys</i>                    | 13333.33            | 2.701                                         | 12.07 |
| <i>Fragaria nubicola</i>                     | 18333.33            | 6.766                                         | 20.29 |
| <i>Galium aparine</i>                        | 11666.67            | 3.753                                         | 12.55 |
| <i>Geranium lucidum</i>                      | 3333.33             | 1.692                                         | 4.06  |
| <i>Girardinia diversifolia</i>               | 3333.33             | 1.907                                         | 4.28  |
| <i>Habenaria intermedia</i>                  | 3333.33             | 0.505                                         | 2.84  |
| <i>Halenia elliptica</i>                     | 3333.33             | 0.573                                         | 2.91  |
| <i>Iris nepalensis</i>                       | 6666.67             | 1.794                                         | 6.49  |
| <i>Koeleria cristata</i>                     | 3333.33             | 1.866                                         | 4.24  |
| <i>Lamium album</i>                          | 3333.33             | 1.721                                         | 4.09  |
| <i>Lotus corniculatus</i>                    | 3333.33             | 0.397                                         | 2.73  |
| <i>Malvastrum coromandelianum</i>            | 3333.33             | 1.858                                         | 4.23  |
| <i>Mentha longifolia</i>                     | 3333.33             | 1.171                                         | 3.53  |
| <i>Nasturtium officinale</i>                 | 3333.33             | 3.511                                         | 5.92  |
| <i>Nepeta laevigata</i>                      | 1666.67             | 0.732                                         | 2.48  |
| <i>Oenothera rosea</i>                       | 3333.33             | 0.788                                         | 3.13  |
| <i>Origanum vulgare</i>                      | 3333.33             | 1.951                                         | 4.32  |
| <i>Oxalis corniculata</i>                    | 11666.67            | 2.865                                         | 10.51 |

|                                              |                  |               |               |
|----------------------------------------------|------------------|---------------|---------------|
| <i>Pennisetum flaccidum</i>                  | 3333.33          | 1.638         | 4.00          |
| <i>Phragmites communis</i>                   | 1666.67          | 1.656         | 3.43          |
| <i>Pimpinella diversifolia</i>               | 3333.33          | 1.055         | 3.41          |
| <i>Plantago erosa</i>                        | 3333.33          | 1.232         | 3.59          |
| <i>Plectranthus japonicus</i>                | 3333.33          | 0.866         | 3.21          |
| <i>Polygala abyssinica</i>                   | 3333.33          | 1.607         | 3.97          |
| <i>Polygonatum cirrhifolium</i>              | 3333.33          | 4.253         | 6.68          |
| <i>Polygonatum multiflorum</i>               | 3333.33          | 0.854         | 3.20          |
| <i>Polygonum nepalense</i>                   | 3333.33          | 1.565         | 3.93          |
| <i>Polystichum neolobatum</i>                | 1666.67          | 3.025         | 4.83          |
| <i>Potentilla nepalensis</i>                 | 3333.33          | 0.985         | 3.33          |
| <i>Pteris cretica</i>                        | 3333.33          | 0.450         | 2.79          |
| <i>Ranunculus laetus</i>                     | 1666.67          | 1.640         | 3.41          |
| <i>Rumex nepalensis</i>                      | 3333.33          | 0.732         | 3.08          |
| <i>Salvia lanata</i>                         | 3333.33          | 0.547         | 2.89          |
| <i>Smilax aspera</i>                         | 3333.33          | 0.500         | 2.84          |
| <i>Sonchus asper</i>                         | 1666.67          | 0.518         | 2.26          |
| <i>Stellaria media</i>                       | 3333.33          | 0.655         | 3.59          |
| <i>Thalictrum foliolosum</i>                 | 6666.67          | 1.782         | 6.48          |
| <i>Themeda anathera</i>                      | 3333.33          | 0.380         | 2.72          |
| <i>Thymus linearis</i>                       | 3333.33          | 0.435         | 2.77          |
| <i>Trichosanthes bracteata</i>               | 3333.33          | 0.200         | 2.53          |
| <i>Trifolium repens</i>                      | 1666.67          | 0.473         | 2.22          |
| <i>Urtica ardens</i>                         | 1666.67          | 1.393         | 3.16          |
| <i>Urtica dioica</i>                         | 3333.33          | 0.862         | 3.21          |
| <i>Verbascum thapsus</i>                     | 8333.33          | 1.748         | 8.17          |
| <i>Viola canescens</i>                       | 3333.33          | 1.084         | 3.44          |
| <b>Total</b>                                 | <b>278333.33</b> | <b>97.732</b> | <b>300.00</b> |
| <b>Elevation-E<sub>2</sub> (2100-3000 m)</b> |                  |               |               |
| <i>Adiantum venustum</i>                     | 6666.67          | 1.852         | 9.14          |
| <i>Agrimonia pilosa</i>                      | 3333.33          | 1.167         | 4.24          |
| <i>Ainsliaea aptera</i>                      | 3333.33          | 1.053         | 4.08          |
| <i>Ajuga bracteosa</i>                       | 3333.33          | 1.170         | 4.24          |
| <i>Androsace sarmentosa</i>                  | 5000.00          | 0.540         | 4.01          |
| <i>Anemone obtusiloba</i>                    | 3333.33          | 0.709         | 3.60          |
| <i>Angelica glauca</i>                       | 3333.33          | 1.057         | 4.08          |
| <i>Arisaema flavum</i>                       | 3333.33          | 0.780         | 3.70          |
| <i>Artemisia indica</i>                      | 6666.67          | 2.201         | 8.29          |
| <i>Artemisia roxburghiana</i>                | 3333.33          | 1.200         | 4.28          |
| <i>Asplenium dalhousiae</i>                  | 3333.33          | 0.838         | 3.78          |
| <i>Astilbe rivularis</i>                     | 1666.67          | 0.542         | 2.73          |
| <i>Bergenia ciliata</i>                      | 3333.33          | 1.104         | 4.15          |
| <i>Bromus mollis</i>                         | 3333.33          | 0.449         | 3.24          |
| <i>Carduus nutans</i>                        | 3333.33          | 1.388         | 4.55          |

|                                 |          |       |       |
|---------------------------------|----------|-------|-------|
| <i>Carex remota</i>             | 3333.33  | 0.982 | 3.98  |
| <i>Clinopodium vulgare</i>      | 3333.33  | 0.735 | 3.64  |
| <i>Corydalis govaniana</i>      | 6666.67  | 1.112 | 5.44  |
| <i>Dioscorea deltoidea</i>      | 3333.33  | 0.364 | 3.12  |
| <i>Dioscorea melanophyma</i>    | 3333.33  | 0.208 | 4.24  |
| <i>Erigeron bellidioides</i>    | 3333.33  | 0.452 | 3.24  |
| <i>Erigeron multicaulis</i>     | 3333.33  | 1.013 | 4.02  |
| <i>Eriophorum comosum</i>       | 3333.33  | 1.082 | 4.12  |
| <i>Fagopyrum dibotrys</i>       | 3333.33  | 0.413 | 3.19  |
| <i>Fragaria nubicola</i>        | 6666.67  | 2.473 | 7.33  |
| <i>Geranium wallichianum</i>    | 3333.33  | 0.780 | 3.70  |
| <i>Girardinia diversifolia</i>  | 3333.33  | 0.426 | 4.54  |
| <i>Habenaria intermedia</i>     | 3333.33  | 0.645 | 3.51  |
| <i>Halenia elliptica</i>        | 11666.67 | 2.659 | 9.52  |
| <i>Heracleum candicans</i>      | 3333.33  | 1.086 | 4.13  |
| <i>Iris nepalensis</i>          | 3333.33  | 0.866 | 6.49  |
| <i>Koeleria cristata</i>        | 3333.33  | 0.552 | 3.38  |
| <i>Lamium album</i>             | 6666.67  | 1.376 | 5.81  |
| <i>Mentha longifolia</i>        | 5000.00  | 1.350 | 5.13  |
| <i>Nepeta laevigata</i>         | 11666.67 | 2.514 | 10.65 |
| <i>Origanum vulgare</i>         | 3333.33  | 0.650 | 3.52  |
| <i>Oxalis corniculata</i>       | 3333.33  | 0.612 | 6.13  |
| <i>Pennisetum flaccidum</i>     | 3333.33  | 0.899 | 3.87  |
| <i>Plantago erosa</i>           | 1666.67  | 1.755 | 4.41  |
| <i>Plectranthus japonicus</i>   | 13333.33 | 3.561 | 12.38 |
| <i>Podophyllum hexandrum</i>    | 3333.33  | 0.775 | 3.69  |
| <i>Polygonatum cirrhifolium</i> | 1666.67  | 1.665 | 8.29  |
| <i>Potentilla argyrophylla</i>  | 3333.33  | 0.812 | 3.74  |
| <i>Potentilla nepalensis</i>    | 3333.33  | 1.239 | 4.34  |
| <i>Pteris cretica</i>           | 3333.33  | 0.965 | 3.96  |
| <i>Ranunculus hirtellus</i>     | 3333.33  | 2.612 | 6.25  |
| <i>Roscoea purpurea</i>         | 3333.33  | 1.782 | 5.09  |
| <i>Rumex nepalensis</i>         | 3333.33  | 0.982 | 3.98  |
| <i>Salvia nubicola</i>          | 1666.67  | 0.898 | 3.22  |
| <i>Selinum vaginatum</i>        | 3333.33  | 0.970 | 3.96  |
| <i>Smilacina purpurea</i>       | 3333.33  | 1.416 | 5.23  |
| <i>Smilax vaginata</i>          | 3333.33  | 0.867 | 3.82  |
| <i>Sonchus asper</i>            | 3333.33  | 1.039 | 5.39  |
| <i>Stellaria media</i>          | 3333.33  | 1.422 | 4.59  |
| <i>Thalictrum foliolosum</i>    | 5000.00  | 0.983 | 4.62  |
| <i>Thymus linearis</i>          | 3333.33  | 0.846 | 3.79  |
| <i>Trifolium repens</i>         | 3333.33  | 1.636 | 6.22  |
| <i>Urtica ardens</i>            | 5000.00  | 0.923 | 4.54  |
| <i>Verbascum thapsus</i>        | 3333.33  | 1.239 | 4.34  |



|                                              |                  |               |               |
|----------------------------------------------|------------------|---------------|---------------|
| <i>Viola canescens</i>                       | 18333.33         | 4.257         | 13.34         |
| <b>Total</b>                                 | <b>258333.33</b> | <b>71.942</b> | <b>300.00</b> |
| <b>Elevation-E<sub>3</sub> (3000-3900 m)</b> |                  |               |               |
| <i>Androsace sarmentosa</i>                  | 3333.33          | 0.186         | 2.64          |
| <i>Angelica glauca</i>                       | 1666.67          | 0.299         | 2.13          |
| <i>Aquilegia fragrans</i>                    | 1666.67          | 0.331         | 4.09          |
| <i>Artemisia roxburghiana</i>                | 5000.00          | 1.119         | 5.80          |
| <i>Asplenium dalhousiae</i>                  | 5000.00          | 3.294         | 9.32          |
| <i>Bergenia stracheyi</i>                    | 8333.33          | 2.21          | 9.90          |
| <i>Bistorta amplexicaulis</i>                | 1666.67          | 0.595         | 2.61          |
| <i>Bromus mollis</i>                         | 6666.67          | 0.515         | 5.52          |
| <i>Carduus nutans</i>                        | 8333.33          | 4.69          | 14.87         |
| <i>Carex breviculmis</i>                     | 10000.00         | 2.448         | 11.93         |
| <i>Carex cardiolepis</i>                     | 5000.00          | 1.52          | 6.45          |
| <i>Carex remota</i>                          | 1666.67          | 0.539         | 2.52          |
| <i>Clinopodium vulgare</i>                   | 5000.00          | 0.685         | 6.05          |
| <i>Corydalis govaniana</i>                   | 1666.67          | 0.674         | 2.74          |
| <i>Dioscorea deltoidea</i>                   | 5000.00          | 0.527         | 4.84          |
| <i>Eriophorum comosum</i>                    | 3333.33          | 0.872         | 4.70          |
| <i>Fagopyrum dibotrys</i>                    | 1666.67          | 0.222         | 2.01          |
| <i>Fragaria nubicola</i>                     | 3333.33          | 1.239         | 5.30          |
| <i>Galium aparine</i>                        | 8333.33          | 1.415         | 8.62          |
| <i>Gypsophila cerastioides</i>               | 1666.67          | 0.168         | 1.92          |
| <i>Halenia elliptica</i>                     | 3333.33          | 1.026         | 4.95          |
| <i>Heracleum candicans</i>                   | 3333.33          | 0.264         | 2.77          |
| <i>Impatiens scabrida</i>                    | 3333.33          | 0.315         | 2.85          |
| <i>Koeleria cristata</i>                     | 6666.67          | 1.126         | 6.50          |
| <i>Lotus corniculatus</i>                    | 8333.33          | 1.96          | 8.55          |
| <i>Mentha longifolia</i>                     | 5000.00          | 1.423         | 6.29          |
| <i>Origanum vulgare</i>                      | 3333.33          | 0.519         | 4.13          |
| <i>Pedicularis hoffmeister</i>               | 5000.00          | 2.419         | 7.90          |
| <i>Pennisetum flaccidum</i>                  | 6666.67          | 1.252         | 7.66          |
| <i>Phragmites communis</i>                   | 1666.67          | 0.474         | 2.41          |
| <i>Plantago erosa</i>                        | 6666.67          | 6.147         | 15.58         |
| <i>Podophyllum hexandrum</i>                 | 1666.67          | 0.094         | 1.80          |
| <i>Polygonatum cirrhifolium</i>              | 1666.67          | 0.94          | 3.17          |
| <i>Polygonatum verticillatum</i>             | 5000.00          | 1.144         | 4.89          |
| <i>Polygonum nepalense</i>                   | 1666.67          | 0.605         | 2.63          |
| <i>Primula denticulata</i>                   | 1666.67          | 0.295         | 2.12          |
| <i>Primula petiolaris</i>                    | 3333.33          | 0.821         | 4.62          |
| <i>Ranunculus hirtellus</i>                  | 3333.33          | 0.592         | 4.25          |
| <i>Roscoea purpurea</i>                      | 1666.67          | 0.69          | 2.76          |
| <i>Rumex nepalensis</i>                      | 1666.67          | 0.249         | 2.05          |
| <i>Salvia nubicola</i>                       | 1666.67          | 0.51          | 2.47          |

|                                   |                  |               |               |
|-----------------------------------|------------------|---------------|---------------|
| <i>Selinum candollii</i>          | 3333.33          | 0.152         | 2.59          |
| <i>Selinum vaginatum</i>          | 6666.67          | 0.689         | 5.80          |
| <i>Senecio chrysanthemoides</i>   | 1666.67          | 0.159         | 1.90          |
| <i>Sibbaldia cuneata</i>          | 10000.00         | 1.659         | 11.61         |
| <i>Smilacina purpurea</i>         | 3333.33          | 0.518         | 3.18          |
| <i>Sonchus asper</i>              | 10000.00         | 1.68          | 10.69         |
| <i>Stellaria media</i>            | 1666.67          | 0.326         | 2.17          |
| <i>Thalictrum foliolosum</i>      | 15000.00         | 3.604         | 17.79         |
| <i>Thamnocalamus spathiflorus</i> | 5000.00          | 0.448         | 4.71          |
| <i>Thymus linearis</i>            | 1666.67          | 0.321         | 2.17          |
| <i>Urtica ardens</i>              | 5000.00          | 1.992         | 7.21          |
| <i>Verbascum thapsus</i>          | 3333.33          | 1.65          | 5.96          |
| <i>Vicatia coniifolia</i>         | 5000.00          | 2.224         | 9.93          |
| <b>Total</b>                      | <b>236666.67</b> | <b>61.836</b> | <b>300.00</b> |

Data presented in Table 32 reveals that 91 forb species were recorded in moist temperate lower deciduous forests at different elevations. Maximum number of species were recorded from E<sub>1</sub> (49) which was followed by E<sub>2</sub> (46) and least were reported from E<sub>3</sub> (40). Among three elevations, at E<sub>1</sub> highest forb density (255000.00 plants/ha) and basal area (50.714 cm<sup>2</sup>/m<sup>2</sup>) was recorded followed by E<sub>2</sub> with forb density as 235000.00 plants/hectare with basal area of 45.707 cm<sup>2</sup>/m<sup>2</sup>. While the lowest values for density (198333.33 plants/ha) and basal area (40.080 cm<sup>2</sup>/m<sup>2</sup>) of forbs was recorded at elevation E<sub>3</sub>.

A perusal of Table reveals that at E<sub>1</sub>, maximum density (18333.33 plants/ha) of an individual forb was recorded in *Ainsliaea aptera* followed by *Ranunculus laetus* (15000.00 plants/ha). While very low density (1666.67 plants/ha) was recorded for species such as *Adiantum venustum*, *Ajuga bracteosa*, *Arisaema flavum*, *Carex cardiolepis*, *Halenia elliptica*, *Lamium album*, *Phragmites communis*, *Potentilla leschenaultiana*, *Scrophularia himalensis* and *Smilax glaucophylla*. At E<sub>1</sub> highest basal area was recorded for *Ranunculus laetus* (3.516 cm<sup>2</sup>/m<sup>2</sup>), while the least basal area was observed for *Vicatia coniifolia* (0.083 cm<sup>2</sup>/m<sup>2</sup>). At E<sub>2</sub> highest density of (15000.00 plants/ha) was recorded for *Carex remota*, while lowest density of 1666.67 plants/ha was recorded for *Ainsliaea aptera*, *Angelica glauca*, *Bergenia stracheyi*, *Erigeron bellidioides*, *Gypsophila cerastioides*, *Lotus corniculatus*, *Potentilla atrosanguinea*, *Selinum candollii* and *Senecio chrysanthemoides*. At E<sub>2</sub>, highest basal area was observed for *Bistorta amplexicaulis* (3.304 cm<sup>2</sup>/m<sup>2</sup>), while lowest basal area (0.171 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Lotus corniculatus*. At E<sub>3</sub>, *Oenothera rosea* and *Salvia lanata* recorded highest density (11666.67 plants/ha). Whereas lowest density of 1666.67 plants/ha was recorded for species such as *Fragaria nubicola*, *Urtica ardens*, *Artemisia roxburghiana*, *Gerbera gossypina*,

*Polygonum hydropiper* *Potentilla fragarioides*, *Scutellaria scandens*, *Silene vulgaris* and *Valeriana jatamansi*. At E<sub>3</sub> highest basal area was observed for *Salvia lanata* (2.775 cm<sup>2</sup>/m<sup>2</sup>), which was followed by *Fragaria nubicola* (2.612 cm<sup>2</sup>/m<sup>2</sup>). While lowest basal area was recorded for *Swertia cordata* (0.068 cm<sup>2</sup>/m<sup>2</sup>) (Table 32)

*Ainsliaea aptera* was most dominant forb species at E<sub>1</sub> with highest IVI of 19.41 and least IVI was recorded for *Lamium album* (2.17). *Carex remota* was most dominant herb species at E<sub>2</sub> with highest IVI of 15.45, *Verbascum thapsus* with an IVI as 13.58 was the codominant species. Whereas *Lotus corniculatus* was rare species with least value for IVI as 1.99. At E<sub>3</sub>, *Salvia lanata* was observed as most dominant forb species with highest IVI of 18.09, which was co-dominated by *Oenothera rosea* with IVI as 14.26. Whereas *Polygonum hydropiper* was observed as least dominant forb species with an importance value index of 2.52 (Table 32).

**Table 32: Density, basal area, and importance value index (IVI) of forbs in moist temperate lower deciduous forests at different elevations**

| Forb Species                                 | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|----------------------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (500-1300 m)</b> |                     |                                               |       |
| <i>Ainsliaea aptera</i>                      | 18333.33            | 3.185                                         | 19.41 |
| <i>Adiantum venustum</i>                     | 1666.67             | 0.736                                         | 3.11  |
| <i>Agrimonia pilosa</i>                      | 5000.00             | 1.505                                         | 6.93  |
| <i>Ajuga bracteosa</i>                       | 1666.67             | 1.007                                         | 3.65  |
| <i>Androsace lanuginosa</i>                  | 3333.33             | 0.635                                         | 2.28  |
| <i>Androsace sarmentosa</i>                  | 3333.33             | 0.518                                         | 4.32  |
| <i>Anemone obtusiloba</i>                    | 5000.00             | 0.364                                         | 5.65  |
| <i>Arctium lappa</i>                         | 8333.33             | 0.899                                         | 8.00  |
| <i>Arisaema flavum</i>                       | 1666.67             | 0.449                                         | 2.54  |
| <i>Bupleurum hamiltonii</i>                  | 11666.67            | 1.200                                         | 10.88 |
| <i>Carex breviculmis</i>                     | 1666.67             | 0.391                                         | 2.42  |
| <i>Carex cardiolepis</i>                     | 1666.67             | 0.415                                         | 2.47  |
| <i>Carex remota</i>                          | 3333.33             | 0.366                                         | 3.01  |
| <i>Chenopodium opulifolium</i>               | 8333.33             | 1.853                                         | 9.90  |
| <i>Corydalis govaniana</i>                   | 8333.33             | 1.373                                         | 8.95  |
| <i>Dicliptera bupleuroides</i>               | 10000.00            | 2.119                                         | 11.08 |
| <i>Dioscorea deltoidea</i>                   | 3333.33             | 0.202                                         | 3.69  |
| <i>Fagopyrum dibotrys</i>                    | 3333.33             | 0.307                                         | 2.90  |
| <i>Galium aparine</i>                        | 10000.00            | 0.937                                         | 9.72  |
| <i>Galium asperuloides</i>                   | 3333.33             | 0.382                                         | 3.04  |
| <i>Girardinia diversifolia</i>               | 3333.33             | 0.312                                         | 2.91  |

|                                               |                  |               |               |
|-----------------------------------------------|------------------|---------------|---------------|
| <i>Habenaria intermedia</i>                   | 3333.33          | 0.461         | 3.20          |
| <i>Halenia elliptica</i>                      | 1666.67          | 0.370         | 2.38          |
| <i>Heracleum candicans</i>                    | 5000.00          | 0.777         | 5.47          |
| <i>Impatiens scabrida</i>                     | 5000.00          | 0.578         | 5.08          |
| <i>Iris nepalensis</i>                        | 5000.00          | 1.558         | 7.03          |
| <i>Lamium album</i>                           | 1666.67          | 0.263         | 2.17          |
| <i>Nepeta laevigata</i>                       | 6666.67          | 1.277         | 8.11          |
| <i>Phragmites communis</i>                    | 1666.67          | 0.339         | 2.32          |
| <i>Plantago depressa</i>                      | 3333.33          | 0.393         | 3.07          |
| <i>Polygala abyssinica</i>                    | 5000.00          | 1.176         | 6.27          |
| <i>Polygonatum cirrhifolium</i>               | 5000.00          | 1.426         | 6.77          |
| <i>Polygonatum multiflorum</i>                | 5000.00          | 1.210         | 6.34          |
| <i>Polygonatum verticillatum</i>              | 3333.33          | 0.449         | 3.18          |
| <i>Potentilla fragarioides</i>                | 10000.00         | 2.320         | 12.48         |
| <i>Potentilla leschenaultiana</i>             | 1666.67          | 0.618         | 2.87          |
| <i>Primula denticulata</i>                    | 5000.00          | 0.989         | 5.90          |
| <i>Ranunculus hirtellus</i>                   | 6666.67          | 1.599         | 7.76          |
| <i>Ranunculus laetus</i>                      | 15000.00         | 3.516         | 17.79         |
| <i>Roscoeia purpurea</i>                      | 10000.00         | 3.160         | 14.16         |
| <i>Rumex nepalensis</i>                       | 5000.00          | 2.386         | 8.69          |
| <i>Salvia nubicola</i>                        | 5000.00          | 0.803         | 6.81          |
| <i>Scrophularia himalensis</i>                | 1666.67          | 2.354         | 6.34          |
| <i>Silene griffithii</i>                      | 3333.33          | 0.305         | 2.89          |
| <i>Smilax glaucophylla</i>                    | 1666.67          | 0.305         | 2.25          |
| <i>Stellaria media</i>                        | 3333.33          | 0.476         | 3.23          |
| <i>Thymus linearis</i>                        | 11666.67         | 0.963         | 11.41         |
| <i>Verbascum thapsus</i>                      | 3333.33          | 1.405         | 6.73          |
| <i>Vicatia conifolia</i>                      | 3333.33          | 0.083         | 2.45          |
| <b>Total</b>                                  | <b>255000.00</b> | <b>50.714</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (1300-2000 m)</b> |                  |               |               |
| <i>Adiantum venustum</i>                      | 3333.33          | 0.411         | 3.21          |
| <i>Ainsliaea aptera</i>                       | 1666.67          | 0.726         | 4.14          |
| <i>Ajuga bracteosa</i>                        | 6666.67          | 1.880         | 9.67          |
| <i>Anaphalis contorta</i>                     | 6666.67          | 1.568         | 8.99          |
| <i>Androsace lanuginosa</i>                   | 10000.00         | 0.693         | 10.31         |
| <i>Androsace sarmentosa</i>                   | 3333.33          | 0.886         | 4.25          |
| <i>Angelica glauca</i>                        | 1666.67          | 0.710         | 3.17          |
| <i>Bergenia stracheyi</i>                     | 1666.67          | 0.281         | 2.24          |
| <i>Bistorta amplexicaulis</i>                 | 5000.00          | 3.304         | 12.09         |
| <i>Carex breviculmis</i>                      | 10000.00         | 1.057         | 9.26          |
| <i>Carex remota</i>                           | 15000.00         | 2.087         | 15.45         |
| <i>Chenopodium opulifolium</i>                | 5000.00          | 1.006         | 7.06          |
| <i>Clinopodium vulgare</i>                    | 3333.33          | 0.479         | 3.36          |

|                                               |                  |               |               |
|-----------------------------------------------|------------------|---------------|---------------|
| <i>Erigeron bellidioides</i>                  | 1666.67          | 0.334         | 2.35          |
| <i>Fagopyrum dibotrys</i>                     | 8333.33          | 1.036         | 9.44          |
| <i>Fragaria nubicola</i>                      | 8333.33          | 0.821         | 8.97          |
| <i>Galium aparine</i>                         | 8333.33          | 1.831         | 12.11         |
| <i>Geranium lucidum</i>                       | 3333.33          | 0.299         | 2.97          |
| <i>Gypsophila cerastioides</i>                | 1666.67          | 0.243         | 2.15          |
| <i>Halenia elliptica</i>                      | 5000.00          | 0.729         | 5.53          |
| <i>Heracleum candicans</i>                    | 8333.33          | 2.145         | 11.87         |
| <i>Lotus corniculatus</i>                     | 1666.67          | 0.171         | 1.99          |
| <i>Origanum vulgare</i>                       | 3333.33          | 0.730         | 4.84          |
| <i>Pedicularis hoffmeisteri</i>               | 5000.00          | 0.985         | 6.09          |
| <i>Phragmites communis</i>                    | 5000.00          | 1.106         | 6.35          |
| <i>Plantago erosa</i>                         | 3333.33          | 1.014         | 4.53          |
| <i>Plectranthus japonicus</i>                 | 6666.67          | 1.073         | 7.90          |
| <i>Podophyllum hexandrum</i>                  | 3333.33          | 0.243         | 2.85          |
| <i>Polygonatum verticillatum</i>              | 6666.67          | 1.490         | 8.81          |
| <i>Potentilla atrosanguinea</i>               | 1666.67          | 0.304         | 2.29          |
| <i>Primula denticulata</i>                    | 3333.33          | 0.211         | 2.78          |
| <i>Pteris cretica</i>                         | 5000.00          | 1.661         | 8.50          |
| <i>Ranunculus hirtellus</i>                   | 3333.33          | 0.932         | 4.35          |
| <i>Roscoea purpurea</i>                       | 3333.33          | 0.848         | 5.10          |
| <i>Salvia nubicola</i>                        | 5000.00          | 0.991         | 6.10          |
| <i>Selinum candollii</i>                      | 1666.67          | 0.421         | 2.54          |
| <i>Senecio chrysanthemoides</i>               | 1666.67          | 0.214         | 2.09          |
| <i>Senecio nudicaulis</i>                     | 8333.33          | 0.794         | 7.99          |
| <i>Sibbaldia cuneata</i>                      | 10000.00         | 2.289         | 12.88         |
| <i>Silene griffithii</i>                      | 10000.00         | 1.453         | 11.98         |
| <i>Smilacina purpurea</i>                     | 5000.00          | 0.725         | 5.52          |
| <i>Stellaria media</i>                        | 3333.33          | 0.582         | 4.51          |
| <i>Urtica ardens</i>                          | 5000.00          | 1.199         | 6.56          |
| <i>Valeriana pyrolaefolia</i>                 | 5000.00          | 0.828         | 5.75          |
| <i>Verbascum thapsus</i>                      | 10000.00         | 2.185         | 13.58         |
| <i>Vicatia coniifolia</i>                     | 3333.33          | 0.732         | 5.54          |
| <b>Total</b>                                  | <b>235000.00</b> | <b>45.707</b> | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (2000-2700 m)</b> |                  |               |               |
| <i>Achyranthes bidentata</i>                  | 3333.33          | 1.079         | 5.69          |
| <i>Ajuga bracteosa</i>                        | 6666.67          | 2.167         | 11.41         |
| <i>Amaranthus blitum</i>                      | 3333.33          | 1.375         | 7.76          |
| <i>Androsace lanuginosa</i>                   | 8333.33          | 0.476         | 9.35          |
| <i>Apluda mutica</i>                          | 3333.33          | 0.152         | 3.38          |
| <i>Arisaema flavum</i>                        | 5000.00          | 0.978         | 7.61          |
| <i>Artemisia roxburghiana</i>                 | 1666.67          | 0.682         | 3.87          |
| <i>Artemisia vestita</i>                      | 10000.00         | 1.393         | 12.48         |

|                                |                  |               |               |
|--------------------------------|------------------|---------------|---------------|
| <i>Bistorta amplexicaulis</i>  | 5000.00          | 0.963         | 7.57          |
| <i>Clinopodium vulgare</i>     | 3333.33          | 0.696         | 4.74          |
| <i>Dioscorea deltoidea</i>     | 11666.67         | 0.705         | 12.93         |
| <i>Erigeron multicaulis</i>    | 5000.00          | 0.279         | 4.53          |
| <i>Fragaria nubicola</i>       | 1666.67          | 2.612         | 8.68          |
| <i>Gerbera gossypina</i>       | 1666.67          | 0.265         | 2.83          |
| <i>Habenaria intermedia</i>    | 5000.00          | 0.792         | 7.14          |
| <i>Heracleum candicans</i>     | 3333.33          | 0.163         | 3.41          |
| <i>Impatiens scabrida</i>      | 5000.00          | 1.480         | 8.86          |
| <i>Iris nepalensis</i>         | 3333.33          | 1.702         | 8.58          |
| <i>Lamium album</i>            | 3333.33          | 0.726         | 4.81          |
| <i>Lotus corniculatus</i>      | 5000.00          | 0.259         | 4.48          |
| <i>Nasturtium officinale</i>   | 3333.33          | 1.057         | 5.64          |
| <i>Oenothera rosea</i>         | 11666.67         | 1.241         | 14.26         |
| <i>Plantago erosa</i>          | 5000.00          | 1.843         | 9.76          |
| <i>Polygonatum multiflorum</i> | 8333.33          | 1.992         | 13.14         |
| <i>Polygonum hydropiper</i>    | 1666.67          | 0.141         | 2.52          |
| <i>Potentilla fragarioides</i> | 1666.67          | 0.604         | 3.67          |
| <i>Primula floribunda</i>      | 10000.00         | 1.338         | 12.34         |
| <i>Saccharum filifolium</i>    | 3333.33          | 2.362         | 8.89          |
| <i>Salvia lanata</i>           | 11666.67         | 2.775         | 18.09         |
| <i>Scutellaria scandens</i>    | 1666.67          | 0.512         | 3.44          |
| <i>Silene vulgaris</i>         | 6666.67          | 1.862         | 10.65         |
| <i>Smilax aspera</i>           | 3333.33          | 0.364         | 5.24          |
| <i>Smilax glaucophylla</i>     | 3333.33          | 0.931         | 7.49          |
| <i>Stellaria media</i>         | 8333.33          | 0.715         | 9.95          |
| <i>Swertia cordata</i>         | 3333.33          | 0.068         | 3.17          |
| <i>Themeda anathera</i>        | 3333.33          | 0.797         | 7.66          |
| <i>Trifolium pratense</i>      | 10000.00         | 0.704         | 10.76         |
| <i>Urtica ardens</i>           | 1666.67          | 0.991         | 4.64          |
| <i>Valeriana jatamansi</i>     | 1666.67          | 0.404         | 3.18          |
| <i>Viola canescens</i>         | 3333.33          | 0.433         | 5.41          |
| <b>Total</b>                   | <b>198333.33</b> | <b>40.080</b> | <b>299.98</b> |

A perusal of Table 33 reveals that total of 105 forb species were recorded in Kail forests at different elevations. Among three elevations E<sub>1</sub> showed maximum density (218167.33 plants/ha) and basal area (100.36 m<sup>2</sup>) for 58 species, which was followed by E<sub>2</sub> with density (195001.33 plants/ha) and basal area of (76.79 cm<sup>2</sup>/m<sup>2</sup>) for 54 species. While the lowest density (173902.00 plants/ha) and basal area (74.76 cm<sup>2</sup>/m<sup>2</sup>) representing 51 species was recorded at E<sub>3</sub>.

It is evident from Table 33 that highest density (18333.33 plants/ha) was recorded for *Iris nepalensis* and *Verbascum thapsus*, which was followed by *Anaphalis contorta* with density (15000 plants/ha), while lowest density (<1700 plants/ha) was recorded for *Adiantum venustum*, *Anemone obtusiloba*, *Angelica glauca*, *Dioscorea deltoidea*, *Erigeron bellidioides*, *Geranium lucidum*, *Gypsophila cerastioides*, *Pedicularis hoffmeisteri*, *Phragmites communis*, *Plantago depressa*, *Podophyllum hexandrum*, *Polygonatum cirrhifolium*, *Polygonatum multiflorum*, *Potentilla argyrophylla*, *Primula petiolaris*, *Pteris cretica*, *Ranunculus hirtellus*, *Roscoeia purpurea*, *Scrophularia himalensis*, *Selaginella kraussiana*, *Senecio chrysanthemoides*, *Silene griffithii*, *Silene vulgaris*, *Smilacina purpurea* and *Urtica ardens*.

Maximum basal area at E<sub>1</sub> was recorded in *Primula denticulata* (19.20 cm<sup>2</sup>/m<sup>2</sup>), which was followed by *Verbascum thapsus* (15.53 cm<sup>2</sup>/m<sup>2</sup>). However lowest basal area was found in *Bistorta amplexicaulis* (0.10 cm<sup>2</sup>/m<sup>2</sup>). At E<sub>2</sub> *Leucas lanata* recorded highest density (13333.33 plants/ha), followed by *Aster molliusculus* (11666.67 plants/ha). Whereas, lowest density was recorded for *Dioscorea deltoidea* (1500.33 plants/ha). Maximum basal area (10.53 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Fragaria nubicola*, which was followed by *Urtica ardens* (6.90 cm<sup>2</sup>/m<sup>2</sup>). However, lowest basal area was recorded for *Dioscorea deltoidea* (0.08 cm<sup>2</sup>/m<sup>2</sup>) at E<sub>2</sub>. At E<sub>3</sub>, maximum density (11666.67 plants/ha) of an individual forb was recorded for *Androsace rotundifolia* and *Verbascum thapsus*, followed by *Salvia nubicola*, *Bupleurum hamiltonii* and *Crepis sancta* (10000 plants/ha). While the lowest density (1666.67 plants/ha) was recorded for *Ajuga parviflora*, *Amaranthus blitum*, *Arabis amplexicaulis*, *Artemisia roxburghiana*, *Atylosia scarabaeoides*, *Clinopodium vulgare*, *Duchesnea indica*, *Echinops niveus*, *Fagopyrum dibotrys*, *Geranium lucidum*, *Gerbera gossypina*, *Impatiens scabrida*, *Plectranthus japonicas*, *Primula floribunda*, *Salvia lanata*, *Scutellaria scandens*, *Stellaria media*, *Swertia cordata*, *Trifolium repens* and *Urtica dioica*. Highest basal was observed for *Verbascum thapsus* (12.05 cm<sup>2</sup>/m<sup>2</sup>), which was followed by *Trifolium repens* (11.31 cm<sup>2</sup>/m<sup>2</sup>). However minimum basal area (0.03 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Androsace sarmentosa* (Table 33).

At E<sub>1</sub>, *Verbascum thapsus* was found to be dominant forb species with an importance value index of 32.45, whereas *Iris nepalensis* was observed as a co-dominant species (IVI = 26.74) and *Primula denticulata* as associate species (IVI = 21.30). Whereas, *Dioscorea deltoidea* was observed as rare species with mere IVI (2.07) along with 52 other species which are having IVI (<10). At E<sub>2</sub>, *Fragaria nubicola* was observed as dominant forb species

with highest IVI (18.52), *Leucas lanata* was recorded as co-dominant (IVI = 17.36) and *Urtica ardens* (IVI =15.85) as an associate species. However, *Arabis amplexicaulis* was observed as least dominant forb species with an importance value index of (2.35) along with 46 other rare species (IVI < 10). At E<sub>3</sub>, *Trifolium repens* was dominant forb (IVI = 27.56), *Verbascum thapsus* (IVI = 24.37) was co-dominant and *Bupleurum hamiltonii* (IVI = 15.22) was associate species. However, *Arisaema flavum* was observed as rarest forb species with an importance value index of 2.01 along with other 44 rare species with IVI <10 (Table 33).

**Table 33: Density, basal area, and importance value index (IVI) of forbs in Kail (*Pinus wallichiana*) forests at different elevations**

| Forb species                                  | Density (Plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|-----------------------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (1400-2100 m)</b> |                     |                                               |       |
| <i>Adiantum venustum</i>                      | 1666.67             | 0.12                                          | 2.10  |
| <i>Ainsliaea aptera</i>                       | 5000.00             | 1.03                                          | 4.52  |
| <i>Ajuga bracteosa</i>                        | 5000.00             | 3.41                                          | 6.89  |
| <i>Anaphalis contorta</i>                     | 15000.00            | 4.63                                          | 16.31 |
| <i>Androsace lanuginosa</i>                   | 3333.33             | 0.50                                          | 3.23  |
| <i>Androsace sarmentosa</i>                   | 3333.33             | 0.30                                          | 3.03  |
| <i>Anemone obtusiloba</i>                     | 1666.67             | 0.58                                          | 2.56  |
| <i>Angelica glauca</i>                        | 1666.67             | 0.33                                          | 2.30  |
| <i>Arabis amplexicaulis</i>                   | 3333.33             | 0.72                                          | 3.46  |
| <i>Artemisia roxburghiana</i>                 | 10000.00            | 1.27                                          | 10.69 |
| <i>Bergenia stracheyi</i>                     | 8333.33             | 1.45                                          | 7.68  |
| <i>Bistorta amplexicaulis</i>                 | 3333.33             | 0.10                                          | 2.84  |
| <i>Bupleurum falcatum</i>                     | 3333.33             | 0.90                                          | 3.63  |
| <i>Carex breviculmis</i>                      | 3333.33             | 0.33                                          | 3.06  |
| <i>Carex cardiolepis</i>                      | 3333.33             | 0.63                                          | 3.36  |
| <i>Chenopodium opulifolium</i>                | 3333.33             | 0.91                                          | 3.64  |
| <i>Clinopodium vulgare</i>                    | 3333.33             | 0.77                                          | 3.51  |
| <i>Corydalis govaniana</i>                    | 3333.33             | 0.42                                          | 3.16  |
| <i>Dioscorea deltoidea</i>                    | 1666.67             | 0.12                                          | 2.07  |
| <i>Erigeron bellidioides</i>                  | 1666.67             | 0.28                                          | 2.25  |
| <i>Fagopyrum dibotrys</i>                     | 3333.33             | 0.32                                          | 3.06  |
| <i>Galium aparine</i>                         | 3333.33             | 0.27                                          | 3.00  |
| <i>Geranium lucidum</i>                       | 1666.67             | 0.40                                          | 2.37  |
| <i>Gypsophila cerastioides</i>                | 1666.67             | 0.80                                          | 2.78  |
| <i>Halenia elliptica</i>                      | 4500.33             | 1.79                                          | 6.50  |
| <i>Impatiens scabrida</i>                     | 3333.33             | 0.51                                          | 3.24  |
| <i>Iris nepalensis</i>                        | 18333.33            | 4.87                                          | 26.74 |
| <i>Lotus corniculatus</i>                     | 5000.00             | 0.68                                          | 4.17  |
| <i>Nepeta laevigata</i>                       | 5000.00             | 2.98                                          | 8.90  |
| <i>Pedicularis hoffmeisteri</i>               | 1666.67             | 0.62                                          | 2.60  |
| <i>Phragmites communis</i>                    | 1666.67             | 0.36                                          | 2.34  |
| <i>Plantago depressa</i>                      | 1666.67             | 5.01                                          | 6.97  |



|                                               |                  |               |               |
|-----------------------------------------------|------------------|---------------|---------------|
| <i>Plectranthus japonicus</i>                 | 3333.33          | 1.38          | 4.11          |
| <i>Podophyllum hexandrum</i>                  | 1666.67          | 0.40          | 2.38          |
| <i>Polygonatum cirrhifolium</i>               | 1666.67          | 1.89          | 3.86          |
| <i>Polygonatum multiflorum</i>                | 1666.67          | 2.20          | 4.17          |
| <i>Potentilla argyrophylla</i>                | 1666.67          | 1.63          | 3.61          |
| <i>Potentilla atosanguinea</i>                | 2000.33          | 0.44          | 3.17          |
| <i>Primula denticulata</i>                    | 10000.00         | 19.20         | 21.30         |
| <i>Primula petiolaris</i>                     | 1666.67          | 0.67          | 2.65          |
| <i>Pteris cretica</i>                         | 1666.67          | 0.63          | 2.60          |
| <i>Ranunculus hirtellus</i>                   | 1666.67          | 1.17          | 3.14          |
| <i>Roscoea purpurea</i>                       | 1666.67          | 1.78          | 3.75          |
| <i>Salvia nubicola</i>                        | 3333.33          | 2.50          | 5.23          |
| <i>Scrophularia himalensis</i>                | 1666.67          | 1.13          | 3.10          |
| <i>Selaginella kraussiana</i>                 | 1666.67          | 1.16          | 3.13          |
| <i>Senecio chrysanthemoides</i>               | 1666.67          | 1.16          | 3.13          |
| <i>Sibbaldia cuneata</i>                      | 3333.33          | 0.85          | 3.59          |
| <i>Silene griffithii</i>                      | 1666.67          | 0.47          | 2.44          |
| <i>Silene vulgaris</i>                        | 1666.67          | 0.38          | 2.35          |
| <i>Smilacina purpurea</i>                     | 1666.67          | 0.29          | 2.27          |
| <i>Stellaria media</i>                        | 3333.33          | 1.95          | 4.68          |
| <i>Thymus linearis</i>                        | 3333.33          | 1.12          | 3.85          |
| <i>Urtica ardens</i>                          | 1666.67          | 0.72          | 2.70          |
| <i>Valeriana jatamansi</i>                    | 3333.33          | 2.39          | 5.12          |
| <i>Valeriana pyrolaefolia</i>                 | 3333.33          | 0.94          | 3.67          |
| <i>Verbascum thapsus</i>                      | 18333.33         | 15.53         | 32.45         |
| <i>Vicatia conifolia</i>                      | 3333.33          | 0.94          | 3.67          |
| <b>Total</b>                                  | <b>218167.33</b> | <b>100.36</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (2100-2800 m)</b> |                  |               |               |
| <i>Achyranthes aspera</i>                     | 2000.33          | 0.41          | 3.48          |
| <i>Achyranthes bidentata</i>                  | 5000.00          | 2.13          | 6.56          |
| <i>Ajuga bracteosa</i>                        | 6666.67          | 1.36          | 7.67          |
| <i>Ajuga parviflora</i>                       | 1666.67          | 1.38          | 3.91          |
| <i>Amaranthus blitum</i>                      | 1666.67          | 0.90          | 3.29          |
| <i>Androsace lanuginosa</i>                   | 3333.33          | 0.26          | 3.29          |
| <i>Arabis amplexicaulis</i>                   | 1666.67          | 0.22          | 2.35          |
| <i>Arisaema flavum</i>                        | 3333.33          | 0.32          | 3.37          |
| <i>Artemisia roxburghiana</i>                 | 1666.67          | 0.18          | 2.41          |
| <i>Aster molliusculus</i>                     | 11666.67         | 0.89          | 12.12         |
| <i>Atylosia scarabaeoides</i>                 | 1666.67          | 0.57          | 2.86          |
| <i>Bidens biternata</i>                       | 3333.33          | 0.63          | 3.77          |
| <i>Bistorta amplexicaulis</i>                 | 3333.33          | 1.21          | 5.81          |
| <i>Clinopodium vulgare</i>                    | 1666.67          | 0.47          | 2.73          |
| <i>Cyathula tomentosa</i>                     | 3333.33          | 1.02          | 5.56          |
| <i>Datura stramonium</i>                      | 8333.33          | 1.82          | 9.10          |
| <i>Dicliptera bupleuroides</i>                | 3333.33          | 0.22          | 3.24          |
| <i>Dioscorea deltoidea</i>                    | 1500.33          | 0.08          | 3.05          |
| <i>Duchesnea indica</i>                       | 1666.67          | 0.48          | 2.74          |
| <i>Echinops niveus</i>                        | 1666.67          | 0.24          | 2.43          |

|                                               |                  |              |               |
|-----------------------------------------------|------------------|--------------|---------------|
| <i>Fagopyrum dibotrys</i>                     | 1666.67          | 0.48         | 2.74          |
| <i>Fragaria nubicola</i>                      | 6666.67          | 10.53        | 18.52         |
| <i>Galium aparine</i>                         | 3333.33          | 1.73         | 6.49          |
| <i>Geranium lucidum</i>                       | 1666.67          | 0.21         | 2.39          |
| <i>Gerbera gossypina</i>                      | 1666.67          | 0.39         | 2.62          |
| <i>Habenaria intermedia</i>                   | 2500.33          | 0.34         | 3.39          |
| <i>Heracleum candicans</i>                    | 3333.33          | 0.69         | 3.85          |
| <i>Impatiens scabrida</i>                     | 1666.67          | 0.90         | 3.28          |
| <i>Iris nepalensis</i>                        | 3333.33          | 1.43         | 4.81          |
| <i>Leucas lanata</i>                          | 13333.33         | 3.11         | 17.36         |
| <i>Micromeria biflora</i>                     | 3333.33          | 1.21         | 4.53          |
| <i>Oenothera rosea</i>                        | 8333.33          | 4.35         | 13.67         |
| <i>Phragmites communis</i>                    | 3333.33          | 1.14         | 4.44          |
| <i>Plantago depressa</i>                      | 5000.00          | 1.72         | 7.30          |
| <i>Plantago erosa</i>                         | 5000.00          | 0.92         | 6.26          |
| <i>Plectranthus japonicus</i>                 | 1666.67          | 0.71         | 3.04          |
| <i>Polygonatum multiflorum</i>                | 3333.33          | 1.89         | 5.41          |
| <i>Polygonum hydropiper</i>                   | 3333.33          | 0.99         | 4.23          |
| <i>Primula floribunda</i>                     | 1666.67          | 0.59         | 2.88          |
| <i>Pteris cretica</i>                         | 3333.33          | 2.43         | 7.40          |
| <i>Rumex nepalensis</i>                       | 3333.33          | 0.63         | 3.76          |
| <i>Salvia lanata</i>                          | 1666.67          | 0.55         | 2.83          |
| <i>Scutellaria scandens</i>                   | 1666.67          | 0.66         | 2.98          |
| <i>Silene vulgaris</i>                        | 8333.33          | 3.51         | 12.58         |
| <i>Stellaria media</i>                        | 1666.67          | 0.29         | 2.50          |
| <i>Swertia cordata</i>                        | 1666.67          | 0.32         | 2.53          |
| <i>Thalictrum foliolosum</i>                  | 3333.33          | 1.08         | 4.35          |
| <i>Themeda anathera</i>                       | 6666.67          | 4.48         | 13.02         |
| <i>Trifolium repens</i>                       | 1666.67          | 3.70         | 6.94          |
| <i>Urtica ardens</i>                          | 6666.67          | 6.90         | 15.85         |
| <i>Urtica dioica</i>                          | 1666.67          | 0.27         | 2.47          |
| <i>Valeriana jatamansi</i>                    | 3333.33          | 0.63         | 3.77          |
| <i>Verbascum thapsus</i>                      | 4000.33          | 1.91         | 7.55          |
| <i>Viola canescens</i>                        | 3333.33          | 1.27         | 4.61          |
| <b>Total</b>                                  | <b>195001.33</b> | <b>76.79</b> | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (2800-3600 m)</b> |                  |              |               |
| <i>Anaphalis contorta</i>                     | 3333.33          | 0.18         | 3.23          |
| <i>Androsace rotundifolia</i>                 | 11666.67         | 0.84         | 12.15         |
| <i>Androsace sarmentosa</i>                   | 1666.67          | 0.03         | 2.25          |
| <i>Arisaema flavum</i>                        | 1666.67          | 0.14         | 2.01          |
| <i>Artemisia indica</i>                       | 6666.67          | 0.92         | 9.48          |
| <i>Astilbe rivularis</i>                      | 1666.67          | 0.27         | 2.42          |
| <i>Bupleurum hamiltonii</i>                   | 10000.00         | 2.23         | 15.22         |
| <i>Carex breviculmis</i>                      | 1666.67          | 0.54         | 2.78          |
| <i>Carex remota</i>                           | 3333.33          | 0.53         | 4.84          |
| <i>Chenopodium opulifolium</i>                | 1666.67          | 0.29         | 2.46          |
| <i>Corydalis govaniana</i>                    | 5000.00          | 1.53         | 7.10          |
| <i>Crepis sancta</i>                          | 10000.00         | 1.29         | 11.83         |

|                                 |                  |              |               |
|---------------------------------|------------------|--------------|---------------|
| <i>Dicliptera bupleuroides</i>  | 1666.67          | 0.35         | 2.54          |
| <i>Dioscorea deltoidea</i>      | 3333.33          | 1.04         | 5.51          |
| <i>Erigeron bellidioides</i>    | 5000.00          | 1.06         | 6.47          |
| <i>Erigeron multicaulis</i>     | 1666.67          | 0.42         | 2.63          |
| <i>Fagopyrum dibotrys</i>       | 5000.00          | 1.02         | 6.42          |
| <i>Fragaria nubicola</i>        | 5000.00          | 1.11         | 6.53          |
| <i>Galium asperuloides</i>      | 3333.33          | 0.15         | 3.19          |
| <i>Geranium lucidum</i>         | 1666.67          | 0.06         | 2.14          |
| <i>Gypsophila cerastioides</i>  | 1666.67          | 0.58         | 2.84          |
| <i>Halenia elliptica</i>        | 1666.67          | 0.20         | 2.33          |
| <i>Iris nepalensis</i>          | 1666.67          | 0.72         | 3.03          |
| <i>Lamium album</i>             | 1666.67          | 0.45         | 2.67          |
| <i>Lotus corniculatus</i>       | 5000.00          | 2.40         | 8.26          |
| <i>Myriactis nepalensis</i>     | 5000.00          | 0.75         | 6.05          |
| <i>Nepeta laevigata</i>         | 1666.67          | 0.33         | 2.51          |
| <i>Phragmites communis</i>      | 1666.67          | 1.43         | 3.97          |
| <i>Polygala abyssinica</i>      | 2100.33          | 0.33         | 3.43          |
| <i>Polygonatum cirrhifolium</i> | 2300.67          | 1.71         | 5.28          |
| <i>Polygonatum multiflorum</i>  | 1500.33          | 0.21         | 5.54          |
| <i>Potentilla argyrophylla</i>  | 3333.33          | 0.79         | 5.18          |
| <i>Potentilla nepalensis</i>    | 1666.67          | 1.10         | 3.54          |
| <i>Primula petiolaris</i>       | 1666.67          | 1.12         | 3.56          |
| <i>Ranunculus hirtellus</i>     | 1666.67          | 1.95         | 4.67          |
| <i>Rosularia rosulata</i>       | 1666.67          | 1.94         | 4.66          |
| <i>Ranunculus laetus</i>        | 1666.67          | 3.08         | 6.18          |
| <i>Rumex nepalensis</i>         | 1666.67          | 0.21         | 2.34          |
| <i>Salvia nubicola</i>          | 10000.00         | 2.18         | 13.01         |
| <i>Scrophularia himalensis</i>  | 1666.67          | 0.28         | 2.44          |
| <i>Smilax glaucophylla</i>      | 3000.67          | 0.24         | 4.24          |
| <i>Stellaria media</i>          | 1666.67          | 0.87         | 3.23          |
| <i>Swertia cordata</i>          | 3333.33          | 3.46         | 8.76          |
| <i>Thymus linearis</i>          | 1666.67          | 1.19         | 3.66          |
| <i>Trifolium repens</i>         | 6666.67          | 11.31        | 27.56         |
| <i>Urtica ardens</i>            | 1666.67          | 3.31         | 6.49          |
| <i>Urtica dioica</i>            | 1666.67          | 1.69         | 4.33          |
| <i>Valeriana jatamansi</i>      | 1666.67          | 0.57         | 2.82          |
| <i>Valeriana pyrolaefolia</i>   | 3333.33          | 2.36         | 7.29          |
| <i>Verbascum thapsus</i>        | 11666.67         | 12.05        | 24.37         |
| <i>Vicatia coniiifolia</i>      | 1666.67          | 1.94         | 4.65          |
| <b>Total</b>                    | <b>173902.00</b> | <b>74.76</b> | <b>300.00</b> |

A perusal of the data presented in Table 34 reveals that 104 forb species were present in Kharsu Oak forests at different elevations. Maximum number of species were recorded at E<sub>1</sub> (69) followed by E<sub>2</sub> (64) and least were recorded at E<sub>3</sub> (55). Among three elevations, highest forb density (256900.66 plants/ha) and basal area (85.601 cm<sup>2</sup>/m<sup>2</sup>) was recorded at E<sub>1</sub> which was followed by E<sub>2</sub> with forb density as 2416983.99 plants/ha and basal area as 59.615

cm<sup>2</sup>/m<sup>2</sup>. While the lowest density (188312.56 plants/ha) and basal area (59.488 cm<sup>2</sup>/m<sup>2</sup>) of forbs was recorded at elevation E<sub>3</sub>.

At E<sub>1</sub>, maximum density (23333.33 plants/ha) of an individual forb was recorded for *Viola canescens* followed by *Fragaria nubicola* (16666.67 plants/ha). While very low density (1666.67 plants/ha) was recorded for *Ainsliaea aptera*, *Ajuga bracteosa*, *Androsace lanuginosa*, *Anemone obtusiloba*, *Arisaema flavum*, *Artemisia roxburghiana*, *Bergenia ciliate*, *Carex breviculmis*, *Cirsium wallichii*, *Erigeron bellidioides*, *Erigeron multicaulis*, *Gypsophila cerastioides*, *Impatiens scabrida*, *Lotus corniculatus*, *Nasturtium officinale*, *Pteris cretica*, *Ranunculus laetus*, *Rumex nepalensis*, *Salvia nubicola*, *Senecio chrysanthemoides*, *Serratula pallid*, *Sonchus asper* and *Vicatia coniifolia* at E<sub>1</sub>. Highest basal area was recorded for *Viola canescens* (5.307 cm<sup>2</sup>/m<sup>2</sup>), while the least value of basal area was observed for *Adiantum venustum* (0.163 cm<sup>2</sup>/m<sup>2</sup>) at E<sub>1</sub>. At E<sub>2</sub>, Highest density of (13333.33 plant/ha) was recorded for *Salvia nubicola*, which was followed *Iris nepalensis* (11666.67 plants/ha), while lowest density of 1666.67 plants/ha was recorded for *Anemone obtusiloba*, *Arabis amplexicaulis*, *Arundinella nepalensis*, *Bistorta amplexicaulis*, *Carex cardiolepis*, *Carex remota*, *Clinopodium vulgare*, *Fagopyrum dibotrys*, *Galium aparine*, *Geranium wallichianum*, *Habenaria intermedia*, *Lotus corniculatus*, *Myriactis nepalensis*, *Nepeta laevigata*, *Nepeta leucophylla*, *Phragmites communis*, *Primula denticulate*, *Primula petiolaris*, *Selinum vaginatum*, *Senecio alatus*, *Smilacina purpurea*, *Stellaria media*, *Swertia cordata*, *Urtica ardens*, *Valeriana jatamansi* and *Youngia japonica*. Likewise, highest values for basal area was observed for *Taraxacum officinale* (4.202 cm<sup>2</sup>/m<sup>2</sup>) and lowest basal area (0.070 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Silene griffithii*. At E<sub>3</sub> *Halenia elliptica* exhibited highest density (15000.00 plants/ha), followed by *Carex breviculmis* and *Fragaria nubicola* with density as 8333.33 plants/ha each. Whereas lowest forb density of 1666.67 plants/ha was recorded for *Androsace sarmentosa*, *Anemone obtusiloba*, *Carex cardiolepis*, *Carex remota*, *Clinopodium vulgare*, *Eriophorum comosum*, *Impatiens scabrida*, *Podophyllum hexandrum*, *Polygonatum cirrhifolium*, *Polygonatum verticillatum*, *Primula denticulate*, *Salvia nubicola*, *Selinum vaginatum*, *Silene griffithii*, *Silene vulgaris*, *Taraxacum officinale*, *Thymus linearis*, *Urtica ardens* and *Youngia japonica*. At E<sub>3</sub>, maximum basal area was observed for *Pedicularis hoffmeisteri* (5.664 cm<sup>2</sup>/m<sup>2</sup>) which was followed by *Bistorta amplexicaulis* (4.540 cm<sup>2</sup>/m<sup>2</sup>). While, lowest values for basal area (0.067 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Podophyllum hexandrum* (Table 34).

**Table 34: Density, basal area, and importance value index (IVI) of forbs in Kharsu Oak (*Q. semecarpifolia*) forests at different elevations**

| Forb Species                                | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|---------------------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation- E<sub>1</sub> (2300-2800)</b> |                     |                                               |       |
| <i>Adiantum venustum</i>                    | 3333.33             | 0.163                                         | 2.32  |
| <i>Ainsliaea aptera</i>                     | 1666.67             | 0.508                                         | 3.27  |
| <i>Ajuga bracteosa</i>                      | 1666.67             | 1.165                                         | 3.49  |
| <i>Anaphalis busua</i>                      | 3333.33             | 0.810                                         | 3.07  |
| <i>Anaphalis contorta</i>                   | 3333.33             | 0.396                                         | 2.59  |
| <i>Androsace lanuginosa</i>                 | 1666.67             | 0.299                                         | 2.47  |
| <i>Anemone obtusiloba</i>                   | 1666.67             | 0.392                                         | 2.58  |
| <i>Arabis amplexicaulis</i>                 | 3333.33             | 1.107                                         | 3.97  |
| <i>Arisaema flavum</i>                      | 1666.67             | 1.362                                         | 3.72  |
| <i>Artemisia indica</i>                     | 3333.33             | 1.157                                         | 3.62  |
| <i>Artemisia roxburghiana</i>               | 1666.67             | 2.478                                         | 5.02  |
| <i>Arundinella nepalensis</i>               | 3333.33             | 0.415                                         | 3.16  |
| <i>Asplenium trichomanes</i>                | 3333.33             | 4.564                                         | 9.86  |
| <i>Astilbe rivularis</i>                    | 3333.33             | 0.548                                         | 2.77  |
| <i>Bergenia ciliata</i>                     | 1666.67             | 0.546                                         | 2.21  |
| <i>Bergenia stracheyi</i>                   | 3333.33             | 0.438                                         | 1.95  |
| <i>Carduus nutans</i>                       | 3333.33             | 2.326                                         | 4.98  |
| <i>Carex breviculmis</i>                    | 1666.67             | 0.909                                         | 3.19  |
| <i>Carex remota</i>                         | 3333.33             | 0.682                                         | 2.65  |
| <i>Chenopodium opulifolium</i>              | 3333.33             | 0.723                                         | 2.83  |
| <i>Cirsium wallichii</i>                    | 1666.67             | 3.432                                         | 5.86  |
| <i>Clinopodium vulgare</i>                  | 3333.33             | 0.640                                         | 2.60  |
| <i>Erigeron bellidioides</i>                | 1666.67             | 0.253                                         | 2.42  |
| <i>Erigeron multicaulis</i>                 | 1666.67             | 0.284                                         | 2.18  |
| <i>Fragaria nubicola</i>                    | 16666.67            | 2.909                                         | 16.76 |
| <i>Galium asperuloides</i>                  | 3333.33             | 0.183                                         | 1.79  |
| <i>Girardinia diversifolia</i>              | 5000.00             | 2.010                                         | 4.34  |
| <i>Gypsophila cerastioides</i>              | 1666.67             | 0.920                                         | 3.20  |
| <i>Habenaria intermedia</i>                 | 3333.33             | 0.979                                         | 3.82  |
| <i>Impatiens scabrida</i>                   | 1666.67             | 1.600                                         | 3.99  |
| <i>Iris nepalensis</i>                      | 3333.33             | 1.398                                         | 3.76  |
| <i>Koeleria cristata</i>                    | 3333.33             | 0.909                                         | 3.19  |
| <i>Lamium album</i>                         | 6666.67             | 0.858                                         | 4.42  |
| <i>Lotus corniculatus</i>                   | 1666.67             | 0.692                                         | 2.93  |
| <i>Myriactis nepalensis</i>                 | 3333.33             | 0.255                                         | 2.42  |
| <i>Nasturtium officinale</i>                | 1666.67             | 0.965                                         | 3.25  |
| <i>Nepeta laevigata</i>                     | 3333.33             | 0.375                                         | 2.56  |
| <i>Pedicularis hoffmeisteri</i>             | 5000.00             | 1.855                                         | 7.16  |
| <i>Phragmites communis</i>                  | 3333.33             | 1.123                                         | 3.44  |
| <i>Plectranthus japonicus</i>               | 3333.33             | 2.014                                         | 4.48  |
| <i>Polygonatum cirrhifolium</i>             | 6666.67             | 2.140                                         | 8.05  |
| <i>Potentilla argyrophylla</i>              | 3333.33             | 1.601                                         | 4.00  |

|                                               |                  |               |               |
|-----------------------------------------------|------------------|---------------|---------------|
| <i>Primula denticulata</i>                    | 3333.33          | 0.475         | 2.68          |
| <i>Pteris cretica</i>                         | 1666.67          | 0.702         | 2.26          |
| <i>Ranunculus laetus</i>                      | 1666.67          | 1.074         | 2.69          |
| <i>Roscoea purpurea</i>                       | 6666.67          | 1.338         | 5.26          |
| <i>Rumex nepalensis</i>                       | 1666.67          | 2.177         | 4.12          |
| <i>Saccharum filifolium</i>                   | 10000.00         | 4.660         | 11.68         |
| <i>Salvia lanata</i>                          | 3333.33          | 1.286         | 3.63          |
| <i>Salvia nubicola</i>                        | 1666.67          | 0.257         | 1.74          |
| <i>Scirpus roylei</i>                         | 3333.33          | 1.073         | 3.10          |
| <i>Scrophularia himalensis</i>                | 5000.00          | 0.451         | 2.38          |
| <i>Selinum vaginatum</i>                      | 6666.67          | 2.644         | 9.27          |
| <i>Senecio alatus</i>                         | 3333.33          | 0.595         | 2.54          |
| <i>Senecio chrysanthemoides</i>               | 1666.67          | 1.311         | 6.42          |
| <i>Senecio nudicaulis</i>                     | 3333.33          | 0.289         | 2.46          |
| <i>Serratula pallida</i>                      | 1666.67          | 0.452         | 3.07          |
| <i>Silene griffithii</i>                      | 3333.33          | 0.351         | 2.67          |
| <i>Smilacina purpurea</i>                     | 4567.33          | 3.498         | 9.63          |
| <i>Solena amplexicaulis</i>                   | 3333.33          | 0.519         | 2.87          |
| <i>Sonchus asper</i>                          | 1666.67          | 0.798         | 3.06          |
| <i>Swertia cordata</i>                        | 3333.33          | 0.239         | 2.13          |
| <i>Taraxacum officinale</i>                   | 6666.67          | 3.251         | 7.22          |
| <i>Thymus linearis</i>                        | 3333.33          | 0.393         | 3.14          |
| <i>Trifolium repens</i>                       | 3333.33          | 0.270         | 2.44          |
| <i>Urtica dioica</i>                          | 5000.00          | 1.819         | 4.99          |
| <i>Verbascum thapsus</i>                      | 4000.00          | 1.678         | 4.97          |
| <i>Vicatia conifolia</i>                      | 1666.67          | 0.310         | 2.49          |
| <i>Viola canescens</i>                        | 23333.33         | 5.307         | 24.78         |
| <b>Total</b>                                  | <b>256900.66</b> | <b>85.601</b> | <b>300.00</b> |
| <b>Elevation- E<sub>2</sub> (2800-3200 m)</b> |                  |               |               |
| <i>Achyranthes bidentata</i>                  | 6666.67          | 0.928         | 7.30          |
| <i>Adiantum venustum</i>                      | 2000.33          | 0.221         | 2.75          |
| <i>Ainsliaea aptera</i>                       | 3333.33          | 1.112         | 5.24          |
| <i>Ajuga bracteosa</i>                        | 2800.67          | 1.091         | 5.89          |
| <i>Androsace rotundifolia</i>                 | 3000.33          | 1.385         | 6.39          |
| <i>Anemone obtusiloba</i>                     | 1666.67          | 0.705         | 2.87          |
| <i>Angelica glauca</i>                        | 6666.67          | 0.901         | 6.27          |
| <i>Arabis amplexicaulis</i>                   | 1666.67          | 0.129         | 1.90          |
| <i>Arisaema flavum</i>                        | 2222.67          | 0.200         | 2.71          |
| <i>Artemisia indica</i>                       | 5000.00          | 1.343         | 6.32          |
| <i>Artemisia roxburghiana</i>                 | 6666.67          | 0.586         | 5.74          |
| <i>Arundinella nepalensis</i>                 | 1666.67          | 0.096         | 1.85          |
| <i>Astilbe rivularis</i>                      | 3333.33          | 0.180         | 2.68          |
| <i>Bergenia stracheyi</i>                     | 3333.33          | 0.673         | 3.51          |
| <i>Bistorta amplexicaulis</i>                 | 1666.67          | 0.499         | 2.52          |
| <i>Carduus nutans</i>                         | 5000.00          | 1.549         | 6.66          |
| <i>Carex cardiolepis</i>                      | 1666.67          | 0.862         | 3.13          |
| <i>Carex remota</i>                           | 1666.67          | 0.861         | 3.13          |
| <i>Cirsium wallichii</i>                      | 8333.33          | 2.962         | 11.41         |

|                                               |                  |               |               |
|-----------------------------------------------|------------------|---------------|---------------|
| <i>Clinopodium vulgare</i>                    | 1666.67          | 0.589         | 2.67          |
| <i>Erigeron bellidioides</i>                  | 2500.33          | 0.112         | 2.57          |
| <i>Fagopyrum dibotrys</i>                     | 1666.67          | 0.319         | 2.22          |
| <i>Fragaria nubicola</i>                      | 2000.67          | 0.425         | 3.09          |
| <i>Galium aparine</i>                         | 1666.67          | 0.266         | 2.13          |
| <i>Geranium lucidum</i>                       | 6666.67          | 0.578         | 5.73          |
| <i>Geranium wallichianum</i>                  | 1666.67          | 0.134         | 1.91          |
| <i>Gypsophila cerastioides</i>                | 3000.33          | 1.008         | 5.75          |
| <i>Habenaria intermedia</i>                   | 1666.67          | 0.238         | 2.08          |
| <i>Impatiens scabrida</i>                     | 3333.33          | 1.251         | 5.47          |
| <i>Iris nepalensis</i>                        | 11666.67         | 2.696         | 13.34         |
| <i>Lamium album</i>                           | 8333.33          | 2.273         | 11.24         |
| <i>Lotus corniculatus</i>                     | 1666.67          | 0.505         | 2.53          |
| <i>Myriactis nepalensis</i>                   | 1666.67          | 0.184         | 1.99          |
| <i>Nepeta laevigata</i>                       | 1666.67          | 0.386         | 2.33          |
| <i>Nepeta leucophylla</i>                     | 1666.67          | 0.886         | 3.17          |
| <i>Pedicularis hoffmeisteri</i>               | 2500.33          | 2.490         | 6.56          |
| <i>Phragmites communis</i>                    | 1666.67          | 0.676         | 2.82          |
| <i>Polygonatum cirrhifolium</i>               | 1500.67          | 1.002         | 5.74          |
| <i>Polygonatum multiflorum</i>                | 5000.00          | 1.142         | 5.98          |
| <i>Polygonum nepalense</i>                    | 5000.00          | 0.783         | 5.38          |
| <i>Potentilla argyrophylla</i>                | 6666.67          | 2.096         | 9.26          |
| <i>Primula denticulata</i>                    | 1666.67          | 0.411         | 2.37          |
| <i>Primula petiolaris</i>                     | 1666.67          | 0.270         | 2.14          |
| <i>Pteris cretica</i>                         | 2500.33          | 2.807         | 8.77          |
| <i>Rosularia rosulata</i>                     | 6666.67          | 3.017         | 10.81         |
| <i>Salvia nubicola</i>                        | 13333.33         | 2.278         | 14.33         |
| <i>Scirpus roylei</i>                         | 6666.67          | 1.623         | 7.48          |
| <i>Selinum vaginatum</i>                      | 1666.67          | 0.450         | 2.44          |
| <i>Senecio alatus</i>                         | 1666.67          | 0.560         | 2.62          |
| <i>Senecio chrysanthemoides</i>               | 3333.33          | 0.372         | 3.99          |
| <i>Senecio nudicaulis</i>                     | 3333.33          | 0.217         | 2.74          |
| <i>Silene griffithii</i>                      | 1900.67          | 0.070         | 2.50          |
| <i>Silene vulgaris</i>                        | 3500.33          | 1.620         | 6.78          |
| <i>Smilacina purpurea</i>                     | 1666.67          | 0.436         | 2.42          |
| <i>Stellaria media</i>                        | 1666.67          | 0.383         | 2.33          |
| <i>Swertia cordata</i>                        | 1666.67          | 0.277         | 2.15          |
| <i>Taraxacum officinale</i>                   | 3333.33          | 4.202         | 10.42         |
| <i>Thalictrum foliolosum</i>                  | 3333.33          | 0.629         | 3.43          |
| <i>Thymus linearis</i>                        | 5000.00          | 0.811         | 5.42          |
| <i>Tragopogon gracilis</i>                    | 2222.33          | 0.359         | 2.98          |
| <i>Urtica ardens</i>                          | 1666.67          | 1.726         | 4.58          |
| <i>Valeriana jatamansi</i>                    | 1666.67          | 0.394         | 2.35          |
| <i>Vicatia coniiifolia</i>                    | 2000.67          | 0.168         | 2.66          |
| <i>Youngia japonica</i>                       | 1666.67          | 0.212         | 2.04          |
| <b>Total</b>                                  | <b>216983.99</b> | <b>59.615</b> | <b>300.00</b> |
| <b>Elevation- E<sub>3</sub> (3200-3600 m)</b> |                  |               |               |
| <i>Ajuga bracteosa</i>                        | 6666.67          | 1.693         | 8.10          |

|                                  |          |       |       |
|----------------------------------|----------|-------|-------|
| <i>Anaphalis contorta</i>        | 5000.00  | 0.698 | 3.97  |
| <i>Androsace sarmentosa</i>      | 1666.67  | 0.384 | 3.44  |
| <i>Anemone obtusiloba</i>        | 1666.67  | 0.611 | 3.83  |
| <i>Angelica glauca</i>           | 1500.33  | 1.194 | 5.85  |
| <i>Aquilegia fragrans</i>        | 3333.33  | 0.817 | 4.64  |
| <i>Artemisia indica</i>          | 5000.00  | 0.458 | 4.63  |
| <i>Artemisia roxburghiana</i>    | 3333.33  | 0.866 | 3.33  |
| <i>Aster molliusculus</i>        | 5000.00  | 1.488 | 8.08  |
| <i>Bergenia stracheyi</i>        | 3333.33  | 0.758 | 4.07  |
| <i>Bistorta amplexicaulis</i>    | 2200.67  | 4.540 | 9.50  |
| <i>Carduus nutans</i>            | 3333.33  | 1.799 | 5.82  |
| <i>Carex breviculmis</i>         | 8333.33  | 1.887 | 9.81  |
| <i>Carex cardiolepis</i>         | 1666.67  | 1.145 | 4.72  |
| <i>Carex remota</i>              | 1666.67  | 0.676 | 3.94  |
| <i>Cirsium wallichii</i>         | 3333.33  | 1.224 | 4.39  |
| <i>Clinopodium vulgare</i>       | 1666.67  | 0.417 | 3.04  |
| <i>Corydalis govaniana</i>       | 3000.33  | 0.491 | 3.16  |
| <i>Erigeron bellidioides</i>     | 3333.33  | 0.443 | 4.01  |
| <i>Eriophorum comosum</i>        | 1666.67  | 0.504 | 3.65  |
| <i>Fagopyrum dibotrys</i>        | 2722.33  | 0.803 | 5.42  |
| <i>Fragaria nubicola</i>         | 8333.33  | 2.319 | 16.60 |
| <i>Galium aparine</i>            | 3000.25  | 0.308 | 3.32  |
| <i>Gypsophila cerastioides</i>   | 3333.33  | 0.271 | 2.56  |
| <i>Halenia elliptica</i>         | 15000.00 | 2.363 | 16.58 |
| <i>Impatiens scabrida</i>        | 1666.67  | 0.825 | 4.19  |
| <i>Koeleria cristata</i>         | 5000.00  | 1.535 | 8.18  |
| <i>Lotus corniculatus</i>        | 6666.67  | 1.287 | 8.46  |
| <i>Mentha longifolia</i>         | 3333.33  | 0.323 | 2.88  |
| <i>Pedicularis hoffmeisteri</i>  | 6666.67  | 5.664 | 14.77 |
| <i>Podophyllum hexandrum</i>     | 1666.67  | 0.067 | 1.64  |
| <i>Polygonatum cirrhifolium</i>  | 1666.67  | 0.780 | 4.11  |
| <i>Polygonatum verticillatum</i> | 1666.67  | 0.638 | 3.87  |
| <i>Primula denticulata</i>       | 1666.67  | 0.364 | 3.41  |
| <i>Primula petiolaris</i>        | 2222.33  | 0.737 | 4.27  |
| <i>Ranunculus hirtellus</i>      | 5000.00  | 1.105 | 7.11  |
| <i>Rumex nepalensis</i>          | 5000.00  | 1.226 | 3.82  |
| <i>Salvia nubicola</i>           | 1666.67  | 0.784 | 4.58  |
| <i>Selinum candolli</i>          | 3333.33  | 0.767 | 4.44  |
| <i>Selinum vaginatum</i>         | 1666.67  | 0.745 | 4.40  |
| <i>Senecio chrysanthemoides</i>  | 2000.33  | 0.446 | 4.01  |
| <i>Sibbaldia cuneata</i>         | 2980.33  | 2.013 | 11.53 |
| <i>Silene griffithii</i>         | 1666.67  | 0.240 | 3.20  |
| <i>Silene vulgaris</i>           | 1666.67  | 0.429 | 3.52  |
| <i>Smilacina purpurea</i>        | 6666.67  | 1.402 | 8.65  |
| <i>Sonchus asper</i>             | 1785.33  | 1.225 | 4.86  |
| <i>Stellaria media</i>           | 3333.33  | 0.413 | 3.49  |
| <i>Taraxacum officinale</i>      | 1666.67  | 1.635 | 4.62  |
| <i>Thlaspi cochleariforme</i>    | 1900.33  | 0.679 | 3.59  |



|                               |                  |               |               |
|-------------------------------|------------------|---------------|---------------|
| <i>Thymus linearis</i>        | 1666.67          | 0.471         | 3.47          |
| <i>Urtica ardens</i>          | 1666.67          | 0.649         | 2.85          |
| <i>Valeriana pyrolaefolia</i> | 3333.33          | 0.682         | 3.95          |
| <i>Verbascum thapsus</i>      | 5000.00          | 3.125         | 7.36          |
| <i>Vicatia coniiifolia</i>    | 3333.33          | 0.396         | 3.47          |
| <i>Youngia japonica</i>       | 1666.67          | 0.680         | 4.87          |
| <b>Total</b>                  | <b>188582.56</b> | <b>59.488</b> | <b>300.00</b> |

At E<sub>1</sub>, *Viola canescens* was dominant forb species with highest IVI (24.78), while *Fragaria nubicola* (IVI=16.76) and *Saccharum filifolium* (IVI=11.68) was co-dominant and associate species. *Galium asperuloides* (IVI=1.79) was rare species along with 66 other species. At E<sub>2</sub>, *Salvia nubicola* was the dominant forb (IVI=14.33) and *Iris nepalensis* was co-dominated species with IVI of 13.34. Whereas, *Arundinella nepalensis* was rare species with least IVI as 1.85 along with 57 other species. At E<sub>3</sub>, *Fragaria nubicola* was dominant forb species with highest IVI of 16.60 at E<sub>3</sub>, *Halenia elliptica* was co-dominated forb (IVI = 16.58). Whereas, *Podophyllum hexandrum* was rare species with an importance value index of 1.64 (Table 34).

73 forb species were recorded in the upper Oak-Fir forests at different elevations (Table 35). Highest forb species (46) was recorded at E<sub>1</sub> whereas at E<sub>2</sub>, 45 forb species and at E<sub>3</sub>, 32 forb species were recorded. Among three elevations, at E<sub>1</sub> highest forb density (256666.66 plants/ha) and basal area (67.588 cm<sup>2</sup>/m<sup>2</sup>) was observed followed by E<sub>2</sub> with density of 221666.66 plants/ha and total basal area as 50.661 cm<sup>2</sup>/m<sup>2</sup>. While the lowest density (178333.33 plants/ha) and basal area (48.237 cm<sup>2</sup>/m<sup>2</sup>) of forbs was recorded at E<sub>3</sub>.

At E<sub>1</sub> highest density (16666.67 plants/ha) and basal area (5.106 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Anaphalis contorta* and *Sonchus asper* respectively. Lowest density at E<sub>1</sub> was observed in *Valeriana jatamansi*, *Verbascum thapsus* *Chenopodium opulifolium*, *Fagopyrum dibotrys* and *Agrimonia pilosa* as 1666.67 plants/ha, while least basal area (0.086 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Thymus linearis*. At E<sub>2</sub>, highest density and basal area was recorded in *Iris nepalensis* (15000.00 plants/ha) and *Achyranthes bidentata* (2.935 cm<sup>2</sup>/m<sup>2</sup>) respectively. Lowest density at E<sub>2</sub> was observed in *Aster molliusculus*, *Clinopodium vulgare*, *Rumex nepalensis* and *Senecio alatus* as 1666.67 plants/ha while *Heracleum candicans* displayed least basal area of 0.075 cm<sup>2</sup>/m<sup>2</sup>. Maximum density (15000 plants/ha) and basal area (1.476 cm<sup>2</sup>/m<sup>2</sup>) at E<sub>3</sub> was recorded for *Anaphalis contorta* and *Rumex nepalensis* respectively. Lowest density of 1666.67 plants/ha was recorded in *Artemisia roxburghiana* and *Selinum candolli*, whereas minimum basal area (0.148 cm<sup>2</sup>/m<sup>2</sup>) was observed in *Podophyllum hexandrum* (Table 35).

**Table 35: Density, basal area, and importance value index (IVI) of forbs in upper Oak-Fir forests at different elevations**

| Forb Species                                 | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI   |
|----------------------------------------------|---------------------|-----------------------------------------------|-------|
| <b>Elevation-E<sub>1</sub> (2100-2600 m)</b> |                     |                                               |       |
| <i>Adiantum venustum</i>                     | 8333.33             | 2.336                                         | 9.56  |
| <i>Agrimonia pilosa</i>                      | 1666.67             | 1.254                                         | 3.95  |
| <i>Ainsliaea aptera</i>                      | 3333.33             | 0.306                                         | 3.18  |
| <i>Ajuga bracteosa</i>                       | 3333.33             | 0.706                                         | 3.78  |
| <i>Anaphalis contorta</i>                    | 16666.67            | 4.412                                         | 20.18 |
| <i>Androsace lanuginosa</i>                  | 8333.33             | 3.068                                         | 10.64 |
| <i>Anemone obtusiloba</i>                    | 5000.00             | 0.558                                         | 4.20  |
| <i>Arabis amplexicaulis</i>                  | 3333.33             | 0.203                                         | 3.03  |
| <i>Arctium lappa</i>                         | 5000.00             | 0.469                                         | 5.52  |
| <i>Arisaema flavum</i>                       | 8333.33             | 4.525                                         | 12.80 |
| <i>Artemisia roxburghiana</i>                | 6666.67             | 3.931                                         | 11.28 |
| <i>Arundinella nepalensis</i>                | 3333.33             | 0.836                                         | 3.97  |
| <i>Bergenia ciliate</i>                      | 3333.33             | 1.084                                         | 4.33  |
| <i>Carex remota</i>                          | 3333.33             | 2.079                                         | 5.81  |
| <i>Chenopodium opulifolium</i>               | 1666.67             | 0.556                                         | 2.91  |
| <i>Erigeron multicaulis</i>                  | 8333.33             | 0.940                                         | 7.49  |
| <i>Eriophorum comosum</i>                    | 5000.00             | 1.231                                         | 5.19  |
| <i>Fagopyrum dibotrys</i>                    | 1666.67             | 0.139                                         | 2.30  |
| <i>Fragaria nubicola</i>                     | 10000.00            | 1.195                                         | 9.96  |
| <i>Galium aparine</i>                        | 3333.33             | 1.460                                         | 4.89  |
| <i>Habenaria intermedia</i>                  | 8333.33             | 1.889                                         | 8.90  |
| <i>Impatiens scabrida</i>                    | 8333.33             | 2.241                                         | 9.42  |
| <i>Iris nepalensis</i>                       | 5000.00             | 1.564                                         | 5.69  |
| <i>Koeleria cristata</i>                     | 3333.33             | 0.822                                         | 3.95  |
| <i>Phragmites communis</i>                   | 5000.00             | 0.918                                         | 4.73  |
| <i>Plectranthus japonicus</i>                | 5000.00             | 0.972                                         | 4.81  |
| <i>Polygonatum multiflorum</i>               | 6666.67             | 0.754                                         | 5.13  |
| <i>Polygonum nepalense</i>                   | 5000.00             | 0.292                                         | 3.80  |
| <i>Primula denticulate</i>                   | 10000.00            | 3.088                                         | 11.31 |
| <i>Pteris cretica</i>                        | 3333.33             | 0.471                                         | 3.43  |
| <i>Ranunculus hirtellus</i>                  | 3333.33             | 0.925                                         | 4.10  |
| <i>Roscoeia purpurea</i>                     | 6666.67             | 1.520                                         | 7.71  |
| <i>Rumex nepalensis</i>                      | 3333.33             | 2.795                                         | 6.87  |
| <i>Salvia nubicola</i>                       | 3333.33             | 0.694                                         | 3.76  |
| <i>Scirpus roylei</i>                        | 5000.00             | 0.635                                         | 4.31  |
| <i>Smilacina purpurea</i>                    | 5000.00             | 0.449                                         | 4.04  |
| <i>Solena amplexicaulis</i>                  | 3333.33             | 0.680                                         | 3.74  |
| <i>Sonchus asper</i>                         | 10000.00            | 5.106                                         | 15.75 |
| <i>Swertia cordata</i>                       | 3333.33             | 0.783                                         | 4.53  |
| <i>Thymus linearis</i>                       | 3333.33             | 0.086                                         | 2.86  |
| <i>Trifolium repens</i>                      | 11666.67            | 1.024                                         | 8.90  |
| <i>Urtica ardens</i>                         | 15000.00            | 4.231                                         | 16.38 |
| <i>Valeriana jatamansi</i>                   | 1666.67             | 0.110                                         | 2.25  |
| <i>Verbascum thapsus</i>                     | 1666.67             | 2.100                                         | 5.20  |
| <i>Vicatia coniiifolia</i>                   | 6666.66             | 1.362                                         | 9.57  |

|                                   |                  |               |               |
|-----------------------------------|------------------|---------------|---------------|
| <i>Viola canescens</i>            | 3333.33          | 0.789         | 3.90          |
| <b>Total</b>                      | <b>256666.66</b> | <b>67.588</b> | <b>300.00</b> |
| <b>Elevation-E2 (2600-3100 m)</b> |                  |               |               |
| <i>Achyranthes bidentata</i>      | 8333.33          | 2.935         | 12.86         |
| <i>Adiantum venustum</i>          | 3333.33          | 0.304         | 3.76          |
| <i>Agrimonia pilosa</i>           | 3333.33          | 1.098         | 5.33          |
| <i>Ainsliaea aptera</i>           | 3333.33          | 0.686         | 4.51          |
| <i>Ajuga bracteosa</i>            | 3333.33          | 1.084         | 5.30          |
| <i>Anaphalis contorta</i>         | 6666.67          | 1.455         | 9.19          |
| <i>Androsace rotundifolia</i>     | 3333.33          | 0.247         | 3.65          |
| <i>Anemone obtusiloba</i>         | 3333.33          | 0.685         | 4.51          |
| <i>Angelica glauca</i>            | 3333.33          | 0.933         | 5.00          |
| <i>Arisaema flavum</i>            | 5000.00          | 0.700         | 5.29          |
| <i>Artemisia indica</i>           | 5000.00          | 1.256         | 6.38          |
| <i>Arundinella nepalensis</i>     | 3333.33          | 0.717         | 4.57          |
| <i>Asplenium trichomanes</i>      | 3333.33          | 1.055         | 5.24          |
| <i>Aster molliusculus</i>         | 1666.67          | 0.769         | 3.93          |
| <i>Bergenia ciliata</i>           | 5000.00          | 1.246         | 6.37          |
| <i>Bistorta amplexicaulis</i>     | 6666.67          | 1.710         | 9.69          |
| <i>Clinopodium vulgare</i>        | 1666.67          | 0.931         | 5.92          |
| <i>Erigeron multicaulis</i>       | 3333.33          | 1.393         | 5.91          |
| <i>Eriophorum comosum</i>         | 6666.67          | 2.746         | 11.74         |
| <i>Fagopyrum dibotrys</i>         | 5000.00          | 0.866         | 7.28          |
| <i>Fragaria nubicola</i>          | 3333.33          | 0.356         | 3.86          |
| <i>Galium aparine</i>             | 5000.00          | 0.474         | 4.84          |
| <i>Galium asperuloides</i>        | 3333.33          | 0.286         | 3.72          |
| <i>Habenaria intermedia</i>       | 3333.33          | 1.205         | 5.54          |
| <i>Heracleum candicans</i>        | 3333.33          | 0.075         | 3.31          |
| <i>Impatiens scabrida</i>         | 10000.00         | 2.184         | 12.12         |
| <i>Iris nepalensis</i>            | 15000.00         | 2.215         | 16.09         |
| <i>Koeleria cristata</i>          | 3333.33          | 0.955         | 5.04          |
| <i>Myriactis nepalensis</i>       | 3333.33          | 1.135         | 5.40          |
| <i>Phragmites communis</i>        | 10000.00         | 0.823         | 9.44          |
| <i>Plectranthus japonicus</i>     | 5000.00          | 1.333         | 6.54          |
| <i>Polygonatum multiflorum</i>    | 5000.00          | 2.291         | 8.43          |
| <i>Potentilla argyrophylla</i>    | 3333.33          | 0.750         | 4.64          |
| <i>Primula denticulata</i>        | 5000.00          | 0.746         | 5.38          |
| <i>Pteris cretica</i>             | 3333.33          | 0.714         | 4.57          |
| <i>Ranunculus hirtellus</i>       | 5000.00          | 1.317         | 6.51          |
| <i>Rumex nepalensis</i>           | 1666.67          | 0.641         | 3.68          |
| <i>Salvia nubicola</i>            | 6666.67          | 2.289         | 10.84         |
| <i>Selinum vaginatum</i>          | 5000.00          | 0.439         | 6.44          |
| <i>Senecio alatus</i>             | 1666.67          | 0.539         | 3.48          |
| <i>Smilacina purpurea</i>         | 3333.33          | 0.451         | 4.80          |
| <i>Thalictrum foliolosum</i>      | 10000.00         | 1.767         | 9.63          |
| <i>Thymus linearis</i>            | 10000.00         | 0.666         | 10.79         |
| <i>Urtica ardens</i>              | 8333.33          | 2.777         | 12.55         |
| <i>Verbascum thapsus</i>          | 3333.33          | 1.413         | 5.95          |
| <b>Total</b>                      | <b>221666.66</b> | <b>50.661</b> | <b>300.00</b> |

| Elevation-E3 (3100-3500 m)       |                  |               |               |
|----------------------------------|------------------|---------------|---------------|
| <i>Anaphalis contorta</i>        | 15000.00         | 2.914         | 23.07         |
| <i>Androsace sarmentosa</i>      | 6666.67          | 1.296         | 10.74         |
| <i>Anemone obtusiloba</i>        | 5000.00          | 0.449         | 5.88          |
| <i>Angelica glauca</i>           | 6666.67          | 1.569         | 11.30         |
| <i>Aquilegia fragrans</i>        | 6666.67          | 2.348         | 12.92         |
| <i>Artemisia indica</i>          | 3333.33          | 1.578         | 7.30          |
| <i>Artemisia roxburghiana</i>    | 1666.67          | 1.589         | 6.39          |
| <i>Aster molliusculus</i>        | 5000.00          | 0.642         | 6.28          |
| <i>Bergenia stracheyi</i>        | 6666.66          | 2.189         | 13.52         |
| <i>Bistorta amplexicaulis</i>    | 3333.33          | 0.356         | 4.76          |
| <i>Carex remota</i>              | 11666.67         | 3.238         | 19.72         |
| <i>Corydalis govaniana</i>       | 3333.33          | 0.372         | 4.80          |
| <i>Eriophorum comosum</i>        | 5000.00          | 2.575         | 12.46         |
| <i>Fagopyrum dibotrys</i>        | 3333.33          | 0.520         | 5.10          |
| <i>Fragaria nubicola</i>         | 5000.00          | 1.658         | 8.39          |
| <i>Galium aparine</i>            | 3333.33          | 1.016         | 6.13          |
| <i>Gypsophila cerastioides</i>   | 3333.33          | 1.308         | 6.74          |
| <i>Heracleum candicans</i>       | 5000.00          | 0.863         | 6.74          |
| <i>Impatiens scabrida</i>        | 3333.33          | 1.074         | 6.25          |
| <i>Koeleria cristata</i>         | 5000.00          | 1.669         | 8.41          |
| <i>Lotus corniculatus</i>        | 11666.67         | 2.257         | 15.51         |
| <i>Podophyllum hexandrum</i>     | 5000.00          | 0.148         | 5.26          |
| <i>Polygonatum verticillatum</i> | 3333.33          | 1.011         | 6.12          |
| <i>Ranunculus hirtellus</i>      | 5000.00          | 0.756         | 6.52          |
| <i>Rumex nepalensis</i>          | 11666.67         | 5.258         | 23.90         |
| <i>Salvia nubicola</i>           | 5000.00          | 1.062         | 7.15          |
| <i>Selinum candolli</i>          | 1666.67          | 0.404         | 3.94          |
| <i>Silene griffithii</i>         | 3333.33          | 1.051         | 6.20          |
| <i>Smilacina purpurea</i>        | 6666.67          | 3.817         | 15.97         |
| <i>Stellaria media</i>           | 8333.33          | 1.845         | 10.63         |
| <i>Urtica ardens</i>             | 5000.00          | 0.645         | 6.29          |
| <i>Valeriana pyrolaefolia</i>    | 3333.33          | 0.760         | 5.60          |
| <b>Total</b>                     | <b>178333.33</b> | <b>48.237</b> | <b>300.00</b> |

*Anaphalis contorta* was dominant species at E<sub>1</sub> with IVI of 20.18, whereas *Urtica ardens* was co-dominant with IVI of 16.38 and *Sonchus asper* was associate species with IVI of 15.75. At E<sub>2</sub>, *Iris nepalensis* was the dominant species (IVI as 16.09) and *Achyranthes bidentata* (IVI as 12.86) as co-dominant and *Urtica ardens* (IVI as 12.55) as associated species. Lowest IVI of 3.31 was observed for *Heracleum candicans*. At E<sub>3</sub>, *Rumex nepalensis* was the dominant species with IVI of 23.90, *Anaphalis contorta* as co-dominant species with IVI of 23.07 and *Lotus corniculatus* as an associate species with IVI of 15.51. *Selinum candolli* exhibited IVI as 3.94 indicating its rarity (Table 35)

A perusal of the data presented in Table 36 reveals that 72 forb species were recorded in moist temperate deciduous forests at different elevations. Maximum number of species

(42) was recorded at E<sub>1</sub>, 29 forbs were recorded at E<sub>2</sub> and 36 forbs at E<sub>3</sub>. Among three elevations, highest density (238333.33 plants/ha) and basal area (87.234 m<sup>2</sup>/cm) of forbs was recorded at E<sub>1</sub> followed by E<sub>2</sub> with density of forbs as 212666.67 plants/ha with basal area of 69.273 cm<sup>2</sup>/m<sup>2</sup>. While the lowest values for density (202666.67 plants/ha) and basal area (68.041 cm<sup>2</sup>/m<sup>2</sup>) of forbs was recorded at elevation E<sub>3</sub>.

At E<sub>1</sub>, among forbs maximum density (21666.67 plants/ha) and basal area (6.859 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Anaphalis contorta* followed by *Fragaria nubicola* (density as 18333.33 plants/ha and basal area as 5.219 cm<sup>2</sup>/m<sup>2</sup>) while, least density (1666.67 plants/ha) and basal area (0.328 cm<sup>2</sup>/m<sup>2</sup>) was recorded for *Nasturtium officinale*. At E<sub>2</sub>, highest density of 28333.33 plants/ha and basal area of 6.385 cm<sup>2</sup>/m<sup>2</sup> was recorded for *Bergenia stracheyi*, followed by *Thalictrum foliolosum* (density = 19333.33 plants/ha and basal area = 5.232 cm<sup>2</sup>/m<sup>2</sup>), while lowest density and basal area of 1666.67 plants/ha and 0.214 cm<sup>2</sup>/m<sup>2</sup>, respectively was recorded for *Anemone obtusiloba*. At E<sub>3</sub> *Anaphalis contorta* exhibited highest density and basal area of 18333.33 plants/ha and 5.835 cm<sup>2</sup>/m<sup>2</sup>, followed by *Polygonatum verticillatum* with density as 15333.33 plants/ha and basal area as 4.731 cm<sup>2</sup>/m<sup>2</sup>. Whereas lowest density of 1666.67 plants/ha and basal area of 0.206 cm<sup>2</sup>/m<sup>2</sup> was recorded for species *Cirsium wallichii* (Table 36).

*Anaphalis contorta* was dominant forb at E<sub>1</sub> with highest IVI of 26.46, while *Fragaria nubicola* was co-dominant (20.24) and *Senecio alatus* was the associate forb species with IVI of 17.96. Whereas IVI of 3.72 was recorded for *Androsace rotundifolia* confirming its rarity. At E<sub>2</sub> *Bergenia stracheyi* was dominant forb with highest IVI of 32.23, co-dominant species was *Carex remota* with an IVI as 30.03 and associate species was *Thalictrum foliolosum* with IVI as 29.12. while, *Polygonatum cirrhifolium* was rare species (IVI = 2.09). At E<sub>3</sub>, *Anaphalis contorta* was dominant species with highest IVI of 27.75, *Polygonatum verticillatum* was co-dominant species with IVI as 23.41 and *Taraxacum officinale* was associate species with IVI of 19.44. Whereas, *Cirsium wallichii* was observed as rare forb species with IVI of 2.70. (Table 36).

**Table 36: Density, basal area, and importance value index (IVI) of forbs in upper moist temperate deciduous forests at different elevations**

| Forb Species                                 | Density (plants/ha) | Basal area (cm <sup>2</sup> /m <sup>2</sup> ) | IVI  |
|----------------------------------------------|---------------------|-----------------------------------------------|------|
| <b>Elevation-E<sub>1</sub> (1700-2300 m)</b> |                     |                                               |      |
| <i>Adiantum venustum</i>                     | 3333.33             | 1.895                                         | 4.88 |
| <i>Ajuga bracteosa</i>                       | 3333.33             | 3.408                                         | 6.46 |

|                                   |                  |               |               |
|-----------------------------------|------------------|---------------|---------------|
| <i>Anaphalis contorta</i>         | 21666.67         | 6.859         | 26.46         |
| <i>Androsace lanuginosa</i>       | 3333.33          | 0.682         | 4.25          |
| <i>Androsace rotundifolia</i>     | 3333.33          | 0.786         | 3.72          |
| <i>Arctium lappa</i>              | 15000.00         | 4.090         | 16.50         |
| <i>Asplenium trichomanes</i>      | 3333.33          | 1.778         | 4.75          |
| <i>Astilbe rivularis</i>          | 3333.33          | 0.864         | 3.80          |
| <i>Bergenia stracheyi</i>         | 5000.00          | 1.232         | 4.82          |
| <i>Carduus nutans</i>             | 5000.00          | 2.331         | 5.97          |
| <i>Carex remota</i>               | 8333.33          | 2.467         | 9.01          |
| <i>Chenopodium opulifolium</i>    | 6666.67          | 2.608         | 9.16          |
| <i>Duchesnea indica</i>           | 3333.33          | 0.818         | 3.75          |
| <i>Erigeron bellidioides</i>      | 6666.67          | 1.691         | 7.56          |
| <i>Fragaria nubicola</i>          | 18333.33         | 5.219         | 20.24         |
| <i>Galium aparine</i>             | 3333.33          | 1.370         | 4.33          |
| <i>Geranium wallichianum</i>      | 5000.00          | 1.324         | 4.92          |
| <i>Koeleria cristata</i>          | 3333.33          | 1.373         | 4.33          |
| <i>Lamium album</i>               | 3333.33          | 0.737         | 4.31          |
| <i>Mentha longifolium</i>         | 3333.33          | 0.993         | 3.93          |
| <i>Nasturtium officinale</i>      | 1666.67          | 0.328         | 3.88          |
| <i>Nepeta leucophylla</i>         | 5000.00          | 1.058         | 4.64          |
| <i>Phragmites communis</i>        | 3333.33          | 2.657         | 5.67          |
| <i>Polygonatum verticillatum</i>  | 5000.00          | 1.674         | 5.29          |
| <i>Potentilla leschenaultiana</i> | 5000.00          | 1.670         | 5.28          |
| <i>Roscoea purpurea</i>           | 5000.00          | 1.547         | 5.15          |
| <i>Salvia nubicola</i>            | 5000.00          | 2.653         | 6.31          |
| <i>Scirpus roylei</i>             | 3333.33          | 2.396         | 5.40          |
| <i>Senecio alatus</i>             | 15000.00         | 4.881         | 17.96         |
| <i>Senecio chrysanthemoides</i>   | 3333.33          | 0.938         | 3.88          |
| <i>Silene griffithii</i>          | 3333.33          | 1.192         | 4.14          |
| <i>Silene vulgaris</i>            | 5000.00          | 2.483         | 6.13          |
| <i>Smilacina purpurea</i>         | 5000.00          | 1.218         | 4.81          |
| <i>Sonchus asper</i>              | 5000.00          | 4.821         | 8.57          |
| <i>Taraxacum officinale</i>       | 3333.33          | 4.821         | 7.93          |
| <i>Thalictrum foliolosum</i>      | 5000.00          | 1.153         | 4.74          |
| <i>Thymus linearis</i>            | 3333.33          | 1.118         | 4.06          |
| <i>Valeriana jatamansi</i>        | 3333.33          | 0.929         | 3.87          |
| <i>Verbascum thapsus</i>          | 5000.00          | 2.153         | 14.61         |
| <i>Vicatia coniiifolia</i>        | 3333.33          | 1.197         | 4.15          |
| <i>Viola canescens</i>            | 13333.33         | 2.538         | 15.51         |
| <i>Youngia japonica</i>           | 3333.33          | 1.283         | 4.88          |
| <b>Total</b>                      | <b>238333.33</b> | <b>87.234</b> | <b>300.00</b> |

| <b>Elevation-E<sub>2</sub> (2300-2900 m)</b> |                  |               |               |
|----------------------------------------------|------------------|---------------|---------------|
| <i>Achyranthes bidentata</i>                 | 10000.00         | 4.010         | 17.96         |
| <i>Adiantum venustum</i>                     | 3333.33          | 1.530         | 5.07          |
| <i>Agrimonia pilosa</i>                      | 11666.67         | 4.842         | 17.36         |
| <i>Ainsliaea aptera</i>                      | 15000.00         | 7.902         | 23.89         |
| <i>Anaphalis contorta</i>                    | 3333.33          | 2.212         | 6.18          |
| <i>Anemone obtusiloba</i>                    | 1666.67          | 0.214         | 3.95          |
| <i>Arisaema flavum</i>                       | 10000.00         | 2.233         | 10.65         |
| <i>Bergenia stracheyi</i>                    | 21666.67         | 6.385         | 32.23         |
| <i>Carex cardiolepis</i>                     | 3333.33          | 0.458         | 2.41          |
| <i>Carex remota</i>                          | 11666.67         | 4.380         | 30.03         |
| <i>Clinopodium vulgare</i>                   | 6666.67          | 1.870         | 7.01          |
| <i>Erigeron bellidioides</i>                 | 6666.67          | 1.355         | 7.90          |
| <i>Erigeron multicaulis</i>                  | 3333.33          | 1.281         | 4.95          |
| <i>Fagopyrum dibotrys</i>                    | 3333.33          | 1.287         | 4.65          |
| <i>Heracleum candicans</i>                   | 3333.33          | 0.991         | 4.26          |
| <i>Iris nepalensis</i>                       | 3333.33          | 0.843         | 3.75          |
| <i>Polygonatum cirrhifolium</i>              | 5000.00          | 0.678         | 2.09          |
| <i>Polygonatum verticillatum</i>             | 16666.67         | 4.691         | 19.38         |
| <i>Primula petiolaris</i>                    | 6666.67          | 3.941         | 14.88         |
| <i>Rumex nepalensis</i>                      | 6666.67          | 1.289         | 7.08          |
| <i>Salvia nubicola</i>                       | 3333.33          | 0.822         | 3.62          |
| <i>Scirpus roylei</i>                        | 3333.33          | 0.882         | 3.80          |
| <i>Senecio chrysanthemoides</i>              | 8333.33          | 2.488         | 9.50          |
| <i>Senecio nudicaulis</i>                    | 5000.00          | 0.809         | 4.12          |
| <i>Silene griffithii</i>                     | 3333.33          | 0.974         | 4.24          |
| <i>Smilacina purpurea</i>                    | 5000.00          | 0.970         | 4.33          |
| <i>Swertia cordata</i>                       | 8333.33          | 2.704         | 9.36          |
| <i>Thalictrum foliolosum</i>                 | 19333.33         | 5.232         | 29.12         |
| <i>Tragopogon gracilis</i>                   | 3333.33          | 2.000         | 6.21          |
| <b>Total</b>                                 | <b>212666.67</b> | <b>69.273</b> | <b>300.00</b> |
| <b>Elevation-E<sub>3</sub> (2900-3500 m)</b> |                  |               |               |
| <i>Agrimonia pilosa</i>                      | 3333.33          | 0.902         | 4.47          |
| <i>Ainsliaea aptera</i>                      | 1666.67          | 1.659         | 4.81          |
| <i>Ajuga bracteosa</i>                       | 3333.33          | 1.537         | 5.39          |
| <i>Anaphalis contorta</i>                    | 15000.00         | 5.835         | 27.75         |
| <i>Androsace sarmentosa</i>                  | 3333.33          | 0.569         | 3.98          |
| <i>Anemone obtusiloba</i>                    | 3333.33          | 1.255         | 4.98          |
| <i>Angelica glauca</i>                       | 8333.33          | 2.160         | 10.21         |
| <i>Artemisia roxburghiana</i>                | 6666.67          | 2.302         | 9.65          |

|                                  |                  |               |               |
|----------------------------------|------------------|---------------|---------------|
| <i>Bergenia stracheyi</i>        | 3333.33          | 1.705         | 5.63          |
| <i>Carduus nutans</i>            | 5000.00          | 1.446         | 6.01          |
| <i>Carex remota</i>              | 3333.33          | 1.654         | 5.56          |
| <i>Cirsium wallichii</i>         | 1666.67          | 0.206         | 2.70          |
| <i>Clinopodium vulgare</i>       | 3333.33          | 0.701         | 4.17          |
| <i>Eriophorum comosum</i>        | 10000.00         | 4.689         | 16.28         |
| <i>Fragaria nubicola</i>         | 8333.33          | 0.631         | 7.98          |
| <i>Gypsophila cerastioides</i>   | 5000.00          | 1.927         | 6.71          |
| <i>Halenia elliptica</i>         | 9666.67          | 3.422         | 15.19         |
| <i>Heracleum candicans</i>       | 5000.00          | 1.072         | 5.47          |
| <i>Impatiens scabrida</i>        | 3333.33          | 0.989         | 4.59          |
| <i>Koeleria cristata</i>         | 9666.67          | 3.506         | 15.32         |
| <i>Lotus corniculatus</i>        | 3333.33          | 0.556         | 3.96          |
| <i>Pedicularis hoffmeisteri</i>  | 3333.33          | 2.884         | 7.35          |
| <i>Polygonatum verticillatum</i> | 13333.33         | 4.731         | 23.41         |
| <i>Ranunculus hirtellus</i>      | 3333.33          | 2.244         | 6.42          |
| <i>Salvia nubicola</i>           | 3333.33          | 1.062         | 4.70          |
| <i>Selinum candolli</i>          | 6666.67          | 2.754         | 10.31         |
| <i>Senecio chrysanthemoides</i>  | 6666.67          | 2.160         | 9.45          |
| <i>Sibbaldia cuneata</i>         | 8333.33          | 2.798         | 11.13         |
| <i>Silene vulgaris</i>           | 8333.33          | 1.609         | 9.41          |
| <i>Smilacina purpurea</i>        | 5000.00          | 0.564         | 4.73          |
| <i>Taraxacum officinale</i>      | 10000.00         | 4.169         | 19.44         |
| <i>Thlaspi cochleariforme</i>    | 3333.33          | 1.209         | 4.91          |
| <i>Thymus linearis</i>           | 3333.33          | 0.377         | 3.70          |
| <i>Valeriana pyrolaefolia</i>    | 3333.33          | 1.722         | 5.66          |
| <i>Vicatia coniifolia</i>        | 3333.33          | 0.343         | 3.65          |
| <i>Youngia japonica</i>          | 5000.00          | 0.688         | 4.91          |
| <b>Total</b>                     | <b>202666.67</b> | <b>68.041</b> | <b>300.00</b> |

There was significant decrease in density of forbs in different forests in the order: FT-4 > FT-3 > FT-5 > FT-2 > FT-7 > FT-8 > FT-9 > FT-1 > FT-6. Likewise, the basal area of forbs decreased significant among forests in the order: Basal area showed the precedence: FT-3 > FT-6 > FT-1 > FT-9 > FT-4 > FT-7 > FT-8 > FT-5 > FT-2. The effect of elevation on density of forbs in different forests yielded significantly decreasing trend as: E<sub>1</sub> (250989.48 plants/ha) > E<sub>2</sub> (221849.00 plants/ha) > E<sub>3</sub> (193125.51 plants/ha). Similarly, basal area showed decreasing trend as: E<sub>1</sub> (88.740) > E<sub>2</sub> (69.273) > E<sub>3</sub> (66.092). The interaction effect of forest types and elevations on density and basal area of forbs was significant (Table 37).



**Table 37: Change in density (plants/ha) and basal area (cm<sup>2</sup>/m<sup>2</sup>) of forbs among forests (F) and elevations (E)**

| Forest Types (F) | Density (plants/ha) at different elevations (E) |                |                | Mean             | Basal area (ccm2/m2) at different elevations (E) |                |                | Mean           |
|------------------|-------------------------------------------------|----------------|----------------|------------------|--------------------------------------------------|----------------|----------------|----------------|
|                  | E <sub>1</sub>                                  | E <sub>2</sub> | E <sub>3</sub> |                  | E <sub>1</sub>                                   | E <sub>2</sub> | E <sub>3</sub> |                |
| <b>FT-1</b>      | 221333.34                                       | 198333.33      | 178333.33      | <b>199333.33</b> | 118.065                                          | 90.345         | 87.951         | <b>98.787</b>  |
| <b>FT-2</b>      | 275837.33                                       | 221989.00      | 186311.67      | <b>228046.00</b> | 49.684                                           | 40.845         | 35.897         | <b>42.142</b>  |
| <b>FT-3</b>      | 258333.33                                       | 236666.67      | 195000.00      | <b>230000.00</b> | 123.975                                          | 110.601        | 105.296        | <b>113.291</b> |
| <b>FT-4</b>      | 278333.33                                       | 258333.33      | 236666.67      | <b>257777.78</b> | 97.732                                           | 71.942         | 61.886         | <b>77.187</b>  |
| <b>FT-5</b>      | 255000.00                                       | 235000.00      | 198333.33      | <b>229444.44</b> | 50.714                                           | 45.707         | 40.08          | <b>45.5</b>    |
| <b>FT-6</b>      | 218167.33                                       | 195001.33      | 173902.00      | <b>195690.22</b> | 100.36                                           | 76.79          | 74.76          | <b>83.79</b>   |
| <b>FT-7</b>      | 256900.66                                       | 216983.99      | 188582.56      | <b>220822.40</b> | 85.601                                           | 59.615         | 59.488         | <b>68.235</b>  |
| <b>FT-8</b>      | 256666.66                                       | 221666.66      | 178333.33      | <b>218888.88</b> | 67.588                                           | 50.661         | 48.237         | <b>55.495</b>  |
| <b>FT-9</b>      | 238333.33                                       | 212666.67      | 202666.67      | <b>217888.89</b> | 87.234                                           | 69.273         | 68.041         | <b>74.849</b>  |
| <b>Mean</b>      | 250989.48                                       | 221849.00      | 193125.51      | 250989.48        | <b>86.770</b>                                    | <b>68.418</b>  | <b>64.626</b>  |                |
|                  | C.D. 0.05                                       |                |                |                  | C.D. 0.05                                        |                |                |                |
|                  |                                                 | C.D.           | SE (d)         |                  |                                                  | C.D.           | SE (d)         |                |
|                  | F                                               | 4710.32        | 2340.65        |                  | F                                                | 3.68           | 1.83           |                |
|                  | E                                               | 2719.50        | 1351.37        |                  | E                                                | 2.13           | 1.06           |                |
|                  | F X E                                           | 8158.51        | 4054.12        |                  | F X E                                            | 6.38           | 3.17           |                |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different.

The forbs density recorded in the present study falls in the range of 199333.33 to 217888.89 plants/ha. Similar forb 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 forb vegetation in different forest types can be related to difference in over story 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). 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 2007). There are reports about allelochemical 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 also affect understory vegetation structure and function.

The low values of density and basal area of forbs at higher elevations can be ascribed to adverse environmental variables like, total atmospheric pressure and partial pressure of atmospheric gases decreases at higher elevations (Allen *et al.* 1998; Stull 2000; Zmarsly *et al.* 2002) which influence gas exchange in plants (Korner 2007; Terashima *et al.* 1995), precipitation and moisture gradients might increase or decrease depending on region (Whitfield 1932; Khurshid-Alam 1973; Vitousek *et al.* 1990; Marshall and Zhang 1994; Vandewater *et al.* 2002; Klimes 2003; Luo *et al.* 2004, 2005), decrease in atmospheric temperature (Smith and Geller 1979; Barry 1981; Korner and Diemer 1987; Korner 2003; Korner and Paulsen 2004), increase in radiation (Korner *et al.* 1983; Korner 2003; Blumthaler 2007) and reduced growing season (Korner 2003; Korner 1998a; Korner 1998b and Wang *et al.* 2007).

Altitudinal variation in herbage growth in forest has been reported by Jamwal and Uniyal (2008); Sevgi and Tecimen (2008); Sharma (2012); Gupta and Sharma (2015); Farooq (2012); Sharma (2012); Mahato (2013); Yadav (2017) and Bhutia (2017).

#### **4.5 REGENERATION STUDIES**

The perusal of data presented in Table 38 reveals that in Ban Oak forests highest number of recruits were recorded at  $E_1$  (740.38 plants/ha) followed by  $E_2$  (422.56 plants/ha) and  $E_3$  (366.47 plants/ha). Similarly, maximum un-established regeneration of 566.98 plants/ha was observed at  $E_1$ , followed by  $E_2$  (564.16 plants/ha) while least values were recorded at  $E_3$  (523.74 plants/ha). For established regeneration, maximum value of 866.97 plants/ha was recorded at  $E_1$ , followed by  $E_2$  (596.36 plants/ha). Lowest established regeneration was recorded at  $E_3$  (521.19 plants/ha).

In Moru Oak forests, recruits, un-established and established regeneration was recorded in the trend of  $E_1 > E_2 > E_3$ . At  $E_1$  values of different regeneration parameters were:  $R/ha = 5134.08$  plants/ha,  $Un/ha = 1022.58$  plants/ha and  $E/ha = 1233.45$  plants/ha, at  $E_2$

their values were: R/ha =2547.39 plants/ha, Un/ha = 936.34 plants/ha and E/ha = 1045.72 plants/ha) and at E<sub>3</sub> their values were: R/ha =246.78 plants/ha, Un/ha = 879.68 plants/ha and E/ha = 969.36 plants/ha) (Table 38).

**Table 38: Regeneration status of different forests types (F) at three different elevations (E)**

| Forests type (F) | Elevation (E)  |         |         |                |         |         |                |         |         |
|------------------|----------------|---------|---------|----------------|---------|---------|----------------|---------|---------|
|                  | E <sub>1</sub> |         |         | E <sub>2</sub> |         |         | E <sub>3</sub> |         |         |
|                  | R/ha           | Un/ha   | E/ha    | R/ha           | Un/ha   | E/ha    | R/ha           | Un/ha   | E/ha    |
| <b>FT-1</b>      | 740.38         | 566.98  | 866.97  | 422.56         | 564.16  | 596.36  | 366.47         | 523.74  | 521.19  |
| <b>FT-2</b>      | 5134.08        | 1022.58 | 1233.45 | 2547.39        | 963.34  | 1045.72 | 2436.78        | 879.68  | 969.36  |
| <b>FT-3</b>      | 10698.54       | 1157.84 | 1428.76 | 7327.77        | 1354.28 | 1363.48 | 5197.24        | 1137.54 | 1249.84 |
| <b>FT-4</b>      | 470.08         | 299.63  | 259.45  | 416.11         | 234.21  | 257.14  | 401.36         | 213.96  | 224.86  |
| <b>FT-5</b>      | 1301.09        | 687.96  | 569.63  | 1093.35        | 596.37  | 523.74  | 865.47         | 521.34  | 485.37  |
| <b>FT-6</b>      | 4521.67        | 1378.95 | 987.63  | 4452.31        | 1178.48 | 963.74  | 3000.25        | 1236.35 | 755.24  |
| <b>FT-7</b>      | 968.64         | 385.15  | 301.24  | 342.52         | 268.49  | 296.38  | 257.54         | 226.33  | 247.87  |
| <b>FT-8</b>      | 638.75         | 253.67  | 196.35  | 261.39         | 223.58  | 149.78  | 226.51         | 204.57  | 132.15  |
| <b>FT-9</b>      | 643.81         | 547.28  | 478.36  | 633.69         | 445.52  | 427.43  | 475.32         | 396.87  | 398.43  |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different. Where: R/ha = regeneration /hectare, Un/ha = Unestablished regeneration/hectare and E/ha = Established regeneration/hectare.

In Deodar forests, maximum recruits of 10698.54 plants/ha were recorded at elevation E<sub>1</sub> that decrease to 7327.77 (plants/ha) at E<sub>2</sub> and lowest recruits of 5197.24 (plants/ha) were recorded at E<sub>3</sub>. In case of un-established regeneration, maximum value (1157.84 plants/ha) was recorded at E<sub>1</sub> followed by E<sub>2</sub> (1354.28 plants/ha) while least value was recorded at E<sub>3</sub> (1137.54 plants/ha). At E<sub>1</sub>, maximum established regeneration of 1428.76 plants/ha was observed which was followed by E<sub>2</sub> (1363.48 plants/ha) and lowest established regeneration (1249.84 plants/ha) was found at E<sub>3</sub> (Table 38).

At E<sub>1</sub>, in western mixed coniferous forests, maximum recruits (470.08 plants/ha) were recorded followed by E<sub>2</sub> (416.11 plants/ha) and E<sub>3</sub> (401.36 plants/ha). Highest value of established regeneration was recorded at E<sub>1</sub> (259.45 plants/ha) that decreased at E<sub>2</sub> to 257.14 plants/ha and lowest value of 224.86 plants/ha was observed at E<sub>3</sub>. Un-established regeneration was found to be highest at E<sub>1</sub> (229.63 plants/ha) as compared to E<sub>2</sub> (234.21 plants/ha) and E<sub>3</sub> (213.96 plants/ha) (Table 38).

In moist temperate lower deciduous forests, number of recruits at E<sub>1</sub> were 1301.09 plants/ha) were highest among all three elevations i.e. E<sub>2</sub> (1093.35 plants/ha) and E<sub>3</sub> (865.47 plants/ha). Un-established regeneration was observed highest at E<sub>1</sub> (687.96 plants/ha) as

compared to  $E_2$  (596.37 plants/ha) and  $E_3$  (521.34 plants/ha). At  $E_1$  maximum established regeneration (569.63 plants/ha) was recorded which was followed by  $E_2$  (523.74 plants/ha) and least was recorded at  $E_3$  (485.37 plants/ha) (Table 38).

$E_1$  exhibited highest recruits (4521.67 plants/ha) in Kail forests, followed by  $E_2$  (4452.31 plants/ha) while least number of recruits (300.25 plants/ha) in Kail forests was observed at  $E_3$ . Un-established regeneration of 1378.95 plants/ha in Kail forests was recorded at  $E_1$  that decreased to 1178.48 plants/ha at  $E_2$  and to 1236.35 plants/ha at  $E_3$ . At  $E_1$  established regeneration of 987.63 plants/ha was observed which was highest as compared to  $E_2$  (963.74 plants/ha) and  $E_3$  (755.24 plants/ha).

In Kharsu Oak forests, number of recruits showed the trend of  $E_1$  (968.64 plants/ha) >  $E_2$  (342.52 plants/ha) >  $E_3$  (257.54 plants/ha). Un-established regeneration of 385.15 was recorded at  $E_1$  which was highest as compared to other elevations i.e.  $E_2$  (268.49 plants/ha) and  $E_3$  (226.33 plants/ha). At  $E_1$  maximum established regeneration (301.24 plants/ha) was observed which was followed by  $E_2$  with 296.38 plants/ha while lowest established regeneration of 247.87 plants/ha was recorded at  $E_3$ .

In upper Oak-Fir forests, highest recruits were recorded at  $E_1$  (638.75 plants/ha) that decreased to 261.39 plants/ha at  $E_2$ , while lowest recruits were observed at  $E_3$  (226.51 plants/ha). Established (196.35 plants/ha) and un-established (253.67 plants/ha) regeneration was maximum at  $E_1$  followed by  $E_2$  ( $E/ha = 149.78$  plants/ha and  $Un/ha = 223.58$  plants/ha). Least number of established (132.15 plants/ha) and un-established regeneration (204.57 plants/ha) were recorded at  $E_3$  (Table 38).

In moist temperate upper deciduous forests, maximum recruits were observed at  $E_1$  (643.81 plants/ha), followed by  $E_2$  (633.69 plants/ha) and  $E_3$  (475.32 plants/ha). Highest value of un-established regeneration was recorded at  $E_1$  (547.28 plants/ha) that decreased to 445.52 plants/ha at  $E_2$  while lowest un-established regeneration (396.87 plants/ha) was observed at  $E_3$ . Established regeneration was recorded maximum at  $E_1$  (478.36 plants/ha) followed by  $E_2$  (427.43 plants/ha) and  $E_3$  (398.43 plants/ha) (Table 38).

Perusal of Table 38 reveals that maximum number of recruits (plants/ha) among all the forests types was recorded in Deodar forests with maximum number of recruits (10698.54 plants/ha) at  $E_1$ , followed by Moru Oak forests (5134.08 plants/ha) and Kail forests (4521.67

plants/ha) while minimum number of recruits (470.08 plants/ha) were recorded in western mixed coniferous forests. Maximum number of un-established regeneration was recorded in Kail forests (1378.95 plants/ha) followed by Deodar forests (1157.84 plants/ha) and upper Oak-Fir forests exhibited low un-established regeneration (253.67 plants/ha). Deodar forests showed highest number of established regeneration (1428.76 plants/ha) followed by Moru Oak forests (1233.45 plants/ha). While, minimum number of established regeneration (196.35 plants/ha) was observed in upper Oak-Fir forests.

At  $E_2$ , maximum recruits were recorded in Deodar forests (7327.77 plants/ha). Likewise, maximum un-established (1354.28 plants/ha) and established (1363.48 plants/ha) regeneration was also observed in Deodar forests, followed by Kail forests and Moru Oak forests with 1178.48 plants/ha (un-established regeneration) and 1045.72 plants/ha (established regeneration), respectively. Lowest un-established and established regeneration (223.58 plants/ha and 149.78 plants/ha, respectively) was observed in upper Oak-Fir forests (Table 38).

**Table 39: Establishment stocking per cent and regeneration success of different forests at three different elevations**

| Forests type (F) | Elevation (E) |      |         |        |            |      |         |       |            |      |         |       |
|------------------|---------------|------|---------|--------|------------|------|---------|-------|------------|------|---------|-------|
|                  | $E_1$         |      |         |        | $E_2$      |      |         |       | $E_3$      |      |         |       |
|                  | Est. Index    | SI   | Est. SI | Reg. % | Est. Index | SI   | Est. SI | Reg % | Est. Index | SI   | Est. SI | Reg % |
| FT-1             | 0.60          | 0.40 | 17.10   | 40.35  | 0.47       | 0.30 | 14.27   | 30.41 | 0.33       | 0.26 | 8.75    | 26.49 |
| FT-2             | 0.61          | 0.60 | 36.09   | 59.56  | 0.49       | 0.51 | 25.34   | 51.44 | 0.43       | 0.48 | 21.16   | 47.52 |
| FT-3             | 0.56          | 0.71 | 39.78   | 70.13  | 0.66       | 0.68 | 45.23   | 68.05 | 0.45       | 0.61 | 27.59   | 60.89 |
| FT-4             | 0.50          | 0.13 | 6.64    | 13.37  | 0.49       | 0.13 | 6.16    | 12.63 | 0.24       | 0.11 | 2.67    | 11.13 |
| FT-5             | 0.52          | 0.30 | 15.52   | 29.66  | 0.37       | 0.27 | 10.03   | 26.91 | 0.49       | 0.25 | 12.10   | 24.63 |
| FT-6             | 0.32          | 0.53 | 24.05   | 53.29  | 0.43       | 0.50 | 21.53   | 50.33 | 0.50       | 0.43 | 20.66   | 42.57 |
| FT-7             | 0.42          | 0.16 | 6.64    | 15.90  | 0.47       | 0.15 | 6.77    | 14.54 | 0.49       | 0.12 | 6.00    | 12.18 |
| FT-8             | 0.39          | 0.10 | 4.05    | 10.39  | 0.47       | 0.08 | 3.90    | 8.23  | 0.39       | 0.07 | 2.86    | 7.35  |
| FT-9             | 0.54          | 0.25 | 13.29   | 24.61  | 0.36       | 0.22 | 7.79    | 21.55 | 0.49       | 0.20 | 9.82    | 19.91 |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in  $E_1$ ,  $E_2$  and  $E_3$  is different. Where: Est. Index = Establishment index, SI = Stocking index and Reg % = Regeneration per cent.

At E<sub>3</sub>, Deodar forests exhibited highest number of recruits (5197.24 plants/ha). Whereas, maximum un-established (1236.35 plants/ha) regeneration was recorded in Kail forests, followed by Deodar forests (1137.54 plants/ha) while minimum un-established regeneration (204.57 plants/ha) was observed in upper Oak-Fir forests. Highest established regeneration (1249.84 plants/ha) was recorded for Deodar forests, followed by Moru Oak forests (969.36 plants/ha). While in upper Oak-Fir s lowest un-established and established regeneration was recorded as: 204.57 plants/ha and 132.15 plants/ha, respectively. (Table 38).

Data pertaining to established stocking per cent presented in Table 39 reveals that, among different forests, overall established stocking index was maximum (39.78 % at E<sub>1</sub>, 45.23 % at E<sub>2</sub> and 27.59 at E<sub>3</sub>) in Deodar forests followed by Moru Oak forests (36.09 % at E<sub>1</sub>, 25.34 % at E<sub>2</sub> and 21.16 % at E<sub>3</sub>) and Kail forests (24.05% at E<sub>1</sub>, 21.53 at E<sub>2</sub> and 20.66 at E<sub>3</sub>). Among different forests per cent regeneration was also highest in Deodar forests at all the three elevations. Highest regeneration per cent (70.13 %) in Deodar forests was recorded at E<sub>1</sub> followed by E<sub>2</sub> (68.05 %) and least regeneration per cent was recorded at E<sub>3</sub> (60.89 %). Regeneration per cent in Moru forests was slightly low as: 59.56 % at E<sub>1</sub>, 51.44 % at E<sub>2</sub> and 47.52 % at E<sub>3</sub> and Kail forests as: 53.29 % at E<sub>1</sub>, 50.33 % at E<sub>2</sub> and 42.57% at E<sub>3</sub>. Lowest regeneration per cent was observed in upper Oak-Fir forests as: 10.39 % at E<sub>1</sub>, 8.23 % at E<sub>2</sub> and 7.35 % at E<sub>3</sub>.

Plants maintain and expand their populations in time and space by the process of regeneration. Population dynamics of plant species can be described by demographic variables such as the recruitment, mortality and growth rates of individuals (Watkinson 1997) and the balance among these variables has been found to regulate the dynamics and the structure of a population (Kohyama and Hara 1989). Regeneration of any species is restricted to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution (Grubb 1977). The natural regeneration of a tree species however depends largely on the production and germination of seeds and the establishment of seedlings and saplings.

The pattern of population dynamics of seedlings, saplings and adults of a plants species can exhibit the recruitment profile, which is used to determine their regeneration status (Bekele 1994). A population with sufficient number of seedlings and saplings depicts satisfactory regeneration behaviour, while inadequate number of seedlings and saplings of the

species in a forest indicates poor regeneration (Tripathi and Khan 2007). The density of seedlings and saplings are considered as regeneration potential of a species. Good and Good (1972) and Duan *et al.* (2009) considered three major components viz., ability to initiate new seedlings, ability of seedlings and saplings to survive and ability of seedlings and saplings to grow for successful regeneration of a species

Table 38 revealed maximum recruits, un-established and established regeneration in deodar forest, followed by Moru Oak forests and Kail forests while least values were recorded for upper Oak-fir forests at E<sub>1</sub>. The better regeneration of Deodar forests might be attributed to less thickness of organic matter, higher available nitrogen, available potassium and soil pH. The results are supported by the work of Calaona and Giannini (1971), Singh and Singh (1987) and Pengshalin *et al.* (2006), who reported that depth of organic matter had indirect relationship with established stocking per cent. Similar finding have also been reported by Gordon (1970) in *Abies pindrow* and Ram Prakash (1991) in *Cedrus deodara*.

Results got support from work of Sood and Bhatia (1991) who while working in forest of Shimla district of Himachal Pradesh observed that three selected sites were dominated by high density seedling and saplings of pure conifers (*Cedrus deodara* and *Pinus roxburghii*) in site III and mixed conifer and broad leaves (*Quercus spp.*, *Picea smithiana* and *Pinus wallichiana*) in site II and pure broadleaves (*Quercus leucotrichophora* and *Rhododendron arboreum*) in site I. Rather (2014) also reported during his work, that the recruitment of deodar was in the good category with few exceptions of fair and poor on some aspects of lower and higher altitude. The presence of larger number of deodar seedlings across the forest range might be attributed to its easy germination. Similar observation was reported by Shrestha (2003) for *Quercus semecarpifolia* in the Himalayan region. The profuse regeneration of the conifers can be attributed to the presence of abundant shrub cover which often plays a vital role in increasing regeneration rate (Garcia *et al.*, 2000). Strong nurse plant relationship between conifer seedlings and shrubs has also been reported by Callaway (1995). Poor to fair regeneration status of *Pinus wallichiana* was due to slow vegetative growth during the seedling stage as compared to *Cedrus deodara* (Rather 2014).

Maximum regeneration was recorded at lower altitude E<sub>1</sub> than E<sub>2</sub> and E<sub>3</sub>. The variation in seedling density among the forests and/or species along the altitudinal gradient may be due to change in climatic conditions which could restrict the distribution of some species via the germination and establishment of seedlings (Vera 1997). Lowest recruits, un-established and

established regeneration was reported at upper Oak-Fir forests and Kharsu Oak forests. This may be attributed to frequent lopping of trees for fodder, fuel and grazing resulting more seedlings under un-established status. Low per cent regeneration success of Oak and its association might be due to over exploitation of Oak for fodder, fuel and grazing. The investigation by Rangel and Vargas (2000) reported that Oak species dominated the canopy but not the understory. Similar results have been reported by Ammer (1996) while studying the natural regeneration of mixed mountain forests in Bavarian Alps. Shrestha (2003) reported the death of saplings and small trees before they reach the canopy in the Himalayan region. Lack of sufficient regeneration is a major problem of mountain forests (Krauchi *et al.* 2000).

The better regeneration of Deodar forest might be attributed to less thickness of organic matter, higher available nitrogen, available potassium and soil pH. The results are supported by the work of Calaona and Giannini (1971). Malik *et al.* (2012) while working on regeneration status of *Pinus gerardiana* reported that the zone-III at lower elevation (2580 m amsl) resulted in maximum weighted average height (169.05) and establishment index (0.84) while as zone-II at lower elevation (2180 m amsl) showed maximum stocking index (0.265), establishment stocking (16.04 %) and regeneration (26.50 %) on the left bank, i.e., western aspect of the area. Singh and Singh (1987) and Pengshalin *et al.* (2006) who reported that depth of organic matter had indirect relationship with established stocking per cent. Similar finding have also been reported by Gordon (1970) in *Abies pindrow* Ram Prakash (1991) in *Cedrus deodara*. The depth of humus layer showed inverse relationship between some major forest communities. Ali (2011) reported maximum weighted average height (79.99 cm), established index (0.39) and establishment stocking per cent (3.81) for *Betula utilis* in Sangla forest, the regeneration success however, decreased from lower (9.54%) to upper (4.24%) elevation. Working on *Pinus gerardiana* in Kinnaur, Kumar (2012) observed maximum establishment index (0.517) and establishment stocking per cent (6.72) for the species in Moorang range, while regeneration success was highest (15.93%) in Kilba range.

Seeds play vital role in the process of natural regeneration of tree species. The most important prerequisite of natural regeneration from seed is the production of adequate quantities of fertile seed by the tree of the area or immediate neighborhood (Deiller *et al.* 2003). Acorns production is highly erratic from year to year and seed loss due to insect, birds and mammals predation can be very high. Since seeds of Oak suffer heavy predation from a



variety of animals and insects infestation therefore natural regeneration may be unsuccessful unless these are adequately controlled (Harmer, 1994). Greeley and Ashe (1907) and Foster and Ashe (1908) observed that the infestation by insect resulted in the scarcity of Oak reproduction in eastern hardwood forests. *Q. leucotrichophora* produces seed crops that vary widely in quantity from year to year (mast crop to no crop). Troup (1921) and Negi *et al.* (1996) have reported mast crop in every 2 – 3 years.

Tree regeneration can be predicted by the structure of their populations (Khan *et al.* 1987). In general regeneration of species is affected by various anthropogenic factors (Sukumar *et al.* 1994; Barik *et al.* 1996b; Iqbal *et al.* 2012) and natural phenomena (Welden *et al.* 1991). Working with the status of natural regeneration of *Juniperous macropoda* in Ladakh region, Sharma and Raj (2004) found biotic pressure of overgrazing and lopping twigs and cones for burning as incense as major factors responsible for poor natural regeneration in the species. Gupta (2007) on the other hand, reported that recruits of *Abies pindrow* were much higher (4250/ha) in selected Kotgarh site than in Kullu (3168/ha) forest. Similarly, investigation on the population structure and regeneration of maples in protected and unprotected areas, Rana *et al.*, (2011) observed that maples regenerated in six habitat types in Himachal Pradesh. On the other hand, Bobiec *et al.* (2011) experimenting on regeneration of Oak (*Quercus robur* L.) in Bialowieza National Park in Poland observed that the average number of Oak seedlings/saplings per hectare varied from 56 in deciduous forests to 333 in mixed-deciduous and 360 in mixed-coniferous forest types.

## **4.6 VEGETATION BIOMASS AND CARBON**

### **4.6.1 Biomass and carbon in trees**

In different forests volume, aboveground biomass (stem + branches + leaves), belowground biomass, total biomass (aboveground + belowground) and total carbon (aboveground + belowground) in constituent trees yielded the following:

In Ban Oak forests, data presented in Table 40 revealed that volume and biomass of trees decreased along the elevation in the order:  $E_1 > E_2 > E_3$ . At  $E_1$ , highest tree volume (154.61 m<sup>3</sup>/ha), aboveground biomass (465.40 t/ha), belowground biomass (87.36 t/ha), total tree biomass (552.76 t/ha) and total carbon (276.38 t/ha) existed followed by  $E_2$  with total volume of trees as 129.85 m<sup>3</sup>/ha, aboveground biomass as 374.27 t/ha, belowground biomass as 68.97 t/ha, total biomass as 443.24 t/ha and total carbon as 221.62 t/ha. The least total tree

volume (104.27 m<sup>3</sup>/ha), aboveground biomass (243.65 t/ha), belowground biomass (47.41 t/ha), total biomass (291.06 t/ha) and total carbon (145.53 t/ha) were recorded at E<sub>3</sub>.

**Table 40: Volume, aboveground (AGB), belowground (BGB, total biomass (TB) and total carbon (TC) of trees in Ban Oak (*Q. leucotrichophora*) forests at different elevations**

| Tree Species                             | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon<br>(t/ha) |
|------------------------------------------|--------------------------------|----------------------|----------------------|---------------|------------------|
|                                          |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC)    |
| Elevation - E <sub>1</sub> (700 -1300 m) |                                |                      |                      |               |                  |
| <i>Albizia chinensis</i>                 | 0.24                           | 0.87                 | 0.19                 | 1.06          | 0.53             |
| <i>Bauhinia variegata</i>                | 0.32                           | 1.16                 | 0.24                 | 1.40          | 0.70             |
| <i>Lyonia ovalifolia</i>                 | 0.95                           | 3.49                 | 0.77                 | 4.26          | 2.13             |
| <i>Mallotus philippensis</i>             | 0.16                           | 0.57                 | 0.11                 | 0.68          | 0.34             |
| <i>Pinus roxburghii</i>                  | 5.91                           | 14.24                | 2.99                 | 17.23         | 8.62             |
| <i>Pistacia integerrimma</i>             | 0.50                           | 1.84                 | 0.37                 | 2.21          | 1.10             |
| <i>Prunus armeniaca</i>                  | 0.90                           | 3.34                 | 0.66                 | 4.00          | 2.00             |
| <i>Pyrus pashia</i>                      | 0.42                           | 1.54                 | 0.30                 | 1.84          | 0.92             |
| <i>Quercus leucotrichophora</i>          | 145.21                         | 438.35               | 83.79                | 522.14        | 261.07           |
| <b>Total</b>                             | <b>154.61</b>                  | <b>465.40</b>        | <b>87.36</b>         | <b>552.76</b> | <b>276.38</b>    |
| Elevation – E <sub>2</sub> (1300-1900 m) |                                |                      |                      |               |                  |
| <i>Lyonia ovalifolia</i>                 | 0.32                           | 1.19                 | 0.26                 | 1.45          | 0.73             |
| <i>Mallotus philippensis</i>             | 0.16                           | 0.55                 | 0.12                 | 0.67          | 0.33             |
| <i>Myrica esculenta</i>                  | 1.26                           | 4.47                 | 0.98                 | 5.45          | 2.73             |
| <i>Neolitsea pallens</i>                 | 0.16                           | 0.54                 | 0.11                 | 0.65          | 0.32             |
| <i>Pinus roxburghii</i>                  | 4.59                           | 15.57                | 3.27                 | 18.84         | 9.42             |
| <i>Pistacia integerrimma</i>             | 1.24                           | 4.57                 | 0.91                 | 5.48          | 2.74             |
| <i>Prunus armeniaca</i>                  | 1.09                           | 3.36                 | 0.67                 | 4.03          | 2.01             |
| <i>Pyrus pashia</i>                      | 0.31                           | 0.95                 | 0.18                 | 1.13          | 0.57             |
| <i>Quercus leucotrichophora</i>          | 120.36                         | 342.58               | 65.48                | 408.06        | 204.03           |
| <i>Rhododendron arboreum</i>             | 0.36                           | 0.49                 | 0.09                 | 0.58          | 0.29             |
| <b>Total</b>                             | <b>129.85</b>                  | <b>374.27</b>        | <b>68.97</b>         | <b>443.24</b> | <b>221.62</b>    |
| Elevation – E <sub>3</sub> (1900-2500 m) |                                |                      |                      |               |                  |
| <i>Cedrus deodara</i>                    | 15.80                          | 21.08                | 4.64                 | 25.72         | 12.86            |
| <i>Juglans regia</i>                     | 2.51                           | 12.69                | 2.66                 | 15.35         | 7.68             |
| <i>Myrica esculenta</i>                  | 0.32                           | 2.31                 | 0.51                 | 2.82          | 1.41             |
| <i>Pinus wallichiana</i>                 | 0.29                           | 0.94                 | 0.19                 | 1.13          | 0.56             |
| <i>Prunus armeniaca</i>                  | 0.66                           | 1.70                 | 0.36                 | 2.06          | 1.03             |
| <i>Quercus leucotrichophora</i>          | 84.61                          | 204.70               | 40.94                | 245.64        | 122.82           |
| <i>Rhododendron arboreum</i>             | 0.08                           | 0.23                 | 0.05                 | 0.28          | 0.14             |
| <b>Total</b>                             | <b>104.27</b>                  | <b>243.65</b>        | <b>47.41</b>         | <b>291.06</b> | <b>145.53</b>    |

At all the three elevations among different trees *Quercus leucotrichophora* exhibited maximum tree volume, AGB, BGB, TB and TC, with highest values at E<sub>1</sub> (tree volume as 145.21 m<sup>3</sup>/ha, AGB as 438.35 t/ha, BGB as 83.79 t/ha, TB of 522.14 t/ha and TC as 261.07

t/ha). While lowest tree volume among the three elevations was exhibited by *Mallotus philippensis* (0.16 m<sup>3</sup>/ha) at elevation E<sub>1</sub>. Lowest aboveground biomass (0.23 t/ha), belowground biomass (0.05 t/ha), total tree biomass (0.28 t/ha) and total tree carbon (0.14 t/ha) was recorded in *Rhododendron arboreum* at elevation E<sub>3</sub>. (Table 40).

At elevation E<sub>1</sub>, tree volume ranged from 0.16 m<sup>3</sup>/ha to 145.21 m<sup>3</sup>/ha while aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.57 t/ha to 438.35 t/ha, 0.11 t/ha to 83.79 t/ha, 0.68 t/ha to 522.14 t/ha and 0.34 t/ha to 261.07 t/ha respectively. At E<sub>2</sub> tree volume varied from 0.15 to 120.36 m<sup>3</sup>/ha and aboveground biomass, belowground biomass total tree biomass varied from 0.49 t/ha to 342.58 t/ha, 0.09 t/ha to 65.48 t/ha, 0.58 t/ha to 408.06 t/ha and 0.29 t/ha to 204.03 t/ha respectively, while volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 0.08 m<sup>3</sup>/ha to 84.61 m<sup>3</sup>/ha, 0.23 t/ha to 204.70 t/ha, 0.05 t/ha to 40.94 t/ha, 0.28 t/ha to 245.64 t/ha and 0.14 t/ha to 122.82 t/ha respectively at elevation E<sub>3</sub> (Table 40).

A perusal of the data presented in Table 41 reveals that Moru Oak forests among three elevations, at elevation E<sub>1</sub> highest tree volume (228.27 m<sup>3</sup>/ha), aboveground tree biomass (455.93 t/ha), belowground tree biomass (92.69 t/ha), total tree biomass (548.62 t/ha) and total carbon (274.31 t/ha) was recorded followed by E<sub>2</sub> with total volume (167.97 m<sup>3</sup>/ha), aboveground biomass (247.44 t/ha), belowground biomass (52.44 t/ha), total biomass (299.87 t/ha) and total carbon (149.93 t/ha). Least total tree volume (119.97 m<sup>3</sup>/ha), aboveground biomass (185.16 t/ha), belowground biomass (38.53 t/ha), total biomass (223.71 t/ha) and total tree carbon (111.86 t/ha) was recorded at E<sub>3</sub>.

Among trees maximum tree volume, AGB, BGB, TB and TC was exhibited for *Quercus floribunda* at all the three elevations, however their highest values was recorded at E<sub>1</sub> with volume as 182.49 m<sup>3</sup>/ha, aboveground biomass as 366.10 t/ha, belowground biomass as 73.22 t/ha, total biomass of 439.32 t/ha and total carbon as 219.66 t/ha. While lowest tree volume (0.44 m<sup>3</sup>/ha), aboveground biomass (1.58 t/ha), belowground biomass (0.33 t/ha), total tree biomass (1.91 t/ha) and total tree carbon (0.96 t/ha) at E<sub>1</sub> was recorded for *Rhododendron arboreum*. Whereas, *Ilex dipyrrena* exhibited lowest values of volume (0.23 t/ha at E<sub>2</sub> and 0.08 t/ha at E<sub>3</sub>), aboveground biomass (0.83 t/ha at E<sub>2</sub> and 0.27 t/ha at E<sub>3</sub>), belowground biomass (0.18 t/ha at E<sub>2</sub> and 0.06 t/ha at E<sub>3</sub>), total biomass (1.01 t/ha at E<sub>2</sub> and 0.33 t/ha at E<sub>3</sub>) and tree carbon (0.51 t/ha at E<sub>2</sub> and 0.16 t/ha at E<sub>3</sub>) as shown in (Table 41).

**Table 41: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total tree carbon (TC) of trees in Moru Oak (*Q. floribunda*) forests at different elevations**

| Tree species                            | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon (t/ha) |
|-----------------------------------------|--------------------------------|----------------------|----------------------|---------------|---------------|
|                                         |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC) |
| Elevation- E <sub>1</sub> (1800-2300 m) |                                |                      |                      |               |               |
| <i>Cedrus deodara</i>                   | 32.06                          | 50.33                | 11.07                | 61.40         | 30.70         |
| <i>Cupressus torulosa</i>               | 4.13                           | 7.99                 | 1.68                 | 9.67          | 4.83          |
| <i>Lyonia ovalifolia</i>                | 4.83                           | 13.97                | 3.07                 | 17.04         | 8.52          |
| <i>Prunus cornuta</i>                   | 0.88                           | 3.24                 | 0.65                 | 3.89          | 1.94          |
| <i>Pyrus lanata</i>                     | 3.44                           | 12.72                | 2.67                 | 15.39         | 7.70          |
| <i>Quercus floribunda</i>               | 182.49                         | 366.10               | 73.22                | 439.32        | 219.66        |
| <i>Rhododendron arboreum</i>            | 0.44                           | 1.58                 | 0.33                 | 1.91          | 0.96          |
| <b>Total</b>                            | <b>228.27</b>                  | <b>455.93</b>        | <b>92.69</b>         | <b>548.62</b> | <b>274.31</b> |
| Elevation- E <sub>2</sub> (2300-2800 m) |                                |                      |                      |               |               |
| <i>Abies pindrow</i>                    | 41.12                          | 74.75                | 16.45                | 91.20         | 45.60         |
| <i>Cedrus deodara</i>                   | 12.29                          | 17.79                | 3.74                 | 21.53         | 10.76         |
| <i>Ilex dipyrena</i>                    | 0.23                           | 0.83                 | 0.18                 | 1.01          | 0.51          |
| <i>Lyonia ovalifolia</i>                | 4.40                           | 2.87                 | 0.57                 | 3.44          | 1.72          |
| <i>Picea smithiana</i>                  | 21.01                          | 26.57                | 5.58                 | 32.15         | 16.07         |
| <i>Pinus wallichiana</i>                | 24.79                          | 23.45                | 4.69                 | 28.14         | 14.07         |
| <i>Quercus floribunda</i>               | 57.94                          | 99.13                | 20.82                | 119.95        | 59.97         |
| <i>Rhododendron arboreum</i>            | 6.18                           | 2.04                 | 0.41                 | 2.45          | 1.23          |
| <b>Total</b>                            | <b>167.97</b>                  | <b>247.44</b>        | <b>52.44</b>         | <b>299.87</b> | <b>149.93</b> |
| Elevation- E <sub>3</sub> (2800-3300 m) |                                |                      |                      |               |               |
| <i>Abies spectabilis</i>                | 28.01                          | 39.22                | 8.63                 | 47.85         | 23.92         |
| <i>Acer caesium</i>                     | 0.81                           | 2.85                 | 0.60                 | 3.45          | 1.72          |
| <i>Aesculus indica</i>                  | 1.12                           | 3.94                 | 0.87                 | 4.81          | 2.40          |
| <i>Cedrus deodara</i>                   | 29.86                          | 39.42                | 7.88                 | 47.30         | 23.65         |
| <i>Ilex dipyrena</i>                    | 0.08                           | 0.27                 | 0.06                 | 0.33          | 0.16          |
| <i>Picea smithiana</i>                  | 32.46                          | 39.28                | 7.86                 | 47.14         | 23.57         |
| <i>Quercus floribunda</i>               | 27.64                          | 60.20                | 12.64                | 72.84         | 36.42         |
| <b>Total</b>                            | <b>119.97</b>                  | <b>185.16</b>        | <b>38.53</b>         | <b>223.71</b> | <b>111.86</b> |

Tree volume, aboveground biomass, belowground biomass, total biomass and total tree carbon of trees at elevation E<sub>1</sub> ranged from 0.44 m<sup>3</sup>/ha to 182.49 m<sup>3</sup>/ha, 1.58 t/ha to 366.10 t/ha, 0.33 t/ha to 73.22 t/ha, 1.91 t/ha to 439.32 t/ha and 0.96 t/ha to 219.66 t/ha respectively. At E<sub>2</sub> tree volume varied from 0.23 m<sup>3</sup>/ha to 57.94 m<sup>3</sup>/ha whereas range of aboveground biomass (0.83 t/ha to 99.13 t/ha), belowground biomass (0.18 t/ha to 20.82 t/ha), total biomass (1.01 t/ha to 119.95 t/ha) and total carbon (0.51 t/ha to 59.97 t/ha) while volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 0.08 m<sup>3</sup>/ha to 32.46 m<sup>3</sup>/ha, 0.27 t/ha to 60.20 t/ha, 0.06 t/ha to 12.64 t/ha, 0.33 t/ha to 72.84 t/ha and 0.16 t/ha to 36.42 t/ha respectively at elevation E<sub>3</sub> (Table 41).

Volume, aboveground, belowground, total biomass and total carbon of trees in Deodar forests varied at different elevations (Table 42).

**Table 42: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in Deodar (*C. deodara*) forests at different elevations**

| Tree Species                             | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon<br>(t/ha) |
|------------------------------------------|--------------------------------|----------------------|----------------------|---------------|------------------|
|                                          |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC)    |
| Elevation - E <sub>1</sub> (900-1800 m)  |                                |                      |                      |               |                  |
| <i>Cedrus deodara</i>                    | 280.98                         | 458.64               | 100.90               | 559.54        | 279.77           |
| <i>Lyonia ovalifolia</i>                 | 0.02                           | 0.06                 | 0.01                 | 0.07          | 0.04             |
| <i>Neolitsea pallens</i>                 | 0.03                           | 0.13                 | 0.03                 | 0.16          | 0.08             |
| <i>Prunus armeniaca</i>                  | 0.08                           | 0.41                 | 0.08                 | 0.49          | 0.25             |
| <i>Prunus cerasoides</i>                 | 0.05                           | 0.25                 | 0.05                 | 0.30          | 0.15             |
| <i>Pyrus pashia</i>                      | 0.04                           | 0.17                 | 0.03                 | 0.20          | 0.10             |
| <i>Quercus leucotrichophora</i>          | 0.58                           | 2.93                 | 0.62                 | 3.55          | 1.77             |
| <b>Total</b>                             | <b>281.76</b>                  | <b>462.59</b>        | <b>101.73</b>        | <b>564.30</b> | <b>282.16</b>    |
| Elevation – E <sub>2</sub> (1800-2700 m) |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                     | 9.15                           | 16.47                | 3.62                 | 20.09         | 10.05            |
| <i>Cedrus deodara</i>                    | 181.56                         | 230.58               | 48.42                | 279.00        | 139.50           |
| <i>Ilex dipyrrena</i>                    | 0.21                           | 0.73                 | 0.16                 | 0.89          | 0.45             |
| <i>Lyonia ovalifolia</i>                 | 0.12                           | 0.46                 | 0.09                 | 0.55          | 0.28             |
| <i>Neolitsea pallens</i>                 | 0.07                           | 0.27                 | 0.06                 | 0.33          | 0.16             |
| <i>Picea smithiana</i>                   | 13.24                          | 20.82                | 4.16                 | 24.98         | 12.49            |
| <i>Pinus wallichiana</i>                 | 3.79                           | 6.90                 | 1.45                 | 8.35          | 4.17             |
| <i>Prunus armeniaca</i>                  | 1.72                           | 6.29                 | 1.27                 | 7.56          | 3.78             |
| <i>Prunus cornuta</i>                    | 0.12                           | 0.54                 | 0.11                 | 0.65          | 0.32             |
| <i>Quercus leucotrichophora</i>          | 1.26                           | 4.54                 | 0.90                 | 5.44          | 2.72             |
| <i>Quercus floribunda</i>                | 0.24                           | 0.85                 | 0.17                 | 1.02          | 0.51             |
| <i>Quercus semecarpifolia</i>            | 1.46                           | 5.24                 | 1.01                 | 6.25          | 3.13             |
| <i>Rhododendron arboreum</i>             | 0.11                           | 0.38                 | 0.07                 | 0.45          | 0.23             |
| <b>Total</b>                             | <b>213.06</b>                  | <b>294.08</b>        | <b>61.49</b>         | <b>355.56</b> | <b>177.78</b>    |
| Elevation – E <sub>3</sub> (2700-3600 m) |                                |                      |                      |               |                  |
| <i>Abies spectabilis</i>                 | 1.88                           | 2.48                 | 0.55                 | 3.03          | 1.51             |
| <i>Cedrus deodara</i>                    | 114.14                         | 200.66               | 42.14                | 242.80        | 121.40           |
| <i>Picea smithiana</i>                   | 2.39                           | 5.48                 | 1.21                 | 6.69          | 3.34             |
| <i>Pinus wallichiana</i>                 | 1.91                           | 5.52                 | 1.10                 | 6.62          | 3.31             |
| <i>Populus ciliata</i>                   | 2.71                           | 5.25                 | 1.10                 | 6.35          | 3.18             |
| <i>Prunus cornuta</i>                    | 0.96                           | 1.92                 | 0.38                 | 2.30          | 1.15             |
| <i>Quercus floribunda</i>                | 1.20                           | 0.32                 | 0.07                 | 0.39          | 0.19             |
| <i>Quercus semecarpifolia</i>            | 40.85                          | 1.57                 | 0.32                 | 1.89          | 0.94             |
| <b>Total</b>                             | <b>203.91</b>                  | <b>223.20</b>        | <b>46.86</b>         | <b>270.06</b> | <b>135.03</b>    |

Among all the elevations, at E<sub>1</sub> highest tree volume (281.76 m<sup>3</sup>/ha), aboveground biomass (462.59 t/ha), belowground biomass (101.73 t/ha), total biomass (564.30 t/ha) and total carbon (282.16 t/ha) existed followed by E<sub>2</sub> with total volume of trees as 213.06 m<sup>3</sup>/ha, aboveground biomass as 294.08 t/ha, belowground biomass as 61.49 t/ha, total biomass as 355.56 t/ha and total carbon as 177.78 t/ha. The least values of total tree volume (203.91 m<sup>3</sup>/ha), AGB (223.20 t/ha), BGB (46.86 t/ha), TB (270.06 t/ha) and TC (135.03 t/ha) were recorded at E<sub>3</sub>.

Tree volume, aboveground biomass, belowground biomass, total biomass and total tree carbon of trees at E<sub>1</sub> ranged from 0.02 m<sup>3</sup>/ha to 280.98 m<sup>3</sup>/ha, 0.06 t/ha to 458.64 t/ha, 0.01 t/ha to 100.90 t/ha, 0.07 t/ha to 559.54 t/ha and 0.04 t/ha to 279.77 t/ha respectively. At E<sub>2</sub> tree volume varied from 0.07 m<sup>3</sup>/ha to 181.56 m<sup>3</sup>/ha whereas range of aboveground biomass (0.27 t/ha to 230.58 t/ha), belowground biomass (0.06 t/ha to 48.42 t/ha), total biomass (0.33 t/ha to 279.00 t/ha) and total carbon (0.16 t/ha to 139.50 t/ha) while volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 0.96 m<sup>3</sup>/ha to 114.14 m<sup>3</sup>/ha, 0.32 t/ha to 200.66 t/ha, 0.07 t/ha to 42.14 t/ha, 0.39 t/ha to 242.80 t/ha and 0.19 t/ha to 121.40 t/ha respectively at E<sub>3</sub> (Table 42)

A perusal of the data presented in Table 43 reveals that western mixed coniferous forests among all the elevations, at E<sub>1</sub> highest tree volume (260.24 m<sup>3</sup>/ha), aboveground biomass (384.50 t/ha), belowground biomass (74.98 t/ha), total biomass (459.48 t/ha) and total carbon (229.74 t/ha) was recorded followed by E<sub>2</sub> with total volume of trees as 202.34 m<sup>3</sup>/ha, aboveground biomass as 270.12 t/ha, belowground biomass as 52.67 t/ha, total biomass as 322.79 t/ha and total carbon as 161.40 t/ha. However, least total tree volume (155.86 m<sup>3</sup>/ha), AGB (274.85 t/ha), BGB (55.36 t/ha), TB (330.21 t/ha) and TC (165.11 t/ha) was recorded at E<sub>3</sub>.

Among trees *Picea smithiana* exhibited maximum tree volume, AGB, BGB, TB and TC at three elevations, however their highest values exhibited were at elevation E<sub>1</sub> with volume as 100.83 m<sup>3</sup>/ha, AGB as 131.02 t/ha, BGB as 26.39 t/ha, TB as 157.41 t/ha and TC as 78.71 t/ha. While lowest tree volume (0.19 m<sup>3</sup>/ha), aboveground biomass (0.64 t/ha), belowground biomass (0.13 t/ha), total tree biomass (0.77 t/ha) and total carbon (0.39 t/ha) at E<sub>1</sub> was observed in *Neolitsea pallens*. At elevation E<sub>2</sub>, *Ilex dipyrrena* exhibited lowest volume (0.06 t/ha), aboveground biomass (0.23 t/ha), belowground biomass (0.05 t/ha), total biomass of (0.28 t/ha) and total carbon (0.14 t/ha), while *Populus ciliata* attained least tree volume of

6.99 m<sup>3</sup>/ha, AGB of 20.63 t/ha, BGB of 4.33 t/ha TB of 24.96 t/ha and TC of 12.48 t/ha at elevation E<sub>3</sub> (Table 43).

**Table 43: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in western mixed coniferous forests at different elevations**

| Tree species                             | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon<br>(t/ha) |
|------------------------------------------|--------------------------------|----------------------|----------------------|---------------|------------------|
|                                          |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC)    |
| Elevation - E <sub>1</sub> (1200-2100 m) |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                     | 80.41                          | 112.57               | 24.77                | 137.34        | 68.67            |
| <i>Aesculus indica</i>                   | 4.83                           | 12.89                | 2.71                 | 15.60         | 7.80             |
| <i>Alnus nitida</i>                      | 3.23                           | 11.06                | 2.43                 | 13.49         | 6.75             |
| <i>Cedrus deodara</i>                    | 54.71                          | 85.89                | 17.18                | 103.07        | 51.53            |
| <i>Juglans regia</i>                     | 0.55                           | 1.28                 | 0.27                 | 1.55          | 0.77             |
| <i>Lyonia ovalifolia</i>                 | 1.06                           | 3.93                 | 0.79                 | 4.72          | 2.36             |
| <i>Neolitsea pallens</i>                 | 0.19                           | 0.64                 | 0.13                 | 0.77          | 0.39             |
| <i>Picea smithiana</i>                   | 100.83                         | 131.02               | 26.39                | 157.41        | 78.71            |
| <i>Pinus wallichiana</i>                 | 13.94                          | 23.42                | 4.67                 | 28.09         | 14.04            |
| <i>Rhododendron arboreum</i>             | 0.50                           | 1.80                 | 0.35                 | 2.15          | 1.08             |
| <b>Total</b>                             | <b>260.24</b>                  | <b>384.50</b>        | <b>74.98</b>         | <b>459.48</b> | <b>229.74</b>    |
| Elevation – E <sub>2</sub> (2100-3000 m) |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                     | 82.43                          | 90.68                | 19.95                | 110.63        | 55.31            |
| <i>Acer caesium</i>                      | 3.15                           | 11.10                | 2.33                 | 13.43         | 6.72             |
| <i>Aesculus indica</i>                   | 2.68                           | 9.45                 | 2.08                 | 11.53         | 5.76             |
| <i>Alnus nitida</i>                      | 2.00                           | 6.86                 | 1.37                 | 8.23          | 4.12             |
| <i>Cedrus deodara</i>                    | 15.77                          | 31.08                | 6.53                 | 37.61         | 18.80            |
| <i>Ilex dipyrrena</i>                    | 0.06                           | 0.23                 | 0.05                 | 0.28          | 0.14             |
| <i>Juglans regia</i>                     | 0.30                           | 1.10                 | 0.23                 | 1.33          | 0.67             |
| <i>Picea smithiana</i>                   | 83.92                          | 97.74                | 19.69                | 117.43        | 58.71            |
| <i>Pinus wallichiana</i>                 | 9.85                           | 14.57                | 2.90                 | 17.47         | 8.74             |
| <i>Populus ciliata</i>                   | 2.18                           | 7.31                 | 1.44                 | 8.75          | 4.38             |
| <b>Total</b>                             | <b>202.34</b>                  | <b>270.12</b>        | <b>52.67</b>         | <b>322.79</b> | <b>161.40</b>    |
| Elevation – E <sub>3</sub> (3000-3900 m) |                                |                      |                      |               |                  |
| <i>Abies spectabilis</i>                 | 77.52                          | 85.28                | 18.76                | 104.04        | 52.02            |
| <i>Cedrus deodara</i>                    | 26.23                          | 41.18                | 8.65                 | 49.83         | 24.91            |
| <i>Picea smithiana</i>                   | 61.44                          | 71.27                | 15.68                | 86.95         | 43.47            |
| <i>Pinus wallichiana</i>                 | 17.28                          | 36.83                | 7.37                 | 44.20         | 22.10            |
| <i>Populus ciliata</i>                   | 6.99                           | 20.63                | 4.33                 | 24.96         | 12.48            |
| <i>Quercus semecarpifolia</i>            | 32.46                          | 64.28                | 12.86                | 77.14         | 38.57            |
| <i>Taxus wallichiana</i>                 | 11.46                          | 40.67                | 8.54                 | 49.21         | 24.61            |
| <b>Total</b>                             | <b>155.86</b>                  | <b>274.85</b>        | <b>55.36</b>         | <b>330.21</b> | <b>165.11</b>    |

At elevation  $E_1$ , tree volume ranged from 0.19  $\text{m}^3/\text{ha}$  to 100.83  $\text{m}^3/\text{ha}$  while aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.64 t/ha to 131.02 t/ha, 0.13 t/ha to 26.39 t/ha, 0.77 t/ha to 157.41 t/ha and 0.39 t/ha to 78.71 t/ha respectively. At  $E_2$  tree volume varied from 0.06 to 83.92  $\text{m}^3/\text{ha}$  and aboveground biomass, belowground biomass total tree biomass varied from 0.23 t/ha to 97.74 t/ha, 0.05 t/ha to 19.95 t/ha, 0.28 t/ha to 117.43 t/ha and 0.14 t/ha to 58.71 t/ha, while volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 6.99  $\text{m}^3/\text{ha}$  to 77.52  $\text{m}^3/\text{ha}$ , 20.63 t/ha to 85.28 t/ha, 4.33 t/ha to 18.76 t/ha, 24.96 t/ha to 104.04 t/ha and 12.48 t/ha to 52.02 t/ha respectively at  $E_3$  (Table 43).

A perusal of the data presented in Table 44 reveals that moist temperate lower deciduous forests among all the elevations, at  $E_1$  highest tree volume (159.18  $\text{m}^3/\text{ha}$ ), aboveground tree biomass (245.42 t/ha), belowground tree biomass (48.38 t/ha), total tree biomass (293.80 t/ha) and total tree carbon (146.90 t/ha) was recorded, followed by  $E_2$  with total volume of trees as 126.40  $\text{m}^3/\text{ha}$ , aboveground tree biomass as 194.28 t/ha, belowground tree biomass as 39.13 t/ha, total biomass as 233.41 t/ha and total carbon as 116.71 t/ha. The least tree volume (104.28  $\text{m}^3/\text{ha}$ ), aboveground biomass (171.58 t/ha), belowground biomass (36.03 t/ha), total biomass (207.61 t/ha) and total tree carbon (103.81 t/ha) was recorded at  $E_3$ .

At elevation  $E_1$ , highest volume (49.45 t/ha), aboveground biomass (57.56 t/ha), belowground biomass (12.09 t/ha), total biomass (69.65 t/ha) and total carbon (34.82 t/ha) was recorded for *Pinus wallichiana*, descended in *Acer caesium* with volume, ABG, BGB, TB and TC as 46.58  $\text{m}^3/\text{ha}$ , 52.63 t/ha, 10.53 t/ha, 63.16 t/ha and 31.58 t/ha respectively. However lowest volume (0.98  $\text{m}^3/\text{ha}$ ), aboveground biomass (3.62 t/ha), belowground biomass (0.73 t/ha) total biomass (4.35 t/ha) and total carbon (2.17 t/ha) at  $E_1$  was recorded for *Pyrus lanata*.

At elevation  $E_2$ , *Cedrus deodara* exhibited maximum volume (51.82  $\text{m}^3/\text{ha}$ ), aboveground biomass (59.59 t/ha), belowground biomass (13.11 t/ha), total biomass (72.70 t/ha) and total carbon (36.35 t/ha). While lowest volume (2.11  $\text{m}^3/\text{ha}$ ), aboveground biomass (7.74 t/ha), belowground biomass (1.63 t/ha), total biomass (9.37 t/ha) and total carbon (4.68 t/ha) was observed in *Ulmus wallichiana*. At elevation  $E_3$ , highest volume was recorded for *Abies pindrow* as 29.89  $\text{m}^3/\text{ha}$ , highest aboveground biomass (34.78 t/ha), belowground biomass (9.08 t/ha), total biomass (52.34 t/ha) and total carbon (26.17 t/ha). Lowest volume



(3.89 m<sup>3</sup>/ha), aboveground biomass (14.50 t/ha), belowground biomass (3.19 t/ha), total biomass (17.69 t/ha) and total carbon (8.85 t/ha) at E<sub>3</sub> was recorded by *Fraxinus micrantha* (Table 44).

**Table 44: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total tree carbon (TC) of trees in moist temperate lower deciduous forests at different elevations**

| Tree species                            | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |                          | Carbon<br>(t/ha) |
|-----------------------------------------|--------------------------------|----------------------|----------------------|--------------------------|------------------|
|                                         |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>biomass<br>(TB) | Total<br>(TC)    |
| Elevation- E <sub>1</sub> (1000-1800 m) |                                |                      |                      |                          |                  |
| <i>Acer caesium</i>                     | 46.58                          | 57.56                | 12.09                | 69.65                    | 34.82            |
| <i>Aesculus indica</i>                  | 4.28                           | 15.1                 | 3.32                 | 18.42                    | 9.21             |
| <i>Cedrus deodara</i>                   | 33.17                          | 51.13                | 11.25                | 62.38                    | 31.19            |
| <i>Fraxinus micratha</i>                | 6.68                           | 17.99                | 3.6                  | 21.59                    | 10.79            |
| <i>Juglans regia</i>                    | 5.81                           | 13.58                | 2.85                 | 16.43                    | 8.22             |
| <i>Pinus wallichiana</i>                | 49.45                          | 52.63                | 10.53                | 63.16                    | 31.58            |
| <i>Prunus cornuta</i>                   | 1.59                           | 5.81                 | 1.22                 | 7.03                     | 3.52             |
| <i>Pyrus lanata</i>                     | 0.98                           | 3.62                 | 0.73                 | 4.35                     | 2.17             |
| <i>Ulmus wallichiana</i>                | 10.67                          | 28.01                | 5.58                 | 33.59                    | 16.8             |
| <b>Total</b>                            | <b>159.18</b>                  | <b>245.42</b>        | <b>48.38</b>         | <b>293.80</b>            | <b>146.90</b>    |
| Elevation- E <sub>2</sub> (1800-2400 m) |                                |                      |                      |                          |                  |
| <i>Acer caesium</i>                     | 14.74                          | 28.25                | 5.93                 | 34.18                    | 17.09            |
| <i>Aesculus indica</i>                  | 3.8                            | 13.43                | 2.95                 | 16.38                    | 8.19             |
| <i>Cedrus deodara</i>                   | 51.82                          | 59.59                | 13.11                | 72.7                     | 36.35            |
| <i>Fraxinus micratha</i>                | 4.32                           | 16.38                | 3.28                 | 19.66                    | 9.83             |
| <i>Juglans regia</i>                    | 2.67                           | 12.11                | 2.54                 | 14.65                    | 7.33             |
| <i>Pinus wallichiana</i>                | 46.94                          | 56.79                | 11.36                | 68.15                    | 34.07            |
| <i>Ulmus wallichiana</i>                | 2.11                           | 7.74                 | 1.63                 | 9.37                     | 4.68             |
| <b>Total</b>                            | <b>126.40</b>                  | <b>194.28</b>        | <b>39.13</b>         | <b>233.41</b>            | <b>116.71</b>    |
| Elevation- E <sub>3</sub> (2400-2700 m) |                                |                      |                      |                          |                  |
| <i>Abies pindrow</i>                    | 29.89                          | 34.78                | 7.65                 | 42.43                    | 21.22            |
| <i>Acer caesium</i>                     | 22.50                          | 43.26                | 9.08                 | 52.34                    | 26.17            |
| <i>Fraxinus micratha</i>                | 3.89                           | 14.50                | 3.19                 | 17.69                    | 8.85             |
| <i>Picea smithiana</i>                  | 21.05                          | 30.73                | 6.15                 | 36.88                    | 18.44            |
| <i>Populus ciliata</i>                  | 12.28                          | 17.94                | 3.77                 | 21.71                    | 10.85            |
| <i>Ulmus wallichiana</i>                | 14.68                          | 30.38                | 6.08                 | 36.46                    | 18.23            |
| <b>Total</b>                            | <b>104.28</b>                  | <b>171.58</b>        | <b>36.03</b>         | <b>207.61</b>            | <b>103.81</b>    |

A wide range in tree volume, tree biomass and carbon was observed in different elevations for different species. However volume, total biomass and total carbon ranges from 0.98 m<sup>3</sup>/ha t/ha to 49.45 m<sup>3</sup>/ha, 4.35 t/ha to 69.65 t/ha and 2.17 t/ha to 34.82 t/ha at E<sub>1</sub>, 2.11

m<sup>3</sup>/ha to 51.82 m<sup>3</sup>/ha, 9.37 to 72.70 t/ha and 4.68 t/ha to 36.35 t/ha at E<sub>2</sub>, 3.89 m<sup>3</sup>/ha to 29.89 m<sup>3</sup>/ha, 17.69 to 52.34 t/ha and 8.85 t/ha to 26.17 t/ha at E<sub>3</sub> respectively (Table 44).

Data presented in Table 45 reveals that Kail forests among all the elevations, at E<sub>1</sub> highest volume (123.98 m<sup>3</sup>/ha), aboveground biomass (221.47 t/ha), belowground biomass (42.24 t/ha), total biomass (263.71 t/ha) and total carbon (131.85 t/ha) was recorded followed by E<sub>2</sub> with total volume of trees (112.50 m<sup>3</sup>/ha), aboveground biomass (169.97 t/ha), belowground biomass (32.13 t/ha), total biomass (202.10 t/ha) and carbon (101.05 t/ha). The least total tree volume (100.15 m<sup>3</sup>/ha), aboveground biomass (123.81 t/ha), belowground biomass (26.00 t/ha), total biomass (149.81 t/ha) and total carbon (74.91 t/ha) were recorded at E<sub>3</sub>.

Among trees *Pinus wallichiana* exhibited maximum tree volume, AGB, BGB, TB and TC at all the three elevations, however its highest values were recorded at E<sub>1</sub> volume as 106.16 m<sup>3</sup>/ha, aboveground biomass as 158.44 t/ha, belowground biomass as 31.69 t/ha, total biomass as 190.13 t/ha and total carbon as 95.06 t/ha. While lowest tree volume (0.03 m<sup>3</sup>/ha), aboveground biomass (0.11 t/ha), belowground biomass (0.02 t/ha), total tree biomass (0.13 t/ha) and total carbon (0.07 t/ha) at E<sub>1</sub> was recorded in *Lyonia ovalifolia*. While *Prunus cornuta* exhibited minimum volume (0.02 t/ha), aboveground biomass (0.18 t/ha), belowground biomass (0.04 t/ha), total biomass of (0.22 t/ha) and total tree carbon (0.11 t/ha) at elevation E<sub>2</sub>, while at elevation E<sub>3</sub> least values with regard to tree volume as 0.44 m<sup>3</sup>/ha, aboveground biomass as 1.12 t/ha, belowground biomass as 0.22 t/ha, total tree biomass as 1.34 t/ha and tree carbon as 0.67 t/ha was recorded in *Taxus wallichiana* (Table 45).

A wide range in volume, biomass and carbon was observed in different elevations for different species. However volume, aboveground biomass, belowground biomass, total biomass and total carbon ranges from 0.03 m<sup>3</sup>/ha to 106.16 m<sup>3</sup>/ha, 0.11 t/ha to 158.44 t/ha, 0.02 t/ha to 31.69 t/ha, 0.13 t/ha to 190.13 t/ha and 0.07 t/ha to 95.06 t/ha respectively at E<sub>1</sub>, 0.02 m<sup>3</sup>/ha to 76.54 m<sup>3</sup>/ha, 0.18 t/ha to 90.31 t/ha, 0.04 t/ha to 18.97 t/ha, 0.22 t/ha to 109.28 t/ha and 0.11 t/ha to 54.64 t/ha respectively at E<sub>2</sub>, while at E<sub>3</sub> volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 0.44 m<sup>3</sup>/ha to 63.11 m<sup>3</sup>/ha, 1.12 t/ha to 79.31 t/ha, 0.22 t/ha to 16.66 t/ha, 1.34 t/ha to 95.97 t/ha and 0.67 t/ha to 47.98 t/ha, respectively (Table 45).

**Table 45: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in Kail (*Pinus wallichiana*) forests at different elevations**

| Tree species                            | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon<br>(t/ha) |
|-----------------------------------------|--------------------------------|----------------------|----------------------|---------------|------------------|
|                                         |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC)    |
| Elevation- E <sub>1</sub> (1400-2100 m) |                                |                      |                      |               |                  |
| <i>Alnus nitida</i>                     | 0.89                           | 3.08                 | 0.68                 | 3.76          | 1.88             |
| <i>Cupressus torulosa</i>               | 0.28                           | 0.98                 | 0.21                 | 1.19          | 0.59             |
| <i>Juglans regia</i>                    | 3.40                           | 12.27                | 2.70                 | 14.97         | 7.48             |
| <i>Lyonia ovalifolia</i>                | 0.03                           | 0.11                 | 0.02                 | 0.13          | 0.07             |
| <i>Neolitsea pallens</i>                | 0.25                           | 0.91                 | 0.19                 | 1.10          | 0.55             |
| <i>Pinus wallichiana</i>                | 106.16                         | 158.44               | 31.69                | 190.13        | 95.06            |
| <i>Prunus cerasoides</i>                | 0.07                           | 0.24                 | 0.05                 | 0.29          | 0.15             |
| <i>Prunus cornuta</i>                   | 0.14                           | 0.50                 | 0.10                 | 0.60          | 0.30             |
| <i>Pyrus pashia</i>                     | 0.05                           | 0.20                 | 0.04                 | 0.24          | 0.12             |
| <i>Quercus leucotrichophora</i>         | 12.38                          | 43.55                | 8.59                 | 52.14         | 26.07            |
| <i>Rhamnus triqueter</i>                | 0.04                           | 0.15                 | 0.03                 | 0.18          | 0.09             |
| <i>Rhododendron arboreum</i>            | 0.30                           | 1.06                 | 0.20                 | 1.26          | 0.63             |
| <b>Total</b>                            | <b>123.98</b>                  | <b>221.47</b>        | <b>42.24</b>         | <b>263.71</b> | <b>131.85</b>    |
| Elevation-E <sub>2</sub> (2100-2800 m)  |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                    | 2.11                           | 7.16                 | 1.58                 | 8.74          | 4.37             |
| <i>Alnus nitida</i>                     | 1.56                           | 1.56                 | 0.33                 | 1.89          | 0.94             |
| <i>Cedrus deodara</i>                   | 22.66                          | 36.88                | 8.11                 | 44.99         | 22.50            |
| <i>Juglans regia</i>                    | 3.12                           | 11.26                | 2.25                 | 13.51         | 6.76             |
| <i>Lyonia ovalifolia</i>                | 0.04                           | 0.16                 | 0.03                 | 0.19          | 0.10             |
| <i>Picea smithiana</i>                  | 3.44                           | 11.92                | 2.38                 | 14.30         | 7.15             |
| <i>Pinus wallichiana</i>                | 76.54                          | 90.31                | 18.97                | 109.28        | 54.64            |
| <i>Populus ciliata</i>                  | 0.94                           | 3.16                 | 0.64                 | 3.80          | 1.90             |
| <i>Prunus cornuta</i>                   | 0.02                           | 0.19                 | 0.04                 | 0.23          | 0.11             |
| <i>Pyrus pashia</i>                     | 0.05                           | 0.18                 | 0.04                 | 0.22          | 0.11             |
| <i>Quercus floribunda</i>               | 0.15                           | 0.55                 | 0.11                 | 0.66          | 0.33             |
| <i>Quercus leucotrichophora</i>         | 0.68                           | 2.44                 | 0.47                 | 2.91          | 1.46             |
| <i>Rhododendron arboreum</i>            | 0.11                           | 0.41                 | 0.08                 | 0.49          | 0.24             |
| <i>Taxus wallichiana</i>                | 1.07                           | 3.81                 | 0.73                 | 4.54          | 2.27             |
| <b>Total</b>                            | <b>112.50</b>                  | <b>169.97</b>        | <b>32.13</b>         | <b>202.10</b> | <b>101.05</b>    |
| Elevation-E <sub>3</sub> (2800-3600 m)  |                                |                      |                      |               |                  |
| <i>Abies spectabilis</i>                | 4.81                           | 6.80                 | 1.50                 | 8.30          | 4.15             |
| <i>Acer caesium</i>                     | 3.78                           | 15.00                | 3.15                 | 18.15         | 9.08             |
| <i>Cedrus deodara</i>                   | 23.45                          | 12.78                | 2.81                 | 15.59         | 7.80             |
| <i>Picea smithiana</i>                  | 4.55                           | 8.65                 | 1.73                 | 10.38         | 5.19             |
| <i>Pinus wallichiana</i>                | 63.11                          | 79.31                | 16.66                | 95.97         | 47.98            |
| <i>Taxus wallichiana</i>                | 0.44                           | 1.12                 | 0.22                 | 1.34          | 0.67             |
| <b>Total</b>                            | <b>100.15</b>                  | <b>123.81</b>        | <b>26.00</b>         | <b>149.81</b> | <b>74.91</b>     |

A perusal of the data presented in Table 46 reveals that Kharsu Oak forests among all the elevations, at E<sub>1</sub> highest tree volume (225.86 m<sup>3</sup>/ha), aboveground tree biomass (430.24 t/ha), belowground tree biomass (83.90 t/ha), total tree biomass (514.14 t/ha) and total tree carbon (257.07 t/ha) was recorded. Which was followed by E<sub>2</sub> with total volume of trees as 192.91 m<sup>3</sup>/ha, aboveground tree biomass as 299.78 t/ha, belowground tree biomass as 60.38 t/ha, total tree biomass as 360.16 t/ha and total tree carbon as 180.08 t/ha. The least values of total tree volume (167.34 m<sup>3</sup>/ha), aboveground biomass (237.01 t/ha), belowground biomass (47.40 t/ha), total biomass (284.41 t/ha) and total tree carbon (142.21 t/ha) were recorded at E<sub>3</sub>.

**Table 46: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total tree carbon (TC) of trees in Kharsu Oak (*Q. semecarpifolia*) forests at different elevations**

| Tree species                            | Volume (m <sup>3</sup> /ha) | Biomass (t/ha)    |                   |               | Carbon (t/ha) |
|-----------------------------------------|-----------------------------|-------------------|-------------------|---------------|---------------|
|                                         |                             | Aboveground (AGB) | Belowground (BGB) | Total (TB)    | Total (TC)    |
| Elevation- E <sub>1</sub> (2300-2800 m) |                             |                   |                   |               |               |
| <i>Abies pindrow</i>                    | 49.58                       | 69.41             | 15.27             | 84.68         | 42.34         |
| <i>Acer caesium</i>                     | 3.44                        | 12.10             | 2.54              | 14.64         | 7.32          |
| <i>Aesculus indica</i>                  | 8.51                        | 8.63              | 1.90              | 10.53         | 5.26          |
| <i>Cedrus deodara</i>                   | 12.80                       | 59.27             | 11.85             | 71.12         | 35.56         |
| <i>Juglans regia</i>                    | 2.87                        | 6.37              | 1.34              | 7.71          | 3.85          |
| <i>Picea smithiana</i>                  | 40.36                       | 58.97             | 11.79             | 70.76         | 35.38         |
| <i>Pinus wallichiana</i>                | 0.27                        | 1.00              | 0.21              | 1.21          | 0.61          |
| <i>Prunus cornuta</i>                   | 0.24                        | 0.90              | 0.18              | 1.08          | 0.54          |
| <i>Quercus floribunda</i>               | 16.65                       | 33.13             | 6.60              | 39.73         | 19.87         |
| <i>Quercus semecarpifolia</i>           | 91.14                       | 180.47            | 35.58             | 216.05        | 108.02        |
| <b>Total</b>                            | <b>225.86</b>               | <b>430.24</b>     | <b>83.90</b>      | <b>514.14</b> | <b>257.07</b> |
| Elevation- E <sub>2</sub> (2800-3200 m) |                             |                   |                   |               |               |
| <i>Abies spectabilis</i>                | 39.91                       | 55.87             | 12.29             | 68.16         | 34.08         |
| <i>Acer acuminatum</i>                  | 1.61                        | 11.35             | 2.38              | 13.73         | 6.87          |
| <i>Cedrus deodara</i>                   | 9.54                        | 21.20             | 4.66              | 25.86         | 12.93         |
| <i>Picea smithiana</i>                  | 47.95                       | 58.02             | 11.60             | 69.62         | 34.81         |
| <i>Pinus wallichiana</i>                | 0.22                        | 4.47              | 0.94              | 5.41          | 2.70          |
| <i>Prunus cornuta</i>                   | 0.09                        | 0.35              | 0.07              | 0.42          | 0.21          |
| <i>Quercus semecarpifolia</i>           | 93.59                       | 148.52            | 31.19             | 179.71        | 89.85         |
| <b>Total</b>                            | <b>192.91</b>               | <b>299.78</b>     | <b>60.38</b>      | <b>360.16</b> | <b>180.08</b> |
| Elevation- E <sub>1</sub> (3200-3600 m) |                             |                   |                   |               |               |
| <i>Abies spectabilis</i>                | 54.02                       | 62.12             | 13.67             | 75.79         | 37.89         |
| <i>Picea smithiana</i>                  | 51.63                       | 63.50             | 13.34             | 76.84         | 38.42         |
| <i>Pinus wallichiana</i>                | 0.31                        | 0.77              | 0.17              | 0.94          | 0.47          |
| <i>Quercus semecarpifolia</i>           | 60.58                       | 107.78            | 21.56             | 129.34        | 64.67         |
| <i>Taxus wallichiana</i>                | 0.80                        | 2.84              | 0.60              | 3.44          | 1.72          |
| <b>Total</b>                            | <b>167.34</b>               | <b>237.01</b>     | <b>47.40</b>      | <b>284.41</b> | <b>142.21</b> |

Among trees *Quercus semecarpifolia* exhibited maximum tree volume, AGB, BGB, TB and TC at all the three elevations, however their highest values were recorded at E<sub>1</sub> with volume as 91.14 m<sup>3</sup>/ha, aboveground biomass as 180.47 t/ha, belowground biomass as 35.58 t/ha, total tree biomass of 216.05 t/ha and total tree carbon as 108.02 t/ha. While lowest tree volume (at E<sub>1</sub> as 0.24 m<sup>3</sup>/ha and at E<sub>2</sub> as 0.09 m<sup>3</sup>/ha), aboveground biomass (0.90 t/ha and 0.35 t/ha), belowground biomass (0.18 t/ha and 0.07 t/ha), total tree biomass (1.08 t/ha and 0.42 t/ha) and total tree carbon (0.54 t/ha and 0.21 t/ha) was recorded for *Prunus cornuta*. While *Pinus wallichiana* exhibited lowest values of volume of 0.31 m<sup>3</sup>/ha, aboveground biomass of 0.77 t/ha, belowground biomass of 0.17 t/ha, total tree biomass of 0.94 t/ha and total tree carbon of 0.47 t/ha at E<sub>3</sub>. (Table 46)

Tree volume, aboveground biomass, belowground biomass, total tree biomass and total carbon at elevation E<sub>1</sub> ranged from 0.24 m<sup>3</sup>/ha to 91.14 m<sup>3</sup>/ha, 0.90 t/ha to 180.47 t/ha, 0.18 t/ha to 35.58 t/ha, 1.08 t/ha to 216.05 t/ha and 0.54 t/ha to 108.02 t/ha, respectively. At elevation E<sub>2</sub>, tree volume varied from 0.09 m<sup>3</sup>/ha to 93.59 m<sup>3</sup>/ha, total tree biomass from 0.42 t/ha to 179.71 t/ha and total carbon from 0.21 t/ha to 89.85 t/ha, while at elevation E<sub>3</sub> volume, total tree biomass and total tree carbon ranged from 0.31 m<sup>3</sup>/ha to 60.58 m<sup>3</sup>/ha, 0.94 t/ha to 129.34 t/ha and 0.47 t/ha to 64.67 t/ha, respectively (Table 46).

The data presented in Table 47 reveals that upper Oak-Fir forests among all the three elevations, at E<sub>1</sub> highest tree volume (292.14 m<sup>3</sup>/ha), aboveground biomass (540.38 t/ha), belowground biomass (101.44 t/ha), total biomass (641.82 t/ha) and total carbon (320.91 t/ha) was recorded, followed by E<sub>2</sub> with total volume of trees as 258.79 m<sup>3</sup>/ha, aboveground biomass as 388.03 t/ha, belowground biomass as 75.50 t/ha, total biomass as 463.53 t/ha and total carbon as 231.76 t/ha. The least tree volume (185.40 m<sup>3</sup>/ha), aboveground biomass (250.91 t/ha), belowground biomass (50.18 t/ha), total biomass (301.09 t/ha) and total carbon (150.55 t/ha) was recorded at E<sub>3</sub>.

Among trees at elevation E<sub>1</sub>, maximum volume (129.78 m<sup>3</sup>/ha), aboveground biomass (159.63 t/ha), belowground biomass (35.12 t/ha), total biomass (194.75 t/ha) and total carbon (97.37 t/ha) was recorded for *Abies pindrow*, while lowest volume (1.10 m<sup>3</sup>/ha), aboveground (3.94 t/ha), belowground (0.77 t/ha), total biomass (4.71 t/ha) and total carbon (2.35 t/ha) was recorded for *Quercus floribunda*. At elevation E<sub>2</sub>, highest volume (106.96 m<sup>3</sup>/ha) exhibited by *Abies spectabilis*, whereas maximum aboveground biomass as 139.06 t/ha, belowground biomass as 27.53 t/ha, total biomass as 166.59 t/ha and total carbon as 83.30 t/ha was

recorded for *Quercus semecarpifolia*. While *Quercus floribunda* showed least volume (1.94 m<sup>3</sup>/ha), aboveground biomass (6.93 t/ha), belowground biomass (1.39 t/ha), total biomass (8.32 t/ha) and total carbon (4.16 t/ha). At elevation E<sub>3</sub>, highest volume (71.17 m<sup>3</sup>/ha), aboveground (112.86 t/ha), belowground (22.57 t/ha), total biomass (135.43 t/ha) and total carbon (67.72 t/ha) was recorded for *Quercus semecarpifolia*. Whereas lowest volume, AGB, BGB, TB and TC was exhibited by *Taxus wallichiana* as 1.30 m<sup>3</sup>/ha, 4.60 t/ha, 0.97 t/ha, 5.57 t/ha and 2.78 t/ha respectively (Table 47).

**Table 47: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in upper Oak-Fir forests at different elevations**

| Tree Species                             | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon<br>(t/ha) |
|------------------------------------------|--------------------------------|----------------------|----------------------|---------------|------------------|
|                                          |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC)    |
| Elevation - E <sub>1</sub> (2100-2600 m) |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                     | 129.78                         | 159.63               | 35.12                | 194.75        | 97.37            |
| <i>Acer caesium</i>                      | 19.99                          | 56.14                | 11.79                | 67.93         | 33.96            |
| <i>Aesculus indica</i>                   | 12.01                          | 42.39                | 9.33                 | 51.72         | 25.86            |
| <i>Juglans regia</i>                     | 27.12                          | 62.64                | 12.53                | 75.17         | 37.58            |
| <i>Picea smithiana</i>                   | 19.47                          | 36.22                | 7.61                 | 43.83         | 21.91            |
| <i>Pinus wallichiana</i>                 | 8.08                           | 18.41                | 3.68                 | 22.09         | 11.05            |
| <i>Prunus cornuta</i>                    | 1.33                           | 4.88                 | 0.97                 | 5.85          | 2.92             |
| <i>Quercus floribunda</i>                | 1.10                           | 3.94                 | 0.77                 | 4.71          | 2.35             |
| <i>Quercus semecarpifolia</i>            | 73.26                          | 156.13               | 29.84                | 185.97        | 92.99            |
| <b>Total</b>                             | <b>292.14</b>                  | <b>540.38</b>        | <b>101.44</b>        | <b>641.82</b> | <b>320.91</b>    |
| Elevation – E <sub>2</sub> (2600-3100 m) |                                |                      |                      |               |                  |
| <i>Abies spectabilis</i>                 | 106.96                         | 117.65               | 25.88                | 143.53        | 71.77            |
| <i>Acer acuminatum</i>                   | 13.72                          | 29.32                | 6.16                 | 35.48         | 17.74            |
| <i>Picea smithiana</i>                   | 30.58                          | 44.65                | 9.82                 | 54.47         | 27.24            |
| <i>Pinus wallichiana</i>                 | 10.94                          | 16.19                | 3.24                 | 19.43         | 9.71             |
| <i>Prunus cornuta</i>                    | 9.35                           | 34.23                | 7.19                 | 41.42         | 20.71            |
| <i>Quercus floribunda</i>                | 1.94                           | 6.93                 | 1.39                 | 8.32          | 4.16             |
| <i>Quercus semecarpifolia</i>            | 85.31                          | 139.06               | 27.53                | 166.59        | 83.30            |
| <b>Total</b>                             | <b>258.79</b>                  | <b>388.03</b>        | <b>75.50</b>         | <b>463.53</b> | <b>231.76</b>    |
| Elevation – E <sub>3</sub> (3100-3500 m) |                                |                      |                      |               |                  |
| <i>Abies spectabilis</i>                 | 64.38                          | 70.82                | 15.58                | 86.40         | 43.20            |
| <i>Picea smithiana</i>                   | 44.94                          | 54.37                | 11.42                | 65.79         | 32.89            |
| <i>Pinus wallichiana</i>                 | 3.62                           | 8.26                 | 1.82                 | 10.08         | 5.04             |
| <i>Quercus semecarpifolia</i>            | 71.17                          | 112.86               | 22.57                | 135.43        | 67.72            |
| <i>Taxus wallichiana</i>                 | 1.30                           | 4.60                 | 0.97                 | 5.57          | 2.78             |
| <b>Total</b>                             | <b>185.40</b>                  | <b>250.91</b>        | <b>50.18</b>         | <b>301.09</b> | <b>150.55</b>    |

Tree volume, aboveground biomass, belowground biomass, total tree biomass and total carbon at E<sub>1</sub> ranged from 0.10 m<sup>3</sup>/ha to 129.78 m<sup>3</sup>/ha, 3.94 t/ha to 159.63 t/ha, 0.77 t/ha to 35.12 t/ha, 4.71 t/ha to 194.75 t/ha and 2.35 t/ha to 97.37 t/ha, respectively. At E<sub>2</sub> tree volume varied from 1.94 m<sup>3</sup>/ha to 106.96 m<sup>3</sup>/ha, aboveground biomass from 6.93 t/ha to 117.65 t/ha, belowground biomass from 1.39 t/ha to 25.88 t/ha, total tree biomass from 8.32 t/ha to 143.53 t/ha and total carbon from 4.16 t/ha to 71.77 t/ha, while at E<sub>3</sub> volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 1.31 m<sup>3</sup>/ha to 71.17 m<sup>3</sup>/ha, 4.60 t/ha to 112.86 t/ha, 0.97 t/ha to 22.57 t/ha, 5.57 to 135.43 t/ha and 2.78 t/ha to 67.72 t/ha, respectively (Table 47).

Volume, biomass and carbon differed considerably at different elevations in upper moist temperate deciduous forests at different elevations (Table 48). Among the three elevations, at E<sub>1</sub> highest tree volume (212.28 m<sup>3</sup>/ha), aboveground biomass (372.95 t/ha), belowground biomass (72.57 t/ha), total biomass (445.52 t/ha) and total carbon (222.76 t/ha) was recorded followed by E<sub>2</sub> with total volume of trees as 168.97 m<sup>3</sup>/ha, aboveground biomass as 281.07 t/ha, belowground biomass as 55.65 t/ha, total biomass as 336.72 t/ha and total carbon 168.36 t/ha. The least values of total tree volume (115.21 m<sup>3</sup>/ha), AGB (155.52 t/ha), BGB (31.10 t/ha), TB (186.60 t/ha) and TC (93.30 t/ha) were recorded at E<sub>3</sub>.

Among trees at elevation E<sub>1</sub>, *Acer caesium* exhibited maximum tree volume (57.61 m<sup>3</sup>/ha), aboveground biomass (125.29 t/ha), belowground biomass (26.31 t/ha), total biomass (151.60 t/ha) and total carbon (75.80 t/ha), while lowest tree volume (0.47 m<sup>3</sup>/ha), aboveground biomass (1.65 t/ha), belowground biomass (0.33 t/ha), total biomass (1.98 t/ha) and total carbon (0.99 t/ha) exhibited by *Taxus wallichiana*. At elevation E<sub>2</sub>, highest tree volume (62.24 m<sup>3</sup>/ha), aboveground biomass (108.78 t/ha), belowground biomass (21.76 t/ha), total biomass (130.54 t/ha) and total carbon (65.27 t/ha) was recorded for *Quercus semecarpifolia* while minimum tree volume, aboveground biomass, belowground biomass, total biomass and total carbon was observed in *Prunus cornuta* as 13.36 m<sup>3</sup>/ha, 5.06 t/ha, 1.06 t/ha, 6.12 t/ha and 3.06 t/ha respectively. At elevation E<sub>3</sub>, *Quercus semecarpifolia* exhibited maximum tree volume (39.35 m<sup>3</sup>/ha), aboveground biomass (50.66 t/ha), belowground biomass (10.13 t/ha), total biomass (60.79 t/ha) and total carbon (30.40 t/ha). Least volume, AGB, BGB, TB and TC was observed for *Taxus wallichiana* as 0.12 m<sup>3</sup>/ha, 8.30 t/ha, 1.74 t/ha, 10.04 t/ha and 5.02 t/ha respectively (Table 48).

**Table 48: Volume, aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of trees in upper moist temperate deciduous forests at different elevations**

| Tree Species                              | Volume<br>(m <sup>3</sup> /ha) | Biomass (t/ha)       |                      |               | Carbon<br>(t/ha) |
|-------------------------------------------|--------------------------------|----------------------|----------------------|---------------|------------------|
|                                           |                                | Aboveground<br>(AGB) | Belowground<br>(BGB) | Total<br>(TB) | Total<br>(TC)    |
| Elevation - E <sub>1</sub> (1700-2300 m)  |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                      | 22.48                          | 57.58                | 12.67                | 70.25         | 35.12            |
| <i>Acer caesium</i>                       | 57.61                          | 125.29               | 26.31                | 151.60        | 75.80            |
| <i>Cedrus deodara</i>                     | 51.20                          | 41.91                | 9.22                 | 51.13         | 25.57            |
| <i>Juglans regia</i>                      | 26.81                          | 53.90                | 10.78                | 64.68         | 32.34            |
| <i>Picea smithiana</i>                    | 30.39                          | 52.77                | 11.08                | 63.85         | 31.93            |
| <i>Quercus semecarpifolia</i>             | 23.32                          | 39.86                | 7.97                 | 47.83         | 23.92            |
| <i>Taxus wallichiana</i>                  | 0.47                           | 1.65                 | 0.33                 | 1.98          | 0.99             |
| <b>Total</b>                              | <b>212.28</b>                  | <b>372.95</b>        | <b>72.57</b>         | <b>445.52</b> | <b>222.76</b>    |
| Elevation – E <sub>2</sub> (2300-2900 m)  |                                |                      |                      |               |                  |
| <i>Abies pindrow</i>                      | 37.31                          | 48.71                | 10.72                | 59.43         | 29.71            |
| <i>Acer caesium</i>                       | 14.00                          | 46.76                | 9.82                 | 56.58         | 28.29            |
| <i>Juglans regia</i>                      | 25.60                          | 40.61                | 8.93                 | 49.54         | 24.77            |
| <i>Picea smithiana</i>                    | 16.45                          | 31.13                | 6.23                 | 37.36         | 18.68            |
| <i>Prunus cornuta</i>                     | 13.36                          | 5.06                 | 1.06                 | 6.12          | 3.06             |
| <i>Quercus semecarpifolia</i>             | 62.24                          | 108.78               | 21.76                | 130.54        | 65.27            |
| <b>Total</b>                              | <b>168.97</b>                  | <b>281.07</b>        | <b>55.65</b>         | <b>336.72</b> | <b>168.36</b>    |
| Elevation – E <sub>3</sub> (2900 -3500 m) |                                |                      |                      |               |                  |
| <i>Abies spectabilis</i>                  | 20.67                          | 23.81                | 5.24                 | 29.05         | 14.52            |
| <i>Acer caesium</i>                       | 37.73                          | 37.43                | 7.86                 | 45.29         | 22.65            |
| <i>Picea smithiana</i>                    | 17.33                          | 35.29                | 7.76                 | 43.05         | 21.53            |
| <i>Quercus semecarpifolia</i>             | 39.35                          | 50.66                | 10.13                | 60.79         | 30.40            |
| <i>Taxus wallichiana</i>                  | 0.12                           | 8.30                 | 1.74                 | 10.04         | 5.02             |
| <b>Total</b>                              | <b>115.21</b>                  | <b>155.50</b>        | <b>31.10</b>         | <b>186.60</b> | <b>93.30</b>     |

A wide range in volume, biomass and carbon was observed in different elevations for different species. However volume, aboveground biomass, belowground biomass, total biomass and total carbon ranges from 0.54 m<sup>3</sup>/ha to 57.61 m<sup>3</sup>/ha, 1.65 t/ha to 125.29 t/ha, 0.33 t/ha to 26.31 t/ha, 1.98 t/ha to 151.60 t/ha and 0.99 t/ha to 75.80 t/ha respectively at E<sub>1</sub>, 13.36 m<sup>3</sup>/ha to 62.24 m<sup>3</sup>/ha, 5.06 t/ha to 108.78 t/ha, 1.06 t/ha to 21.76 t/ha, 6.12 t/ha to 130.54 t/ha and 3.06 t/ha to 65.27 t/ha respectively at E<sub>2</sub>, while at E<sub>3</sub> volume, aboveground biomass, belowground biomass, total tree biomass and total tree carbon ranged from 0.12 m<sup>3</sup>/ha to 39.55 m<sup>3</sup>/ha, 8.30 t/ha to 50.66 t/ha, 1.74 t/ha to 10.13 t/ha, 10.04 t/ha to 60.79 t/ha and 5.02 t/ha to 30.40 t/ha respectively (Table 48).



The result presented in Table 49 reveals that difference in mean total biomass (TB) and mean total carbon stock (TC) in trees among different forests was significant Irrespective of elevation, the total biomass and total carbon in forests decreased in the following order: upper Oak-Fir forests (FT-8) > Ban Oak forests (FT-1) > Deodar Forests (FT-3) > Kharsu Oak forests (FT-7) > western mixed coniferous forests (FT-4) > Moru Oak forests (FT-2) > moist temperate upper deciduous forests (FT-9) > moist temperate lower deciduous forests (FT-5) > Kail forests (FT-6).

**Table 49: Change in total biomass (TB) and total carbon (TC) of trees among forests and elevations**

| Forest types<br>(F) | Elevations (E)       |                |                | Mean   | Elevations (E)      |                |                | Mean   |
|---------------------|----------------------|----------------|----------------|--------|---------------------|----------------|----------------|--------|
|                     | E <sub>1</sub>       | E <sub>2</sub> | E <sub>3</sub> |        | E <sub>1</sub>      | E <sub>2</sub> | E <sub>3</sub> |        |
|                     | Total biomass (t/ha) |                |                |        | Total carbon (t/ha) |                |                |        |
| FT-1                | 552.76               | 443.24         | 291.06         | 429.02 | 276.38              | 221.62         | 145.53         | 214.51 |
| FT-2                | 548.62               | 299.87         | 223.71         | 357.40 | 274.31              | 149.93         | 111.86         | 178.70 |
| FT-3                | 564.30               | 355.56         | 270.06         | 396.64 | 282.16              | 177.78         | 135.03         | 198.32 |
| FT-4                | 459.48               | 322.79         | 330.21         | 370.83 | 229.74              | 161.40         | 165.11         | 185.42 |
| FT-5                | 293.80               | 233.41         | 207.61         | 244.94 | 146.90              | 116.71         | 103.81         | 122.47 |
| FT-6                | 263.71               | 202.10         | 149.81         | 205.21 | 131.85              | 101.05         | 74.91          | 102.60 |
| FT-7                | 514.14               | 360.16         | 284.41         | 386.24 | 257.07              | 180.08         | 142.21         | 193.12 |
| FT-8                | 641.82               | 463.53         | 301.09         | 468.81 | 320.91              | 231.76         | 150.55         | 234.41 |
| FT-9                | 445.52               | 336.72         | 186.60         | 322.95 | 222.76              | 168.36         | 93.30          | 161.47 |
| Mean                | 476.02               | 335.26         | 249.40         |        | 238.01              | 167.63         | 124.70         |        |
|                     | CD <sub>0.05</sub>   |                |                |        | CD <sub>0.05</sub>  |                |                |        |
|                     |                      |                | C.D.           | SE(d)  |                     |                | C.D.           | SE(d)  |
|                     |                      | F              | 15.11          | 7.51   |                     |                | 7.69           | 3.82   |
|                     |                      | E              | 8.72           | 4.33   |                     |                | 4.44           | 2.21   |
|                     |                      | F X E          | 26.17          | 13.00  |                     |                | 13.32          | 6.62   |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = upper Oak-Fir forests and FT-9 = moist temperate upper deciduous forests and, for each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different.

The impact of elevation on total biomass and total carbon was evident from the result that these parameters of trees in Himalayan moist temperate forest decreased with an increase in elevation (Table 49). The precedence followed for total biomass (TB) of the trees was: E<sub>1</sub> (476.02 t/ha) > E<sub>2</sub> (335.26 t/ha) > E<sub>3</sub> (249.40 t/ha) whereas for total carbon (TC) it was: E<sub>1</sub> (238.01 t/ha) > E<sub>2</sub> (167.63 t/ha) > E<sub>3</sub> (124.70 t/ha).

The interaction effect of forest types and elevation on total biomass (TB) and total carbon (TC) was significant. However, upper Oak-Fir forests (FT-8) showed highest biomass in trees as 641.82 t/ha at elevation E<sub>1</sub> and lowest tree biomass was recorded in moist

temperate lower deciduous forests (FT-5) at elevation  $E_3$  as 149.81 t/ha. Likewise, total carbon stock (TC) in trees of forests was highest in upper Oak-Fir forests (FT-8) at elevation  $E_1$  as 320.91 t/ha and lowest in moist temperate lower deciduous forests (FT-5) at elevation  $E_3$  as 101.05 t/ha (Table 49).

Biomass production of forests thereby carbon stored in vegetation varies with species composition, stand area, tree size class, pattern of rainfall, edaphic factors and altitude (Dar and Sundarapandian, 2016). Several formal meta-analyses have synthesized the results of diversity-function experiments in the past which concludes that species loss tends to reduce the efficiency by which communities capture biologically essential resources and convert those into new biomass, thereby species diversity does play significant role in biomass production. But, resource capture and biomass production by the communities saturate at low levels of richness and that diverse communities seldom capture more resources or produce more biomass than their most productive species (Cardinale *et al.* 2007). The same was evident in the present study that in most of the forests biomass production was centric to dominant tree species in them and more than 50% of total biomass was contributed by dominant species.

The present study revealed that in Himalayan moist temperate forest of Shimla district, the biomass production of trees in different forests was statistically different. The difference in biomass carbon in different forests is the ultimate result of accumulated biomass over the time and, thereby it depends upon number of factors like, number and growth habit of the species, site quality, soil on which trees are growing, stand age, management practices and their interactions with belowground components (Graham *et al.* 1992; Unruh *et al.* 1993; Niu and Duiker 2006; Jana *et al.* 2009; Weifeng *et al.* 2011; Yadav *et al.* 2016). In this regard, forest vegetation in Himalayan moist temperate climate varies with environment of the habitat and it inhabits nine types of major forest types beside other undiscovered associations. Broadleaved and coniferous trees extend here from 700 to 3900 m elevation. Among the broadleaved tree species, the three major Oaks such as *Quercus leucotrichophora*, *Quercus floribunda* and *Quercus semecarpifolia* found between 800m and 3000 m altitudes while *Abies pindrow*, *Abies spectabilis*, *Cedrus deodara*, *Pinus wallichiana*, *Picea smithiana* are common conifers at different elevations. Thus, the variation in biomass of trees among forests and along elevation is inevitable.

In our study the aboveground biomass of trees varied from 123.81 to 540.38 t/ha and total biomass of trees ranged from 149.81 to 641.82 t/ha at different elevations. Our results are comparable with the findings of Lal and Lodhiyal (2016) who estimated tree biomass of 481-569 t ha<sup>-1</sup> in Oak dominated forests in Kumaon Himalaya, Sharma *et al.* (2011) studied different forests in Garhwal Himalaya and computed 557.6 t/ha tree biomass for Deodar forests and 387.4 t/ha for Fir forests and Rana *et al.* (1989) as 426-782 t ha<sup>-1</sup> in Oak forests in Kumaun Himalaya. Our biomass values are higher than 285-458 t ha<sup>-1</sup> reported for Oak forests by Rawat and Singh (1988), 236-400 t ha<sup>-1</sup> for Oak dominated forests of high altitude by Adhikari *et al.* (1995) but lower than 651-718 t ha<sup>-1</sup> for natural forests of Kumaun Himalaya by Lodhiyal *et al.* (2014) and 590 t ha<sup>-1</sup> for Kharsu Oak forests of higher altitude by Adhikari *et al.* (1995). *Quercus leucotrichophora* dominated forest stands in Almora were studied by Gosain *et al.* (2015) in central Himalaya and they computed aboveground biomass of Oak forests as 189.8 Mg ha<sup>-1</sup>. Dar and Sundarapandian (2015b) reported tree biomass from 100.8 Mg ha<sup>-1</sup> in *Betula utilis* forest to 294.8 Mg ha<sup>-1</sup> in *Abies pindrow* forest in Kashmir Himalaya. Sharma *et al.* (2016) reported biomass production of *Pinus wallichiana*, *Quercus semecarpifolia*, *Cedrus deodara*, *Abies spectabilis*, and *Betula utilis* mixed forests at high mountains in Garhwal Himalaya and reported highest total biomass density as 464.2 ± 152.5 Mg ha<sup>-1</sup> in *Cedrus deodara* forests and lowest biomass density as 283.4 ± 74.8 Mg ha<sup>-1</sup> in *Quercus semecarpifolia* forests. Negi *et al.* (1983) estimated aboveground biomass of three relatively protected Oak forests in Kumaon Himalaya in the range of 197.2 to 322.8 t/ha. Singh *et al.* (2010) reported total biomass of trees ranging from 129 to 533 Mg ha<sup>-1</sup> for temperate and tropical forests of Garhwal Himalaya. Gairola *et al.* (2011a) computed total live tree biomass density (TBD) varying from 215.5 to 468.2 Mg ha<sup>-1</sup> in forests of Garhwal Himalaya. Sharma *et al.* (2018) reported change in tree biomass density in ridge forests along the elevational gradient in Garhwal Himalaya from 189.38±14.35Mgha<sup>-1</sup> (between 1600 and 1900m asl) to 520.72±114.57Mgha<sup>-1</sup> (between 3100 and 3400m asl).

Differences in tree biomass are the manifestation of inherent growth characteristics of constituent species, their specific ecological niche, climate difference, geographical location, plant species, age of the stand and density of trees (Dar and Sundarapandian, 2015a). Biomass is also related to human or natural disturbances (Lugo and Brown, 1992). Highest Biomass of trees can be related to dominance of mature, large trees and old age growth forests at higher altitudes in comparison to lower altitudes (Thokchom and Yadav, 2017). Aboveground biomass varies from place to place because of varying plant community

structures, variation in plant species and the succession stage of the forest. Lower values can be attributed to low temperature and rainfall precipitation of this climatic zone, which limit the growth of the trees in this region.

In the present study tree biomass and thereby tree carbon in different forests decreased with increase in elevation which can be attributed to the similar reasons as described above. The differences in productivity along elevation may be due to differences in soil conditions, phenology of dominant species, better root net working as well as efficient and economical use of limited resources for maintaining higher photosynthetic activities, leaf area index, better light interception and water use efficiency (Sehgal 1999). Tiwari and Singh (1982) contended that total aboveground biomass of trees varies with crown cover and they reported biomass varying from 53.52 to 247.21 t/ha for mixed conifer forests in Garhwal Himalaya which is low as compared to present finding.

Since carbon in vegetation is an artifact from biomass. Its variation in trees among forests and elevations showed similar changes as tree biomass. Highest total carbon in trees (320.91 t/ha) was recorded at elevation  $E_1$  in upper Oak-Fir forests and lowest total carbon in trees (74.91 t/ha) was recorded in Kail forests at elevation  $E_3$ .

In the entire Indian Himalayan region, it is estimated that forests sequester about 65 million tonne carbon annually in aboveground biomass alone (Singh, 2007). He estimated that total carbon pool in the entire forest area of Indian Himalaya is about 5.4 billion t C (forest biomass + soil) which is approximately equal to the annual carbon emission from fossil fuels in Asia. The potential upper bound of carbon store of Himalaya (forest biomass + soil) is speculated to be about 700 t/ha. Values like this are approached by old growth forest stands, which still remain in remote mountain areas. He emphasized that the Himalayan region has a great potential to store carbon, and old growth forests should be valued from this standpoint. Temperate forests cover 767 million hectares world-wide and account for approximately 14 % of forest carbon storage (Pan *et al.* 2011). The greatest potential for C storage in temperate forests is tree biomass (Son *et al.* 2001; Peichl and Arain 2006), whereas understory, deadwood and litter biomass also have considerable contribution (Whittaker and Woodwell 1986). Productivity and thereby carbon storage in forests depends on stand structure, composition of forest, climate, soil condition, availability of moisture, and conservation and management practices.

In the present study total carbon in trees ranged from 102.60 t/ha to 234.41 t/ha in nine different forest types. The difference in biomass carbon in different forests is the ultimate result of accumulated biomass over the time and, thereby it depends upon number of factors like, number and growth habit of the species, site quality, soil on which trees are growing, stand age, management practices and their interactions with belowground components (Graham *et al.* 1992; Unruh *et al.* 1993; Niu and Duiker 2006; Jana *et al.* 2009; Weifeng *et al.* 2011; Yadav *et al.* 2016). Overstory forest structure is also related to terrain-related abiotic factors and to biotic interactions among overstory and understory plants. Height, biomass, and gap frequency are significantly related to changes in elevation, and aspect. Higher evergreen understory density is correlated with decrease in forest height and biomass, with an impact observed across moisture, elevation, and exposure gradients (Bolstad *et al.* 2018). Filippou (2018) contended that forest management and silvicultural practices have a longer-term impact on the genetic diversity, structure and resilience of long-impacted populations of forest tree.

The result obtained in present study on amount of carbon stock in trees of Himalayan moist temperate forest got support from the work of Gairola *et al.* (2011a) who reported total tree carbon density TCD from 107.8 to 234.1 Mg C ha<sup>-1</sup> in moist temperate Mandal-Chopta forest of Chamoli District, Garhwal Himalaya. Our results are also comparable to the findings of Dar and Sahu (2018) who recorded carbon stock of 228.4  $7 \pm 128.3$  Mg C ha<sup>-1</sup> in temperate forests of Northern Kashmir Himalaya; Rana *et al.* (1989) who reported carbon stock values 166.8 t ha<sup>-1</sup> C for *P. roxburghii* mixed broad leaf forest and Gogoi *et al.* (2017) reported 94.71 to 343.31 Mg C ha<sup>-1</sup> in tropical wet evergreen rainforest of Eastern Himalaya. Tree carbon density range as reported in our study is more or less in line as reported by Dar and Sundarapandian (2015a) for central Himalayan forest ranges.

#### **4.6.2 Biomass and carbon in shrubs**

It was observed that shrub biomass and carbon has differed among different forest types at different elevations (Table 50-58). Data presented in Table 50 reveals that among three elevations, at E<sub>1</sub> highest aboveground biomass (20.883 t/ha), belowground biomass (6.961 t/ha), total biomass (27.844 t/ha) and total carbon (13.922 t/ha) of shrubs was recorded, followed by E<sub>2</sub> with 17.322 t/ha as AGB, 5.774 t/ha as BGB, 23.196 t/ha as TB and 11.548 t/ha as TC. The least values of 15.541 t/ha (aboveground biomass), 5.180 t/ha

(belowground biomass), 20.721 t/ha (total biomass) and 10.361 t/ha (total carbon) of shrubs were recorded at E<sub>3</sub>.

With respect to individual shrub species, highest aboveground biomass (2.582 t/ha), belowground biomass (0.861), total biomass (3.443 t/ha) and total carbon (1.721 t/ha) at E<sub>1</sub> was recorded for *Carissa carandas*. Whereas lowest AGB as 0.060 t/ha, BGB as 0.020 t/ha, TB as 0.08 t/ha and TC as 0.03 t/ha was recorded in *Asparagus adscendens* (Table 50).

At E<sub>2</sub>, highest aboveground biomass (4.608 t/ha), belowground biomass (1.536 t/ha), total biomass (6.144 t/ha) and total carbon (3.072 t/ha) existed in *Berberis lycium* while lowest AGB (0.015 t/ha), BGB (0.005 t/ha), TB (0.020 t/ha) and TC (0.010 t/ha) was recorded in *Clematis buchananiana*. At E<sub>3</sub>, highest aboveground biomass (2.004 t/ha), belowground biomass (0.668 t/ha), total biomass (2.672 t/ha) and total carbon (1.336 t/ha) was observed in *Berberis lycium*, whereas lowest AGB (0.033 t/ha), BGB (0.011 t/ha), TB (0.043 t/ha) and TC (0.022 t/ha) occurred in *Clematis buchananiana* (Table 50).

Shrub aboveground biomass, belowground biomass, total biomass and total carbon of at E<sub>1</sub> ranged from 0.060 to 2.582 t/ha, 0.020 to 0.861 t/ha, 0.08 to 3.443 t/ha and 0.03 to 1.721 t/ha respectively. At E<sub>2</sub> range of aboveground biomass (0.015 t/ha to 4.608 t/ha), belowground biomass (0.005 t/ha to 1.536 t/ha), total biomass (0.020 t/ha to 6.144 t/ha) and total carbon (0.010 t/ha to 3.072 t/ha) while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.033 t/ha to 2.004 t/ha, 0.011 t/ha to 0.668 t/ha, 0.043 t/ha to 2.672 t/ha and 0.022 t/ha to 1.336 t/ha respectively (Table 50).

**Table 50: Aboveground (AGB), belowground (BGB, total biomass (TB) and total carbon (TC) of shrubs in Ban Oak (*Q. leucotrichophora*) forests at different elevations**

| Shrub Species                                  | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|------------------------------------------------|-------------------|-------------------|------------|---------------|
|                                                | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation - E<sub>1</sub> (700 -1300 m)</b> |                   |                   |            |               |
| <i>Agave angustifolia</i>                      | 1.140             | 0.380             | 1.520      | 0.760         |
| <i>Agave cantula</i>                           | 0.120             | 0.040             | 0.160      | 0.080         |
| <i>Asclepias curassavica</i>                   | 0.078             | 0.026             | 0.103      | 0.052         |
| <i>Asparagus adscendens</i>                    | 0.060             | 0.020             | 0.080      | 0.040         |
| <i>Berberis lycium</i>                         | 1.774             | 0.591             | 2.365      | 1.183         |
| <i>Boehmeria platyphylla</i>                   | 0.539             | 0.180             | 0.719      | 0.359         |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Carissa carandas</i>                        | 2.582         | 0.861        | 3.443         | 1.721         |
| <i>Colebrookia oppositifolia</i>               | 0.365         | 0.122        | 0.487         | 0.244         |
| <i>Coriaria nepalensis</i>                     | 0.749         | 0.250        | 0.998         | 0.499         |
| <i>Cotinus coggygia</i>                        | 0.596         | 0.199        | 0.795         | 0.398         |
| <i>Desmodium elegans</i>                       | 0.401         | 0.134        | 0.534         | 0.267         |
| <i>Dodonaea viscosa</i>                        | 0.550         | 0.183        | 0.733         | 0.366         |
| <i>Elaeagnus parvifolia</i>                    | 0.423         | 0.141        | 0.563         | 0.282         |
| <i>Flemingia macrophylla</i>                   | 0.062         | 0.021        | 0.082         | 0.041         |
| <i>Hypericum oblongifolium</i>                 | 0.618         | 0.206        | 0.823         | 0.412         |
| <i>Indigofera atropurpurea</i>                 | 0.079         | 0.026        | 0.105         | 0.053         |
| <i>Jasminum humile</i>                         | 0.819         | 0.273        | 1.092         | 0.546         |
| <i>Jasminum mesneyi</i>                        | 1.081         | 0.360        | 1.442         | 0.721         |
| <i>Justicia adhatoda</i>                       | 0.603         | 0.201        | 0.803         | 0.402         |
| <i>Lantana camara</i>                          | 0.851         | 0.284        | 1.134         | 0.567         |
| <i>Lespedeza juncea</i>                        | 0.234         | 0.078        | 0.312         | 0.156         |
| <i>Meriandra strobilifera</i>                  | 0.868         | 0.289        | 1.157         | 0.579         |
| <i>Opuntia stricta</i>                         | 0.231         | 0.077        | 0.308         | 0.154         |
| <i>Prinsepia utilis</i>                        | 1.972         | 0.657        | 2.629         | 1.314         |
| <i>Randia tetrasperma</i>                      | 0.720         | 0.240        | 0.960         | 0.480         |
| <i>Rubus ellipticus</i>                        | 0.670         | 0.223        | 0.893         | 0.447         |
| <i>Vitex negundo</i>                           | 0.884         | 0.295        | 1.179         | 0.590         |
| <i>Woodfordia fruticosa</i>                    | 1.345         | 0.448        | 1.793         | 0.897         |
| <i>Zizyphus oxyphylla</i>                      | 0.473         | 0.158        | 0.630         | 0.315         |
| <b>Total</b>                                   | <b>20.883</b> | <b>6.961</b> | <b>27.844</b> | <b>13.922</b> |
| <b>Elevation – E<sub>2</sub> (1300-1900 m)</b> |               |              |               |               |
| <i>Asclepias curassavica</i>                   | 0.143         | 0.048        | 0.190         | 0.095         |
| <i>Asparagus adscendens</i>                    | 0.177         | 0.059        | 0.236         | 0.118         |
| <i>Berberis lycium</i>                         | 4.608         | 1.536        | 6.144         | 3.072         |
| <i>Buddleja asiatica</i>                       | 0.045         | 0.015        | 0.060         | 0.030         |
| <i>Carissa carandas</i>                        | 2.680         | 0.893        | 3.573         | 1.787         |
| <i>Clematis buchananiana</i>                   | 0.015         | 0.005        | 0.020         | 0.010         |
| <i>Clematis grata</i>                          | 0.100         | 0.033        | 0.134         | 0.067         |
| <i>Coriaria nepalensis</i>                     | 0.233         | 0.078        | 0.310         | 0.155         |
| <i>Cotoneaster microphylla</i>                 | 0.130         | 0.043        | 0.173         | 0.087         |
| <i>Desmodium elegans</i>                       | 0.425         | 0.142        | 0.567         | 0.283         |
| <i>Euphorbia royleana</i>                      | 0.598         | 0.199        | 0.797         | 0.399         |
| <i>Hypericum oblongifolium</i>                 | 0.378         | 0.126        | 0.503         | 0.252         |
| <i>Indigofera dosua</i>                        | 0.325         | 0.108        | 0.433         | 0.217         |
| <i>Indigofera heterantha</i>                   | 0.070         | 0.023        | 0.093         | 0.047         |
| <i>Jasminum officinale</i>                     | 1.063         | 0.354        | 1.417         | 0.708         |
| <i>Justicia adhatoda</i>                       | 0.266         | 0.089        | 0.355         | 0.178         |
| <i>Lantana camara</i>                          | 1.443         | 0.481        | 1.923         | 0.962         |
| <i>Lespedeza juncea</i>                        | 0.300         | 0.100        | 0.400         | 0.200         |
| <i>Myrsine africana</i>                        | 0.653         | 0.218        | 0.870         | 0.435         |
| <i>Prinsepia utilis</i>                        | 0.633         | 0.211        | 0.843         | 0.422         |
| <i>Rosa brunonii</i>                           | 0.080         | 0.027        | 0.107         | 0.053         |
| <i>Rosa macrophylla</i>                        | 0.050         | 0.017        | 0.067         | 0.033         |
| <i>Rubia cordifolia</i>                        | 0.325         | 0.108        | 0.433         | 0.217         |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Sarcococca saligna</i>                      | 0.075         | 0.025        | 0.100         | 0.050         |
| <i>Skimmia laureola</i>                        | 0.113         | 0.038        | 0.150         | 0.075         |
| <i>Solanum myriacanthum</i>                    | 0.415         | 0.138        | 0.553         | 0.277         |
| <i>Spiraea bella</i>                           | 0.068         | 0.023        | 0.090         | 0.045         |
| <i>Viburnum cotinifolium</i>                   | 0.265         | 0.088        | 0.353         | 0.177         |
| <i>Woodfordia fruticosa</i>                    | 0.445         | 0.148        | 0.593         | 0.297         |
| <i>Zanthoxylum armatum</i>                     | 1.205         | 0.402        | 1.607         | 0.803         |
| <b>Total</b>                                   | <b>17.322</b> | <b>5.774</b> | <b>23.096</b> | <b>11.548</b> |
| <b>Elevation – E<sub>3</sub> (1900-2500 m)</b> |               |              |               |               |
| <i>Andrachne cordifolia</i>                    | 0.129         | 0.043        | 0.172         | 0.086         |
| <i>Argyrobium flaccidum</i>                    | 0.203         | 0.068        | 0.270         | 0.135         |
| <i>Berberis aristata</i>                       | 0.635         | 0.212        | 0.847         | 0.423         |
| <i>Berberis lycium</i>                         | 2.004         | 0.668        | 2.672         | 1.336         |
| <i>Clematis buehneriana</i>                    | 0.033         | 0.011        | 0.043         | 0.022         |
| <i>Clematis grata</i>                          | 0.075         | 0.025        | 0.100         | 0.050         |
| <i>Clematis montana</i>                        | 0.505         | 0.168        | 0.673         | 0.337         |
| <i>Coriaria nepalensis</i>                     | 0.345         | 0.115        | 0.460         | 0.230         |
| <i>Cotoneaster bacillaris</i>                  | 0.655         | 0.218        | 0.873         | 0.437         |
| <i>Daphne papyracea</i>                        | 0.053         | 0.018        | 0.070         | 0.035         |
| <i>Debregeasia salicifolia</i>                 | 0.350         | 0.117        | 0.467         | 0.233         |
| <i>Elaeagnus parvifolia</i>                    | 0.075         | 0.025        | 0.100         | 0.050         |
| <i>Hypericum dyeri</i>                         | 0.368         | 0.123        | 0.490         | 0.245         |
| <i>Hypericum oblongifolium</i>                 | 1.045         | 0.348        | 1.393         | 0.697         |
| <i>Indigofera atropurpurea</i>                 | 0.328         | 0.109        | 0.437         | 0.218         |
| <i>Indigofera dosua</i>                        | 0.255         | 0.085        | 0.340         | 0.170         |
| <i>Indigofera heterantha</i>                   | 0.185         | 0.062        | 0.247         | 0.123         |
| <i>Jasminum humile</i>                         | 0.150         | 0.050        | 0.200         | 0.100         |
| <i>Jasminum officinale</i>                     | 0.718         | 0.239        | 0.957         | 0.479         |
| <i>Lespedeza gerardiana</i>                    | 0.083         | 0.028        | 0.110         | 0.055         |
| <i>Lonicera quinquelocularis</i>               | 0.085         | 0.028        | 0.113         | 0.057         |
| <i>Myrsine africana</i>                        | 0.409         | 0.136        | 0.545         | 0.273         |
| <i>Prinsepia utilis</i>                        | 1.225         | 0.408        | 1.634         | 0.817         |
| <i>Rosa brunonii</i>                           | 0.543         | 0.181        | 0.724         | 0.362         |
| <i>Rosa macrophylla</i>                        | 1.478         | 0.493        | 1.971         | 0.985         |
| <i>Rubia cordifolia</i>                        | 0.318         | 0.106        | 0.423         | 0.212         |
| <i>Sageretia thea</i>                          | 0.178         | 0.059        | 0.237         | 0.118         |
| <i>Sarcococca saligna</i>                      | 0.213         | 0.071        | 0.283         | 0.142         |
| <i>Solanum myriacanthum</i>                    | 0.076         | 0.025        | 0.102         | 0.051         |
| <i>Spiraea canescens</i>                       | 0.268         | 0.089        | 0.357         | 0.178         |
| <i>Yucca gloriosa</i>                          | 0.575         | 0.192        | 0.767         | 0.383         |
| <i>Zanthoxylum armatum</i>                     | 1.984         | 0.661        | 2.645         | 1.323         |
| <b>Total</b>                                   | <b>15.541</b> | <b>5.180</b> | <b>20.721</b> | <b>10.361</b> |

At elevation E<sub>1</sub> highest aboveground biomass (18.937 t/ha), belowground biomass (6.312 t/ha), total biomass (25.250 t/ha) and total carbon (12.625 t/ha) was recorded in Moru Oak forests, followed by E<sub>2</sub> with aboveground biomass as 17.693 t/ha, belowground biomass as 5.894 t/ha, total biomass as 23.587 t/ha and total carbon as (11.799 t/ha). The least values



of aboveground biomass (14.415 t/ha), belowground biomass (4.805 t/ha), total biomass (19.219 t/ha) and total carbon (9.610 t/ha) was recorded at E<sub>3</sub> (Table 51).

At E<sub>1</sub> highest aboveground biomass (5.146 t/ha), belowground biomass (1.715 t/ha), total shrub biomass (6.861 t/ha) and carbon (3.430 t/ha) among different shrubs was recorded for *Rosa brunonii*, followed by *Berberis aristata* with aboveground biomass (4.330 t/ha), belowground biomass (1.443 t/ha), total biomass (5.774 t/ha) and carbon (2.887 t/ha). While lowest aboveground biomass (0.015 t/ha), belowground biomass (0.005 t/ha), total biomass (0.020 t/ha) and total carbon (0.010 t/ha) was recorded for *Schisandra grandiflora* (Table 51).

At elevation E<sub>2</sub>, highest aboveground biomass (2.198 t/ha), belowground biomass (0.733 t/ha), total biomass (2.930 t/ha) and total carbon (1.465 t/ha) was recorded for *Jasminum humile*, followed by *Hypericum oblongifolium* with aboveground biomass (1.778 t/ha), belowground biomass (0.593 t/ha), total biomass (2.370 t/ha) and total carbon (1.185 t/ha). However, *Clematis barbellata* exhibited lowest AGB (0.015 t/ha), BGB (0.005 t/ha), TB (0.020 t/ha) and TC (0.010 t/ha) (Table 51).

At elevation E<sub>3</sub> highest aboveground biomass (2.60 t/ha), belowground biomass (0.87 t/ha), total biomass (3.47 t/ha) and total carbon (1.74 t/ha) was recorded for *Rosa sericea*, followed by *Cotoneaster microphylla* with aboveground biomass, belowground biomass, total biomass and total carbon as 2.197 t/ha, 0.732 t/ha, 2.929 t/ha and 1.465 t/ha respectively. Whereas, least aboveground biomass (0.048 t/ha), belowground biomass (0.016 t/ha) total biomass (0.063 t/ha) and carbon (0.032 t/ha) was recorded for *Clematis buchananiana* at E<sub>3</sub> (Table 51).

Shrub aboveground biomass, belowground biomass, total biomass and total carbon of at E<sub>1</sub> ranged from 0.015 t/ha to 5.146 t/ha, 0.005 t/ha to 1.715 t/ha, 0.020 t/ha to 6.861 t/ha and 0.010 t/ha to 3.430 t/ha respectively. At E<sub>2</sub> range of aboveground biomass (0.015 t/ha to 2.198 t/ha), belowground biomass (0.005 t/ha to 0.733 t/ha), total biomass (0.020 t/ha to 2.930 t/ha) and total carbon (0.010 t/ha to 1.465 t/ha) while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.048 t/ha to 2.60 t/ha, 0.016 t/ha to 0.87 t/ha, 0.063 t/ha to 3.47 t/ha and 0.032 t/ha to 1.74 t/ha respectively (Table 51).

**Table 51: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in Moru Oak (*Q. floribunda*) forests at different elevations**

| Shrub species                                 | Biomass (t/ha)    |                   |               | Carbon (t/ha) |
|-----------------------------------------------|-------------------|-------------------|---------------|---------------|
|                                               | Aboveground (AGB) | Belowground (BGB) | Total (TB)    | Total (TC)    |
| <b>Elevation- E<sub>1</sub> (1800-2300 m)</b> |                   |                   |               |               |
| <i>Agave cantula</i>                          | 3.621             | 1.207             | 4.828         | 2.414         |
| <i>Berberis aristata</i>                      | 4.330             | 1.443             | 5.774         | 2.887         |
| <i>Cotoneaster bacillaris</i>                 | 0.138             | 0.046             | 0.184         | 0.092         |
| <i>Daphne papyracea</i>                       | 0.020             | 0.007             | 0.027         | 0.013         |
| <i>Debregeasia salicifolia</i>                | 0.178             | 0.059             | 0.237         | 0.118         |
| <i>Desmodium elegans</i>                      | 0.305             | 0.102             | 0.407         | 0.203         |
| <i>Hypericum oblongifolium</i>                | 1.923             | 0.641             | 2.563         | 1.282         |
| <i>Indigofera dosua</i>                       | 0.173             | 0.058             | 0.230         | 0.115         |
| <i>Lespedeza stenocarpa</i>                   | 0.123             | 0.041             | 0.164         | 0.082         |
| <i>Prinsepia utilis</i>                       | 0.638             | 0.213             | 0.851         | 0.425         |
| <i>Pteracanthus urticifolius</i>              | 0.165             | 0.055             | 0.220         | 0.110         |
| <i>Rhamnus virgatus</i>                       | 0.205             | 0.068             | 0.274         | 0.137         |
| <i>Rosa brunonii</i>                          | 5.146             | 1.715             | 6.861         | 3.430         |
| <i>Sageretia thea</i>                         | 0.150             | 0.050             | 0.200         | 0.100         |
| <i>Salix denticulata</i>                      | 0.200             | 0.067             | 0.267         | 0.133         |
| <i>Sarcococca saligna</i>                     | 0.591             | 0.197             | 0.788         | 0.394         |
| <i>Schisandra grandiflora</i>                 | 0.015             | 0.005             | 0.020         | 0.010         |
| <i>Skimmia laureola</i>                       | 0.256             | 0.085             | 0.342         | 0.171         |
| <i>Solanum myriacanthum</i>                   | 0.090             | 0.030             | 0.120         | 0.060         |
| <i>Spiraea canescens</i>                      | 0.034             | 0.011             | 0.046         | 0.023         |
| <i>Strobilanthes atropurpureus</i>            | 0.180             | 0.060             | 0.241         | 0.120         |
| <i>Viburnum cotinifolium</i>                  | 0.416             | 0.139             | 0.555         | 0.277         |
| <i>Wikstroemia canescens</i>                  | 0.040             | 0.013             | 0.053         | 0.027         |
| <b>Total</b>                                  | <b>18.937</b>     | <b>6.312</b>      | <b>25.250</b> | <b>12.625</b> |
| <b>Elevation- E<sub>2</sub> (2300-2800 m)</b> |                   |                   |               |               |
| <i>Berberis aristata</i>                      | 1.758             | 0.586             | 2.343         | 1.172         |
| <i>Berberis lycium</i>                        | 0.695             | 0.232             | 0.927         | 0.463         |
| <i>Buddleja crispa</i>                        | 0.776             | 0.259             | 1.035         | 0.518         |
| <i>Clematis barbellata</i>                    | 0.015             | 0.005             | 0.020         | 0.010         |
| <i>Coriaria nepalensis</i>                    | 0.900             | 0.300             | 1.200         | 0.600         |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Cotoneaster bacillaris</i>                 | 0.866         | 0.289        | 1.155         | 0.578         |
| <i>Daphne papyracea</i>                       | 0.550         | 0.183        | 0.733         | 0.366         |
| <i>Desmodium elegans</i>                      | 0.188         | 0.063        | 0.250         | 0.125         |
| <i>Deutzia compacta</i>                       | 0.069         | 0.023        | 0.092         | 0.046         |
| <i>Deutzia staminea</i>                       | 0.760         | 0.253        | 1.013         | 0.507         |
| <i>Hypericum oblongifolium</i>                | 1.778         | 0.593        | 2.370         | 1.185         |
| <i>Indigofera atropurpurea</i>                | 0.140         | 0.047        | 0.187         | 0.093         |
| <i>Indigofera dosua</i>                       | 0.028         | 0.009        | 0.037         | 0.018         |
| <i>Jasminum humile</i>                        | 2.198         | 0.733        | 2.930         | 1.465         |
| <i>Jasminum officinale</i>                    | 1.588         | 0.529        | 2.117         | 1.059         |
| <i>Lespedeza stenocarpa</i>                   | 0.060         | 0.020        | 0.080         | 0.040         |
| <i>Lonicera quinquelocularis</i>              | 0.070         | 0.020        | 0.090         | 0.050         |
| <i>Prinsepia utilis</i>                       | 0.100         | 0.033        | 0.133         | 0.066         |
| <i>Pteracanthus urticifolius</i>              | 0.069         | 0.023        | 0.092         | 0.046         |
| <i>Rabdosia rugosa</i>                        | 0.075         | 0.025        | 0.100         | 0.050         |
| <i>Ribes emodense</i>                         | 0.077         | 0.026        | 0.102         | 0.051         |
| <i>Rosa mycrophyla</i>                        | 0.471         | 0.157        | 0.628         | 0.314         |
| <i>Rubus macilentus</i>                       | 0.980         | 0.327        | 1.307         | 0.653         |
| <i>Sageretia thea</i>                         | 0.098         | 0.033        | 0.130         | 0.065         |
| <i>Salix denticulata</i>                      | 1.158         | 0.386        | 1.544         | 0.772         |
| <i>Sarcococca saligna</i>                     | 0.517         | 0.172        | 0.689         | 0.345         |
| <i>Schisandra grandiflora</i>                 | 0.140         | 0.047        | 0.187         | 0.093         |
| <i>Spiraea bella</i>                          | 0.118         | 0.039        | 0.157         | 0.078         |
| <i>Strobilanthes dalhousianus</i>             | 0.043         | 0.014        | 0.057         | 0.029         |
| <i>Thamnocalamus spathiflorus</i>             | 0.160         | 0.053        | 0.213         | 0.107         |
| <i>Viburnum foetida</i>                       | 0.418         | 0.139        | 0.557         | 0.278         |
| <i>Wikstroemia canescens</i>                  | 0.836         | 0.279        | 1.115         | 0.557         |
| <b>Total</b>                                  | <b>17.693</b> | <b>5.894</b> | <b>23.587</b> | <b>11.799</b> |
| <b>Elevation- E<sub>3</sub> (2800-3300 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                      | 1.516         | 0.505        | 2.022         | 1.011         |
| <i>Berberis lycium</i>                        | 0.465         | 0.155        | 0.620         | 0.310         |
| <i>Clematis buchananiana</i>                  | 0.048         | 0.016        | 0.063         | 0.032         |
| <i>Cotoneaster microphylla</i>                | 2.197         | 0.732        | 2.929         | 1.465         |
| <i>Deutzia compacta</i>                       | 1.132         | 0.377        | 1.510         | 0.755         |
| <i>Elaeagnus parvifolia</i>                   | 0.083         | 0.028        | 0.110         | 0.055         |
| <i>Lespedeza gerardiana</i>                   | 0.748         | 0.249        | 0.997         | 0.498         |
| <i>Lonicera quinquelocularis</i>              | 0.165         | 0.055        | 0.220         | 0.110         |
| <i>Parthenocissus himalayana</i>              | 0.293         | 0.098        | 0.390         | 0.195         |

|                                    |               |              |               |              |
|------------------------------------|---------------|--------------|---------------|--------------|
| <i>Pteracanthus urticifolius</i>   | 0.179         | 0.060        | 0.238         | 0.119        |
| <i>Rabdosia rugosa</i>             | 0.410         | 0.137        | 0.547         | 0.273        |
| <i>Rhamnus virgatus</i>            | 0.085         | 0.028        | 0.113         | 0.057        |
| <i>Rosa macrophylla</i>            | 0.743         | 0.248        | 0.990         | 0.495        |
| <i>Rosa sericea</i>                | 2.604         | 0.868        | 3.472         | 1.736        |
| <i>Rubus biflorus</i>              | 0.673         | 0.224        | 0.897         | 0.448        |
| <i>Rubus hypargyris</i>            | 0.310         | 0.103        | 0.413         | 0.207        |
| <i>Rubus macilentus</i>            | 1.108         | 0.369        | 1.477         | 0.738        |
| <i>Salix denticulata</i>           | 0.357         | 0.119        | 0.476         | 0.238        |
| <i>Skimmia laureola</i>            | 0.264         | 0.088        | 0.352         | 0.176        |
| <i>Strobilanthes atropurpureus</i> | 0.055         | 0.018        | 0.074         | 0.037        |
| <i>Thamnocalamus spathiflorus</i>  | 0.135         | 0.045        | 0.180         | 0.090        |
| <i>Viburnum cotinifolium</i>       | 0.847         | 0.282        | 1.129         | 0.565        |
| <b>Total</b>                       | <b>14.415</b> | <b>4.805</b> | <b>19.219</b> | <b>9.610</b> |

Aboveground, belowground, total biomass and total carbon of shrubs in Deodar forests exhibited difference at different elevations (Table 52). Highest aboveground biomass (17.020 t/ha), belowground biomass (5.673 t/ha), total biomass (22.693 t/ha) and total carbon (11.357 t/ha) in shrubs occurred at E<sub>1</sub>, which was followed by E<sub>2</sub> with 16.286 t/ha, 5.429 t/ha, 21.715 t/ha and 10.857 t/ha of AGB, BGB, TB and TC, respectively. The least values of aboveground biomass (10.917 t/ha), belowground biomass (3.639 t/ha) total biomass (14.556 t/ha) and total carbon (7.278 t/ha) in shrubs was recorded at elevation E<sub>3</sub>.

It was recorded that among different shrubs, at elevation E<sub>1</sub>, *Prinsepia utilis* exhibited highest aboveground biomass (3.597 t/ha), belowground biomass (1.199 t/ha), total biomass (4.796 t/ha) and total carbon (2.398 t/ha) while *Clematis grata* has lowest aboveground biomass (0.035 t/ha), belowground biomass (0.012 t/ha), total biomass (0.046 t/ha) and total carbon (0.023 t/ha). At elevation E<sub>2</sub>, maximum aboveground biomass (3.776 t/ha), belowground biomass (1.259 t/ha), total biomass (5.035 t/ha) and total carbon (2.518 t/ha) was recorded for *Viburnum cotinifolium* while least AGB (0.019 t/ha), BGB (0.006 t/ha), TB (0.025 t/ha) and TC (0.013 t/ha) was observed for *Spiraea canescens*. Maximum values at elevation E<sub>3</sub> were recorded for *Viburnum cotinifolium* (AGB as 2.082 t/ha, BGB as 0.694 t/ha, TB as 2.776 t/ha and TC as 1.388 t/ha) while *Spiraea canescens* exhibited lowest aboveground biomass (0.075 t/ha), belowground biomass (0.025 t/ha), total biomass (0.099 t/ha) and total carbon (0.050 t/ha) (Table 52).

Shrub aboveground biomass, belowground biomass, total biomass and total carbon of at E<sub>1</sub> ranged from 0.035 t/ha to 3.597 t/ha, 0.012 t/ha to 1.199 t/ha, 0.046 t/ha to 4.796 t/ha and 0.023 t/ha to 2.398 t/ha respectively. At E<sub>2</sub> range of aboveground biomass (0.019 t/ha to 3.776 t/ha), belowground biomass (0.006 t/ha to 1.259 t/ha), total biomass (0.025 t/ha to 5.035 t/ha) and total carbon (0.013 t/ha to 2.518 t/ha) while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.075 t/ha to 2.082 t/ha, 0.025 t/ha to 0.694 t/ha, 0.099 t/ha to 2.776 t/ha and 0.050 t/ha to 1.388 t/ha respectively (Table 52).

**Table 52: Aboveground (AGB), belowground (BGB, total biomass (TB) and total carbon (TC) of shrubs in Deodar (*Cedrus deodara*) forests at different elevations**

| Shrub Species                                 | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|-----------------------------------------------|-------------------|-------------------|------------|---------------|
|                                               | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation - E<sub>1</sub> (900-1800 m)</b> |                   |                   |            |               |
| <i>Asparagus adscendens</i>                   | 0.204             | 0.068             | 0.272      | 0.136         |
| <i>Berberis lycium</i>                        | 0.218             | 0.073             | 0.291      | 0.145         |
| <i>Boehmeria platyphylla</i>                  | 0.132             | 0.044             | 0.177      | 0.088         |
| <i>Buddleja asiatica</i>                      | 0.297             | 0.099             | 0.396      | 0.198         |
| <i>Clematis grata</i>                         | 0.035             | 0.012             | 0.046      | 0.023         |
| <i>Desmodium concinnum</i>                    | 0.049             | 0.016             | 0.065      | 0.033         |
| <i>Desmodium elegans</i>                      | 0.268             | 0.089             | 0.358      | 0.179         |
| <i>Dodonaea viscosa</i>                       | 0.655             | 0.218             | 0.874      | 0.437         |
| <i>Elaeagnus parvifolia</i>                   | 0.263             | 0.088             | 0.351      | 0.175         |
| <i>Euphorbia royleana</i>                     | 0.219             | 0.073             | 0.293      | 0.146         |
| <i>Hypericum oblongifolium</i>                | 2.122             | 0.707             | 2.829      | 1.414         |
| <i>Indigofera atropurpurea</i>                | 0.049             | 0.016             | 0.065      | 0.033         |
| <i>Indigofera heterantha</i>                  | 0.080             | 0.027             | 0.106      | 0.053         |
| <i>Jasminum officinale</i>                    | 1.614             | 0.538             | 2.152      | 1.076         |
| <i>Lespedeza juncea</i>                       | 1.032             | 0.344             | 1.376      | 0.688         |
| <i>Meriandra strobilifera</i>                 | 0.126             | 0.042             | 0.168      | 0.084         |
| <i>Myrsine africana</i>                       | 1.132             | 0.377             | 1.510      | 0.755         |
| <i>Osyris quadripartita</i>                   | 1.410             | 0.470             | 1.880      | 0.940         |
| <i>Prinsepia utilis</i>                       | 3.597             | 1.199             | 4.796      | 2.398         |
| <i>Rabdosia rugosa</i>                        | 0.056             | 0.019             | 0.075      | 0.037         |
| <i>Randia tetrasperma</i>                     | 0.262             | 0.087             | 0.350      | 0.175         |
| <i>Rhamnus virgatus</i>                       | 0.080             | 0.027             | 0.107      | 0.053         |
| <i>Rubus ellipticus</i>                       | 0.126             | 0.042             | 0.167      | 0.084         |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Sageretia thea</i>                          | 0.385         | 0.128        | 0.513         | 0.256         |
| <i>Sarcococca saligna</i>                      | 0.335         | 0.112        | 0.447         | 0.223         |
| <i>Viburnum cotinifolium</i>                   | 1.500         | 0.500        | 2.000         | 1.000         |
| <i>Woodfordia fruticosa</i>                    | 0.408         | 0.136        | 0.544         | 0.272         |
| <i>Zanthoxylum armatum</i>                     | 0.365         | 0.122        | 0.487         | 0.243         |
| <b>Total</b>                                   | <b>17.020</b> | <b>5.673</b> | <b>22.693</b> | <b>11.347</b> |
| <b>Elevation – E<sub>2</sub> (1800-2700 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                       | 0.368         | 0.123        | 0.490         | 0.245         |
| <i>Berberis lycium</i>                         | 0.274         | 0.091        | 0.365         | 0.183         |
| <i>Buddleja crispa</i>                         | 0.564         | 0.188        | 0.752         | 0.376         |
| <i>Clematis grata</i>                          | 0.057         | 0.019        | 0.076         | 0.038         |
| <i>Coriaria nepalensis</i>                     | 0.213         | 0.071        | 0.284         | 0.142         |
| <i>Cotoneaster bacillaris</i>                  | 0.636         | 0.212        | 0.848         | 0.424         |
| <i>Daphne papyracea</i>                        | 0.023         | 0.008        | 0.030         | 0.015         |
| <i>Debregeasia salicifolia</i>                 | 0.567         | 0.189        | 0.756         | 0.378         |
| <i>Desmodium elegans</i>                       | 0.056         | 0.019        | 0.074         | 0.037         |
| <i>Deutzia compacta</i>                        | 0.969         | 0.323        | 1.291         | 0.646         |
| <i>Elaeagnus parvifolia</i>                    | 0.653         | 0.218        | 0.871         | 0.436         |
| <i>Indigofera dosua</i>                        | 0.045         | 0.015        | 0.061         | 0.030         |
| <i>Jasminum humile</i>                         | 0.656         | 0.219        | 0.875         | 0.438         |
| <i>Jasminum officinale</i>                     | 0.772         | 0.257        | 1.030         | 0.515         |
| <i>Lespedeza gerardiana</i>                    | 0.023         | 0.008        | 0.031         | 0.015         |
| <i>Lonicera angustifolia</i>                   | 0.376         | 0.125        | 0.501         | 0.251         |
| <i>Myrsine africana</i>                        | 0.958         | 0.319        | 1.278         | 0.639         |
| <i>Prinsepia utilis</i>                        | 0.303         | 0.101        | 0.404         | 0.202         |
| <i>Rhamnus virgatus</i>                        | 0.110         | 0.037        | 0.146         | 0.073         |
| <i>Rosa brunonii</i>                           | 0.292         | 0.097        | 0.389         | 0.195         |
| <i>Rosa macrophylla</i>                        | 0.787         | 0.262        | 1.049         | 0.525         |
| <i>Rubus biflorus</i>                          | 1.237         | 0.412        | 1.650         | 0.825         |
| <i>Sarcococca saligna</i>                      | 0.079         | 0.026        | 0.106         | 0.053         |
| <i>Skimmia laureola</i>                        | 0.150         | 0.050        | 0.201         | 0.100         |
| <i>Solanum myriacanthum</i>                    | 1.229         | 0.410        | 1.639         | 0.819         |
| <i>Spiraea canescens</i>                       | 0.019         | 0.006        | 0.025         | 0.013         |
| <i>Viburnum cotinifolium</i>                   | 3.776         | 1.259        | 5.035         | 2.518         |
| <i>Wikstroemia canescens</i>                   | 1.095         | 0.365        | 1.460         | 0.730         |
| <b>Total</b>                                   | <b>16.286</b> | <b>5.429</b> | <b>21.715</b> | <b>10.857</b> |
| <b>Elevation – E<sub>3</sub> (2700-3600 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                       | 0.380         | 0.127        | 0.507         | 0.254         |
| <i>Berberis lycium</i>                         | 0.743         | 0.248        | 0.990         | 0.495         |
| <i>Clematis grata</i>                          | 0.112         | 0.037        | 0.149         | 0.075         |

|                                    |               |              |               |              |
|------------------------------------|---------------|--------------|---------------|--------------|
| <i>Cotoneaster microphylla</i>     | 0.334         | 0.111        | 0.446         | 0.223        |
| <i>Deutzia compacta</i>            | 0.566         | 0.189        | 0.754         | 0.377        |
| <i>Elaeagnus parvifolia</i>        | 0.974         | 0.325        | 1.298         | 0.649        |
| <i>Lonicera quinquelocularis</i>   | 0.117         | 0.039        | 0.155         | 0.078        |
| <i>Pteracanthus urticifolius</i>   | 0.215         | 0.072        | 0.287         | 0.143        |
| <i>Ribes emodense</i>              | 0.265         | 0.088        | 0.354         | 0.177        |
| <i>Rosa macrophylla</i>            | 1.667         | 0.556        | 2.222         | 1.111        |
| <i>Rubus biflorus</i>              | 1.054         | 0.351        | 1.406         | 0.703        |
| <i>Rubus foliolosus</i>            | 0.181         | 0.060        | 0.242         | 0.121        |
| <i>Schisandra grandiflora</i>      | 0.188         | 0.063        | 0.250         | 0.125        |
| <i>Scurrula elata</i>              | 0.226         | 0.075        | 0.302         | 0.151        |
| <i>Skimmia laureola</i>            | 0.216         | 0.072        | 0.288         | 0.144        |
| <i>Spiraea canescens</i>           | 0.075         | 0.025        | 0.099         | 0.050        |
| <i>Strobilanthes atropurpureus</i> | 0.134         | 0.045        | 0.179         | 0.090        |
| <i>Taxillus vestitus</i>           | 0.946         | 0.315        | 1.261         | 0.630        |
| <i>Thamnocalamus spathiflorus</i>  | 0.442         | 0.147        | 0.590         | 0.295        |
| <i>Viburnum cotinifolium</i>       | 2.082         | 0.694        | 2.776         | 1.388        |
| <b>Total</b>                       | <b>10.917</b> | <b>3.639</b> | <b>14.556</b> | <b>7.278</b> |

Aboveground, belowground, total biomass and total carbon of shrubs in western mixed coniferous forests exhibited difference at different elevations (Table 53). Highest aboveground biomass (18.329 t/ha), belowground biomass (6.110 t/ha), total biomass (24.439 t/ha) and total carbon (12.219 t/ha) was observed in E<sub>1</sub>, which was followed by E<sub>2</sub> with 15.289 t/ha, 5.096 t/ha, 20.385 t/ha and 10.192 t/ha of AGB, BGB, TB and TC respectively. The least aboveground biomass (13.594 t/ha), belowground biomass (4.531 t/ha), total biomass (18.125 t/ha) and total carbon (9.063 t/ha) were recorded from elevation three (E<sub>3</sub>).

*Berberis lycium* has exhibited maximum aboveground biomass (3.578 t/ha), belowground biomass (1.196 t/ha), total biomass (4.783 t/ha) and total carbon (2.391 t/ha) at E<sub>1</sub>, while lowest AGB (0.009 t/ha), BGB (0.003 t/ha), TB (0.013 t/ha) and TC (0.006 t/ha) recorded for *Clematis Montana*. At E<sub>2</sub>, maximum total biomass (1.517 t/ha) and total carbon (0.759 t/ha) was observed in *Cotoneaster bacillaris*, whereas minimum TB (0.030 t/ha) and TC (0.015 t/ha) was observed in *Hedera nepalensis*. Similarly, at E<sub>3</sub>, *Viburnum nervosum* exhibited maximum total biomass (4.718 t/ha) and total carbon (2.359 t/ha) whereas least total biomass (0.030 t/ha) and total carbon (0.015 t/ha) recorded by *Clematis montana* (Table 53).

Range of aboveground biomass, belowground biomass, total biomass and total carbon at E<sub>1</sub> was 0.035 t/ha to 3.597 t/ha, 0.012 t/ha to 1.199 t/ha, 0.046 t/ha to 4.796 t/ha and 0.023 t/ha to 2.398 t/ha, respectively. At E<sub>2</sub> range of aboveground biomass was 0.019 t/ha to 3.776

t/ha, belowground biomass as 0.006 t/ha to 1.259 t/ha, total biomass as 0.025 t/ha to 5.035 t/ha and total carbon as 0.013 t/ha to 2.518 t/ha while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.075 t/ha to 2.082 t/ha, 0.025 t/ha to 0.694 t/ha, 0.099 t/ha to 2.776 t/ha and 0.050 t/ha to 1.388 t/ha, respectively (Table 53).

**Table 53: Aboveground (AGB), belowground (BGB, total biomass (TB) and total carbon (TC) of shrubs in western mixed coniferous forests at different elevations**

| Shrub Species                                  | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|------------------------------------------------|-------------------|-------------------|------------|---------------|
|                                                | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation - E<sub>1</sub> (1200-2100 m)</b> |                   |                   |            |               |
| <i>Andrachne cordifolia</i>                    | 0.102             | 0.034             | 0.135      | 0.068         |
| <i>Berberis lycium</i>                         | 3.587             | 1.196             | 4.783      | 2.391         |
| <i>Buddleja crispa</i>                         | 0.343             | 0.114             | 0.457      | 0.229         |
| <i>Clematis buchananiana</i>                   | 0.015             | 0.005             | 0.021      | 0.010         |
| <i>Clematis montana</i>                        | 0.009             | 0.003             | 0.013      | 0.006         |
| <i>Coriaria nepalensis</i>                     | 0.155             | 0.052             | 0.206      | 0.103         |
| <i>Cotinus coggygria</i>                       | 0.104             | 0.035             | 0.139      | 0.069         |
| <i>Cotoneaster microphylla</i>                 | 0.635             | 0.212             | 0.847      | 0.424         |
| <i>Daphne papyracea</i>                        | 0.090             | 0.030             | 0.120      | 0.060         |
| <i>Debregeasia salicifolia</i>                 | 0.348             | 0.116             | 0.465      | 0.232         |
| <i>Desmodium elegans</i>                       | 0.184             | 0.061             | 0.245      | 0.122         |
| <i>Elaeagnus parvifolia</i>                    | 0.197             | 0.066             | 0.262      | 0.131         |
| <i>Hedera nepalensis</i>                       | 0.016             | 0.005             | 0.021      | 0.011         |
| <i>Hypericum dyeri</i>                         | 1.634             | 0.545             | 2.178      | 1.089         |
| <i>Indigofera atropurpurea</i>                 | 0.053             | 0.018             | 0.071      | 0.036         |
| <i>Indigofera heterantha</i>                   | 0.052             | 0.017             | 0.070      | 0.035         |
| <i>Inula cuspidata</i>                         | 0.065             | 0.022             | 0.086      | 0.043         |
| <i>Jasminum humile</i>                         | 0.533             | 0.178             | 0.710      | 0.355         |
| <i>Jasminum officinale</i>                     | 0.426             | 0.142             | 0.568      | 0.284         |
| <i>Lespedeza juncea</i>                        | 0.144             | 0.048             | 0.191      | 0.096         |
| <i>Lonicera quinquelocularis</i>               | 0.073             | 0.024             | 0.097      | 0.048         |
| <i>Prinsepia utilis</i>                        | 2.358             | 0.786             | 3.144      | 1.572         |
| <i>Rabdosia rugosa</i>                         | 0.098             | 0.033             | 0.131      | 0.066         |
| <i>Rhamnus virgatus</i>                        | 0.114             | 0.038             | 0.152      | 0.076         |
| <i>Rosa brunonii</i>                           | 0.267             | 0.089             | 0.356      | 0.178         |
| <i>Rosa macrophylla</i>                        | 0.590             | 0.197             | 0.787      | 0.394         |
| <i>Rubus ellipticus</i>                        | 0.118             | 0.039             | 0.157      | 0.078         |
| <i>Rubus macilentus</i>                        | 0.349             | 0.116             | 0.465      | 0.233         |
| <i>Salix denticulata</i>                       | 0.245             | 0.082             | 0.327      | 0.164         |
| <i>Sarcococca saligna</i>                      | 0.694             | 0.231             | 0.926      | 0.463         |
| <i>Skimmia laureola</i>                        | 0.596             | 0.199             | 0.794      | 0.397         |
| <i>Sorbaria tomentosa</i>                      | 0.167             | 0.056             | 0.223      | 0.111         |



|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Strobilanthes dalhousianus</i>              | 0.091         | 0.030        | 0.122         | 0.061         |
| <i>Taxillus vestitus</i>                       | 0.076         | 0.025        | 0.101         | 0.050         |
| <i>Thamnocalamus spathiflorus</i>              | 0.691         | 0.230        | 0.922         | 0.461         |
| <i>Viburnum cotinifolium</i>                   | 1.769         | 0.590        | 2.358         | 1.179         |
| <i>Zanthoxylum armatum</i>                     | 1.343         | 0.448        | 1.791         | 0.896         |
| <b>Total</b>                                   | <b>18.329</b> | <b>6.110</b> | <b>24.439</b> | <b>12.219</b> |
| <b>Elevation – E<sub>2</sub> (2100-3000 m)</b> |               |              |               |               |
| <i>Andrachne cordifolia</i>                    | 0.305         | 0.102        | 0.407         | 0.203         |
| <i>Berberis aristata</i>                       | 0.713         | 0.238        | 0.950         | 0.475         |
| <i>Buddleja crispa</i>                         | 0.179         | 0.060        | 0.239         | 0.120         |
| <i>Clematis barbellata</i>                     | 0.141         | 0.047        | 0.189         | 0.094         |
| <i>Coriaria nepalensis</i>                     | 0.217         | 0.072        | 0.289         | 0.145         |
| <i>Cotoneaster bacillaris</i>                  | 1.138         | 0.379        | 1.517         | 0.759         |
| <i>Cotoneaster microphylla</i>                 | 0.303         | 0.101        | 0.404         | 0.202         |
| <i>Daphne papyracea</i>                        | 0.510         | 0.170        | 0.679         | 0.340         |
| <i>Deutzia compacta</i>                        | 0.349         | 0.116        | 0.465         | 0.233         |
| <i>Elaeagnus parvifolia</i>                    | 0.369         | 0.123        | 0.492         | 0.246         |
| <i>Elsholtzia fruticosa</i>                    | 0.363         | 0.121        | 0.483         | 0.242         |
| <i>Hedera nepalensis</i>                       | 0.023         | 0.008        | 0.030         | 0.015         |
| <i>Hypericum dyeri</i>                         | 0.361         | 0.120        | 0.481         | 0.241         |
| <i>Inula cuspidata</i>                         | 0.920         | 0.307        | 1.226         | 0.613         |
| <i>Lespedeza gerardiana</i>                    | 0.050         | 0.017        | 0.067         | 0.033         |
| <i>Lonicera angustifolia</i>                   | 0.097         | 0.032        | 0.129         | 0.064         |
| <i>Lonicera quinquelocularis</i>               | 0.094         | 0.031        | 0.125         | 0.063         |
| <i>Pteracanthus urticifolius</i>               | 1.040         | 0.347        | 1.386         | 0.693         |
| <i>Rhamnus virgatus</i>                        | 0.556         | 0.185        | 0.741         | 0.371         |
| <i>Ribes emodense</i>                          | 0.032         | 0.011        | 0.043         | 0.021         |
| <i>Rosa macrophylla</i>                        | 0.441         | 0.147        | 0.588         | 0.294         |
| <i>Rosa sericea</i>                            | 0.406         | 0.135        | 0.541         | 0.271         |
| <i>Rubus biflorus</i>                          | 0.243         | 0.081        | 0.323         | 0.162         |
| <i>Rubus macilentus</i>                        | 0.265         | 0.088        | 0.353         | 0.177         |
| <i>Salix denticulata</i>                       | 0.921         | 0.307        | 1.228         | 0.614         |
| <i>Scurrula elata</i>                          | 0.206         | 0.069        | 0.274         | 0.137         |
| <i>Skimmia laureola</i>                        | 0.115         | 0.038        | 0.153         | 0.077         |
| <i>Spiraea bella</i>                           | 0.111         | 0.037        | 0.147         | 0.074         |
| <i>Strobilanthes atropurpureus</i>             | 0.080         | 0.027        | 0.106         | 0.053         |
| <i>Strobilanthes dalhousianus</i>              | 0.171         | 0.057        | 0.228         | 0.114         |
| <i>Taxillus vestitus</i>                       | 1.071         | 0.357        | 1.428         | 0.714         |
| <i>Thamnocalamus spathiflorus</i>              | 0.760         | 0.253        | 1.014         | 0.507         |
| <i>Viburnum cotinifolium</i>                   | 0.563         | 0.188        | 0.750         | 0.375         |
| <i>Viburnum foetens</i>                        | 0.965         | 0.322        | 1.286         | 0.643         |
| <i>Viburnum nervosum</i>                       | 0.179         | 0.060        | 0.238         | 0.119         |
| <i>Wikstroemia canescens</i>                   | 0.466         | 0.155        | 0.621         | 0.310         |
| <i>Zanthoxylum armatum</i>                     | 0.571         | 0.190        | 0.762         | 0.381         |
| <b>Total</b>                                   | <b>15.289</b> | <b>5.096</b> | <b>20.385</b> | <b>10.192</b> |
| <b>Elevation – E<sub>3</sub> (3000-3900 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                       | 1.630         | 0.543        | 2.173         | 1.087         |
| <i>Clematis montana</i>                        | 0.023         | 0.008        | 0.030         | 0.015         |

|                                    |               |              |               |              |
|------------------------------------|---------------|--------------|---------------|--------------|
| <i>Cotoneaster microphylla</i>     | 0.283         | 0.094        | 0.377         | 0.188        |
| <i>Deutzia compacta</i>            | 0.422         | 0.141        | 0.562         | 0.281        |
| <i>Lonicera quinquelocularis</i>   | 0.658         | 0.219        | 0.877         | 0.438        |
| <i>Pteracanthus urticifolius</i>   | 0.113         | 0.038        | 0.151         | 0.075        |
| <i>Ribes emodense</i>              | 0.618         | 0.206        | 0.824         | 0.412        |
| <i>Salix denticulata</i>           | 0.710         | 0.237        | 0.947         | 0.473        |
| <i>Scurrula elata</i>              | 0.334         | 0.111        | 0.445         | 0.223        |
| <i>Spiraea bella</i>               | 0.719         | 0.240        | 0.959         | 0.480        |
| <i>Strobilanthes atropurpureus</i> | 1.675         | 0.558        | 2.233         | 1.116        |
| <i>Strobilanthes dalhousianus</i>  | 0.473         | 0.158        | 0.631         | 0.315        |
| <i>Taxillus vestitus</i>           | 2.082         | 0.694        | 2.776         | 1.388        |
| <i>Thamnocalamus spathiflorus</i>  | 0.318         | 0.106        | 0.423         | 0.212        |
| <i>Viburnum nervosum</i>           | 3.539         | 1.180        | 4.718         | 2.359        |
| <b>Total</b>                       | <b>13.594</b> | <b>4.531</b> | <b>18.125</b> | <b>9.063</b> |

A perusal of the data presented in Table 54 reveals the difference in aboveground, belowground, total biomass and total carbon of shrubs in moist temperate lower deciduous forests at different elevations. Among all the elevations, at E<sub>1</sub> highest aboveground biomass (20.722 t/ha), belowground biomass (6.907 t/ha), total biomass (27.629 t/ha) and total carbon (13.815 t/ha) was recorded, followed by E<sub>2</sub> with aboveground biomass as 18.028 t/ha, belowground biomass as 6.009 t/ha, total biomass as 24.037 t/ha and total carbon as 12.019 t/ha. The least aboveground biomass (15.097 t/ha), belowground biomass (5.032 t/ha), total biomass (20.129 t/ha) and total carbon (10.065 t/ha) was recorded at E<sub>3</sub>.

At elevation E<sub>1</sub>, highest aboveground biomass (2.498 t/ha), belowground biomass (0.833 t/ha), total biomass (3.330 t/ha) and total carbon (1.665 t/ha) was recorded for *Viburnum mullaha*, followed by *Cotoneaster bacillaris* with aboveground biomass (1.990 t/ha), belowground biomass (0.663 t/ha), total biomass (2.653 t/ha) and total carbon (1.327 t/ha). While lowest aboveground biomass (0.009 t/ha), belowground biomass (0.003 t/ha), total biomass (0.012 t/ha) and total carbon (0.006 t/ha) was recorded for *Clematis buchananiana* at elevation E<sub>1</sub>. At elevation E<sub>2</sub>, Highest aboveground biomass (4.399 t/ha), belowground biomass (1.466 t/ha), total biomass (5.865t/ha) and carbon (2.933 t/ha) was recorded for *Berberis lycium*, followed by *Hypericum dyeri* with aboveground biomass (2.448 t/ha), belowground biomass (0.816 t/ha), total biomass (3.264 t/ha) and total carbon (1.632 t/ha) at E<sub>2</sub>. However, *Clematis buchananiana* was recorded for lowest aboveground biomass (0.007 t/ha), belowground biomass (0.002 t/ha), total biomass (0.009 t/ha) and total carbon (0.005 t/ha). At elevation E<sub>3</sub>, highest aboveground biomass (2.807 t/ha), belowground biomass (0.936 t/ha), total biomass (3.742 t/ha) and total carbon (1.871 t/ha) was recorded for

*Berberis lycium*, followed by *Myrsine africana* with aboveground biomass, belowground biomass, total biomass and carbon as 1.730 t/ha, 0.577 t/ha, 2.307 t/ha and 1.154 t/ha respectively. Lowest aboveground biomass (0.024 t/ha), belowground biomass (0.008 t/ha), total biomass (0.032 t/ha) and total carbon (0.016 t/ha) was recorded for *Hedera nepalensis* at E<sub>3</sub> (Table 54).

Range of aboveground biomass, belowground biomass, total biomass and total carbon at elevation E<sub>1</sub> was 0.009 t/ha to 2.498 t/ha, 0.003t/ha to 0.833 t/ha, 0.012 t/ha to 3.330 t/ha and 0.006 t/ha to 1.665 t/ha, respectively. At elevation E<sub>2</sub>, range of aboveground biomass as 0.007 t/ha to 4.399 t/ha, belowground biomass as 0.002 t/ha to 1.466 t/ha, total biomass as 0.009t/ha to 5.865 t/ha and total carbon as 0.005 t/ha to 2.933 t/ha while at elevation E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.024 t/ha to 2.807 t/ha, 0.008 t/ha to 0.936 t/ha, 0.032 t/ha to 3.742 t/ha and 0.016 t/ha to 1.871 t/ha, respectively (Table 54)

**Table 54: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in moist temperate lower deciduous forest at different elevations**

| Shrub Species                                 | Biomass (t/ha)    |                   |                    | Carbon (t/ha) |
|-----------------------------------------------|-------------------|-------------------|--------------------|---------------|
|                                               | Aboveground (AGB) | Belowground (BGB) | Total biomass (TB) | Total (TC)    |
| <b>Elevation- E<sub>1</sub> (1000-1800 m)</b> |                   |                   |                    |               |
| <i>Andrachne cordifolia</i>                   | 0.116             | 0.039             | 0.155              | 0.078         |
| <i>Argyrobium flaccidum</i>                   | 1.261             | 0.420             | 1.681              | 0.841         |
| <i>Berberis lycium</i>                        | 0.729             | 0.243             | 0.972              | 0.486         |
| <i>Boehmeria platyphylla</i>                  | 0.338             | 0.113             | 0.450              | 0.225         |
| <i>Buddleja asiatica</i>                      | 0.735             | 0.245             | 0.980              | 0.490         |
| <i>Clematis buechaniana</i>                   | 0.009             | 0.003             | 0.012              | 0.006         |
| <i>Cotoneaster bacillaris</i>                 | 1.990             | 0.663             | 2.653              | 1.327         |
| <i>Daphne papyracea</i>                       | 0.517             | 0.172             | 0.689              | 0.344         |
| <i>Desmodium elegans</i>                      | 0.235             | 0.078             | 0.314              | 0.157         |
| <i>Elsholtzia fruticosa</i>                   | 0.648             | 0.216             | 0.863              | 0.432         |
| <i>Euphorbia royleana</i>                     | 1.903             | 0.634             | 2.537              | 1.269         |
| <i>Indigofera atropurpurea</i>                | 0.565             | 0.188             | 0.753              | 0.376         |
| <i>Jasminum officinale</i>                    | 0.980             | 0.327             | 1.307              | 0.653         |
| <i>Lespedeza stenocarpa</i>                   | 1.062             | 0.354             | 1.416              | 0.708         |
| <i>Lonicera quinquelocularis</i>              | 0.083             | 0.028             | 0.110              | 0.055         |
| <i>Myrsine africana</i>                       | 1.144             | 0.381             | 1.525              | 0.763         |
| <i>Pteracanthus urticifolius</i>              | 0.422             | 0.141             | 0.563              | 0.282         |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Rhamnus virgatus</i>                       | 0.390         | 0.130        | 0.520         | 0.260         |
| <i>Rosa brunonii</i>                          | 1.539         | 0.513        | 2.052         | 1.026         |
| <i>Rubus ellipticus</i>                       | 0.660         | 0.220        | 0.879         | 0.440         |
| <i>Rubus macilentus</i>                       | 1.818         | 0.606        | 2.423         | 1.212         |
| <i>Sageretia thea</i>                         | 0.134         | 0.045        | 0.178         | 0.089         |
| <i>Salix denticulata</i>                      | 0.376         | 0.125        | 0.502         | 0.251         |
| <i>Sarcococca saligna</i>                     | 0.181         | 0.060        | 0.241         | 0.121         |
| <i>Viburnum mullaha</i>                       | 2.498         | 0.833        | 3.330         | 1.665         |
| <i>Zanthoxylum armatum</i>                    | 0.393         | 0.131        | 0.523         | 0.262         |
| <b>Total</b>                                  | <b>20.722</b> | <b>6.907</b> | <b>27.629</b> | <b>13.815</b> |
| <b>Elevation- E<sub>2</sub> (1800-2400 m)</b> |               |              |               |               |
| <i>Berberis lycium</i>                        | 4.399         | 1.466        | 5.865         | 2.933         |
| <i>Buddleja asiatica</i>                      | 0.210         | 0.070        | 0.280         | 0.140         |
| <i>Clematis buchananiana</i>                  | 0.007         | 0.002        | 0.009         | 0.005         |
| <i>Clematis montana</i>                       | 0.019         | 0.006        | 0.025         | 0.013         |
| <i>Coriaria nepalensis</i>                    | 1.001         | 0.334        | 1.335         | 0.668         |
| <i>Cotoneaster bacillaris</i>                 | 0.360         | 0.120        | 0.480         | 0.240         |
| <i>Cotoneaster microphylla</i>                | 0.304         | 0.101        | 0.405         | 0.203         |
| <i>Daphne papyracea</i>                       | 0.486         | 0.162        | 0.648         | 0.324         |
| <i>Elsholtzia fruticosa</i>                   | 0.666         | 0.222        | 0.888         | 0.444         |
| <i>Hedera nepalensis</i>                      | 0.098         | 0.033        | 0.130         | 0.065         |
| <i>Hypericum dyeri</i>                        | 2.448         | 0.816        | 3.264         | 1.632         |
| <i>Indigofera atropurpurea</i>                | 0.083         | 0.028        | 0.110         | 0.055         |
| <i>Indigofera dosua</i>                       | 0.063         | 0.021        | 0.083         | 0.042         |
| <i>Lonicera angustifolia</i>                  | 0.654         | 0.218        | 0.872         | 0.436         |
| <i>Rabdosia rugosa</i>                        | 0.233         | 0.078        | 0.311         | 0.155         |
| <i>Rhamnus virgatus</i>                       | 0.035         | 0.012        | 0.047         | 0.023         |
| <i>Ribes emodense</i>                         | 0.038         | 0.013        | 0.050         | 0.025         |
| <i>Rosa brunonii</i>                          | 1.131         | 0.377        | 1.508         | 0.754         |
| <i>Rosa macrophylla</i>                       | 0.350         | 0.117        | 0.467         | 0.233         |
| <i>Rosa sericea</i>                           | 0.865         | 0.288        | 1.153         | 0.577         |
| <i>Rubus foliolosus</i>                       | 0.180         | 0.060        | 0.240         | 0.120         |
| <i>Rubus hypargyryus</i>                      | 0.953         | 0.318        | 1.270         | 0.635         |
| <i>Sageretia thea</i>                         | 0.250         | 0.083        | 0.333         | 0.167         |
| <i>Salix denticulata</i>                      | 0.103         | 0.034        | 0.137         | 0.068         |
| <i>Sarcococca saligna</i>                     | 0.519         | 0.173        | 0.692         | 0.346         |
| <i>Schisandra grandiflora</i>                 | 0.519         | 0.173        | 0.692         | 0.346         |
| <i>Spiraea bella</i>                          | 0.135         | 0.045        | 0.180         | 0.090         |
| <i>Spiraea canescens</i>                      | 0.073         | 0.024        | 0.097         | 0.048         |
| <i>Strobilanthes atropurpureus</i>            | 0.629         | 0.210        | 0.838         | 0.419         |
| <i>Thamnocalamus spathiflorus</i>             | 0.133         | 0.044        | 0.177         | 0.088         |
| <i>Viburnum cotinifolium</i>                  | 1.089         | 0.363        | 1.452         | 0.726         |
| <b>Total</b>                                  | <b>18.028</b> | <b>6.009</b> | <b>24.037</b> | <b>12.019</b> |
| <b>Elevation- E<sub>3</sub> (2400-2700 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                      | 0.923         | 0.308        | 1.230         | 0.615         |
| <i>Berberis lycium</i>                        | 2.807         | 0.936        | 3.742         | 1.871         |
| <i>Clematis barbellata</i>                    | 0.061         | 0.020        | 0.081         | 0.040         |
| <i>Cotoneaster bacillaris</i>                 | 0.156         | 0.052        | 0.208         | 0.104         |

|                                    |               |              |               |               |
|------------------------------------|---------------|--------------|---------------|---------------|
| <i>Cotoneaster microphylla</i>     | 1.170         | 0.390        | 1.559         | 0.780         |
| <i>Elaeagnus parvifolia</i>        | 0.790         | 0.263        | 1.053         | 0.527         |
| <i>Hedera nepalensis</i>           | 0.024         | 0.008        | 0.032         | 0.016         |
| <i>Lespedeza juncea</i>            | 0.126         | 0.042        | 0.168         | 0.084         |
| <i>Lonicera angustifolia</i>       | 0.119         | 0.040        | 0.158         | 0.079         |
| <i>Lonicera quinquelocularis</i>   | 0.273         | 0.091        | 0.364         | 0.182         |
| <i>Myrsine africana</i>            | 1.730         | 0.577        | 2.307         | 1.154         |
| <i>Pteracanthus urticifolius</i>   | 0.134         | 0.045        | 0.179         | 0.090         |
| <i>Rhamnus virgatus</i>            | 0.168         | 0.056        | 0.223         | 0.112         |
| <i>Ribes emodense</i>              | 0.396         | 0.132        | 0.528         | 0.264         |
| <i>Rosa macrophylla</i>            | 1.230         | 0.410        | 1.640         | 0.820         |
| <i>Rosa sericea</i>                | 0.516         | 0.172        | 0.688         | 0.344         |
| <i>Rubus biflorus</i>              | 0.390         | 0.130        | 0.520         | 0.260         |
| <i>Rubus foliolosus</i>            | 0.230         | 0.077        | 0.307         | 0.153         |
| <i>Rubus hypargyryus</i>           | 0.640         | 0.213        | 0.853         | 0.427         |
| <i>Salix denticulata</i>           | 0.598         | 0.199        | 0.797         | 0.398         |
| <i>Skimmia laureola</i>            | 0.042         | 0.014        | 0.055         | 0.028         |
| <i>Sorbaria tomentosa</i>          | 0.194         | 0.065        | 0.258         | 0.129         |
| <i>Spiraea bella</i>               | 0.192         | 0.064        | 0.256         | 0.128         |
| <i>Spiraea canescens</i>           | 0.053         | 0.018        | 0.070         | 0.035         |
| <i>Strobilanthes atropurpureus</i> | 0.485         | 0.162        | 0.647         | 0.323         |
| <i>Strobilanthes dalhousianus</i>  | 0.031         | 0.010        | 0.042         | 0.021         |
| <i>Thamnocalamus spathiflorus</i>  | 0.295         | 0.098        | 0.393         | 0.197         |
| <i>Viburnum cotinifolium</i>       | 0.225         | 0.075        | 0.300         | 0.150         |
| <i>Viburnum foetens</i>            | 0.174         | 0.058        | 0.232         | 0.116         |
| <i>Viburnum mullaha</i>            | 0.679         | 0.226        | 0.905         | 0.452         |
| <i>Viburnum nervosum</i>           | 0.250         | 0.083        | 0.333         | 0.167         |
| <b>Total</b>                       | <b>15.097</b> | <b>5.032</b> | <b>20.129</b> | <b>10.065</b> |

A perusal of the data presented in Table 55 reveals that among all the elevations of Kail forests, at elevation E<sub>1</sub> highest aboveground biomass (18.084 t/ha), belowground biomass (6.354 t/ha), total biomass (24.438 t/ha) and total carbon (12.219 t/ha) was recorded. Which was followed by E<sub>2</sub> for aboveground biomass (15.697 t/ha), belowground biomass (5.232 t/ha), total biomass (20.930 t/ha and total carbon (10.465 t/ha). The minimum values of aboveground biomass (14.175 t/ha), belowground biomass (4.725 t/ha), total shrub biomass (18.900 t/ha) and total carbon (9.450 t/ha) were recorded at elevation E<sub>3</sub>.

*Hypericum dyeri*, at elevation E<sub>1</sub>, exhibited maximum aboveground biomass (5.529 t/ha), belowground biomass (0.888 t/ha), total shrub biomass (3.417 t/ha) and total carbon (1.709 t/ha). Which was followed by *Myrsine africana* with aboveground biomass (1.566 t/ha), belowground biomass (0.550 t/ha), total biomass (2.116 t/ha) and total carbon (1.058 t/ha). Whereas, minimum aboveground biomass (0.006 t/ha), belowground biomass (0.002

t/ha), total biomass (0.008 t/ha) and total carbon (0.004 t/ha) was recorded for *Clematis montana* at elevation E<sub>1</sub>. At elevation E<sub>2</sub>, highest aboveground biomass (2.608 t/ha), belowground biomass (0.869 t/ha), total shrub biomass (3.478 t/ha) and total carbon (1.739 t/ha) was recorded for *Myrsine africana*. Which was followed by *Viburnum foetens* with aboveground biomass (1.450 t/ha), belowground biomass (0.483 t/ha), total biomass (1.933 t/ha) and carbon (0.967 t/ha). Whereas, minimum aboveground biomass (0.010 t/ha), belowground biomass (0.003 t/ha), total biomass (0.013 t/ha) and carbon (0.007 t/ha) was recorded for *Clematis montana* at elevation E<sub>2</sub>. *Hedera nepalensis*, at elevation E<sub>3</sub>, exhibited lowest aboveground biomass (0.021 t/ha), belowground biomass (0.007 t/ha), total shrub biomass (0.027 t/ha) and carbon (0.014 t/ha). Whereas maximum aboveground biomass (2.388 t/ha), belowground biomass (0.796 t/ha), total shrub biomass (3.184 t/ha) and carbon (1.592 t/ha) were exhibited by *Cotoneaster bacillaris*, which was followed by *Rubus hypargyris* with aboveground biomass as 1.493 t/ha, belowground biomass as 0.498 t/ha, total shrub biomass as 1.990 t/ha and carbon as 0.995 t/ha (Table 55).

Range of aboveground biomass, belowground biomass, total biomass and total carbon trees at E<sub>1</sub> was 0.006 t/ha to 5.529 t/ha, 0.002 t/ha to 0.888 t/ha, 0.008 t/ha to 3.417 t/ha and 0.004 t/ha to 1.709 t/ha, respectively. At E<sub>2</sub> range of aboveground biomass was 0.010 t/ha to 2.608 t/ha, belowground biomass was 0.003 t/ha to 0.869 t/ha, total biomass was 0.0013 t/ha to 3.478 t/ha and total carbon was 0.007 t/ha to 1.739 t/ha while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.021 t/ha to 2.388 t/ha, 0.007 t/ha to 0.796 t/ha, 0.027 t/ha to 3.184 t/ha and 0.014 t/ha to 1.592 t/ha, respectively (Table 55).

**Table 55: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrub species in Kail (*Pinus wallichiana*) forest at different elevations**

| Shrub species                                 | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|-----------------------------------------------|-------------------|-------------------|------------|---------------|
|                                               | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation- E<sub>1</sub> (1400-2100 m)</b> |                   |                   |            |               |
| <i>Andrachne cordifolia</i>                   | 0.279             | 0.098             | 0.377      | 0.188         |
| <i>Berberis aristata</i>                      | 0.597             | 0.210             | 0.807      | 0.403         |
| <i>Berberis lycium</i>                        | 0.417             | 0.146             | 0.563      | 0.281         |
| <i>Boehmeria platyphylla</i>                  | 0.092             | 0.032             | 0.124      | 0.062         |
| <i>Buddleja asiatica</i>                      | 0.291             | 0.102             | 0.393      | 0.197         |

|                                              |               |              |              |               |
|----------------------------------------------|---------------|--------------|--------------|---------------|
| <i>Clematis buchananiana</i>                 | 0.055         | 0.019        | 0.075        | 0.037         |
| <i>Clematis montana</i>                      | 0.006         | 0.002        | 0.008        | 0.004         |
| <i>Coriaria nepalensis</i>                   | 0.311         | 0.109        | 0.421        | 0.210         |
| <i>Cotoneaster bacillaris</i>                | 0.976         | 0.343        | 1.318        | 0.659         |
| <i>Cotoneaster microphylla</i>               | 0.343         | 0.120        | 0.463        | 0.231         |
| <i>Daphne papyracea</i>                      | 0.809         | 0.284        | 1.093        | 0.546         |
| <i>Desmodium elegans</i>                     | 0.532         | 0.187        | 0.719        | 0.359         |
| <i>Elaeagnus parvifolia</i>                  | 0.831         | 0.292        | 1.123        | 0.561         |
| <i>Elsholtzia fruticosa</i>                  | 0.018         | 0.006        | 0.025        | 0.012         |
| <i>Hedera nepalensis</i>                     | 0.030         | 0.010        | 0.040        | 0.020         |
| <i>Hypericum dyeri</i>                       | 2.529         | 0.888        | 3.417        | 1.709         |
| <i>Indigofera atropurpurea</i>               | 0.334         | 0.117        | 0.451        | 0.226         |
| <i>Indigofera dosua</i>                      | 0.082         | 0.029        | 0.111        | 0.055         |
| <i>Inula cuspidata</i>                       | 0.111         | 0.039        | 0.151        | 0.075         |
| <i>Jasminum officinale</i>                   | 0.258         | 0.090        | 0.348        | 0.174         |
| <i>Lespedeza stenocarpa</i>                  | 0.030         | 0.011        | 0.041        | 0.020         |
| <i>Lonicera quinquelocularis</i>             | 0.327         | 0.115        | 0.442        | 0.221         |
| <i>Myrsine africana</i>                      | 1.566         | 0.550        | 2.116        | 1.058         |
| <i>Osyris quadripartita</i>                  | 0.543         | 0.191        | 0.734        | 0.367         |
| <i>Pteracanthus urticifolius</i>             | 0.939         | 0.330        | 1.269        | 0.635         |
| <i>Rabdosia rugosa</i>                       | 0.364         | 0.128        | 0.491        | 0.246         |
| <i>Rosa brunonii</i>                         | 0.520         | 0.183        | 0.703        | 0.352         |
| <i>Rubus ellipticus</i>                      | 1.273         | 0.447        | 1.721        | 0.860         |
| <i>Sageretia thea</i>                        | 0.354         | 0.124        | 0.478        | 0.239         |
| <i>Salix denticulata</i>                     | 0.077         | 0.027        | 0.104        | 0.052         |
| <i>Sarcococca saligna</i>                    | 1.357         | 0.477        | 1.833        | 0.917         |
| <i>Viburnum cotinifolium</i>                 | 1.181         | 0.415        | 1.596        | 0.798         |
| <i>Zanthoxylum armatum</i>                   | 0.655         | 0.230        | 0.885        | 0.442         |
| <b>Total</b>                                 | <b>18.084</b> | <b>6.354</b> | <b>24.43</b> | <b>12.219</b> |
| <b>Elevation-E<sub>2</sub> (2100-2800 m)</b> |               |              |              |               |
| <i>Andrachne cordifolia</i>                  | 0.044         | 0.015        | 0.058        | 0.029         |
| <i>Berberis aristata</i>                     | 1.206         | 0.402        | 1.608        | 0.804         |
| <i>Berberis lycium</i>                       | 0.553         | 0.184        | 0.738        | 0.369         |
| <i>Buddleja asiatica</i>                     | 0.021         | 0.007        | 0.028        | 0.014         |
| <i>Buddleja crispa</i>                       | 0.097         | 0.032        | 0.130        | 0.065         |
| <i>Clematis barbellata</i>                   | 0.019         | 0.006        | 0.026        | 0.013         |
| <i>Clematis montana</i>                      | 0.010         | 0.003        | 0.013        | 0.007         |
| <i>Coriaria nepalensis</i>                   | 1.142         | 0.381        | 1.522        | 0.761         |
| <i>Cotoneaster microphylla</i>               | 0.430         | 0.143        | 0.574        | 0.287         |
| <i>Daphne papyracea</i>                      | 0.500         | 0.167        | 0.667        | 0.333         |
| <i>Debregeasia salicifolia</i>               | 0.225         | 0.075        | 0.300        | 0.150         |
| <i>Elaeagnus parvifolia</i>                  | 0.170         | 0.057        | 0.227        | 0.114         |
| <i>Elsholtzia fruticosa</i>                  | 0.078         | 0.026        | 0.104        | 0.052         |
| <i>Hedera nepalensis</i>                     | 0.038         | 0.013        | 0.050        | 0.025         |
| <i>Hypericum dyeri</i>                       | 1.057         | 0.352        | 1.410        | 0.705         |
| <i>Indigofera dosua</i>                      | 0.018         | 0.006        | 0.024        | 0.012         |
| <i>Lespedeza juncea</i>                      | 0.189         | 0.063        | 0.252        | 0.126         |
| <i>Lonicera angustifolia</i>                 | 0.289         | 0.096        | 0.385        | 0.193         |

|                                              |               |              |              |               |
|----------------------------------------------|---------------|--------------|--------------|---------------|
| <i>Myrsine africana</i>                      | 2.608         | 0.869        | 3.478        | 1.739         |
| <i>Pteracanthus urticifolius</i>             | 0.223         | 0.074        | 0.298        | 0.149         |
| <i>Rabdosia rugosa</i>                       | 0.103         | 0.034        | 0.137        | 0.069         |
| <i>Rhamnus virgatus</i>                      | 0.328         | 0.109        | 0.437        | 0.218         |
| <i>Ribes emodense</i>                        | 0.110         | 0.037        | 0.146        | 0.073         |
| <i>Rosa brunonii</i>                         | 0.366         | 0.122        | 0.487        | 0.244         |
| <i>Rosa macrophylla</i>                      | 0.392         | 0.131        | 0.523        | 0.261         |
| <i>Rosa sericea</i>                          | 0.235         | 0.078        | 0.313        | 0.156         |
| <i>Rubus foliolosus</i>                      | 0.979         | 0.326        | 1.305        | 0.652         |
| <i>Salix denticulata</i>                     | 0.612         | 0.204        | 0.815        | 0.408         |
| <i>Sarcococca saligna</i>                    | 0.236         | 0.079        | 0.314        | 0.157         |
| <i>Skimmia laureola</i>                      | 0.103         | 0.034        | 0.138        | 0.069         |
| <i>Sorbaria tomentosa</i>                    | 0.279         | 0.093        | 0.372        | 0.186         |
| <i>Spiraea bella</i>                         | 0.167         | 0.056        | 0.222        | 0.111         |
| <i>Spiraea canescens</i>                     | 0.162         | 0.054        | 0.215        | 0.108         |
| <i>Strobilanthes dalhousianus</i>            | 0.063         | 0.021        | 0.084        | 0.042         |
| <i>Strobilanthes atropurpureus</i>           | 0.259         | 0.086        | 0.345        | 0.173         |
| <i>Thamnocalamus spathiflorus</i>            | 0.938         | 0.313        | 1.251        | 0.626         |
| <i>Viburnum foetens</i>                      | 1.450         | 0.483        | 1.933        | 0.967         |
| <b>Total</b>                                 | <b>15.697</b> | <b>5.232</b> | <b>20.93</b> | <b>10.465</b> |
| <b>Elevation-E<sub>3</sub> (2800-3600 m)</b> |               |              |              |               |
| <i>Berberis aristata</i>                     | 0.825         | 0.275        | 1.100        | 0.550         |
| <i>Berberis lycium</i>                       | 0.345         | 0.115        | 0.459        | 0.230         |
| <i>Clematis barbellata</i>                   | 0.086         | 0.029        | 0.114        | 0.057         |
| <i>Clematis montana</i>                      | 0.054         | 0.018        | 0.072        | 0.036         |
| <i>Cotoneaster bacillaris</i>                | 2.388         | 0.796        | 3.184        | 1.592         |
| <i>Cotoneaster microphylla</i>               | 0.371         | 0.124        | 0.495        | 0.247         |
| <i>Elaeagnus parvifolia</i>                  | 0.319         | 0.106        | 0.425        | 0.213         |
| <i>Hedera nepalensis</i>                     | 0.021         | 0.007        | 0.027        | 0.014         |
| <i>Lespedeza juncea</i>                      | 0.067         | 0.022        | 0.090        | 0.045         |
| <i>Lonicera angustifolia</i>                 | 0.179         | 0.060        | 0.239        | 0.120         |
| <i>Lonicera quinquelocularis</i>             | 0.087         | 0.029        | 0.115        | 0.058         |
| <i>Myrsine africana</i>                      | 1.204         | 0.401        | 1.606        | 0.803         |
| <i>Pteracanthus urticifolius</i>             | 0.066         | 0.022        | 0.088        | 0.044         |
| <i>Rhamnus virgatus</i>                      | 1.013         | 0.338        | 1.351        | 0.675         |
| <i>Ribes emodense</i>                        | 0.299         | 0.100        | 0.399        | 0.199         |
| <i>Rosa macrophylla</i>                      | 0.430         | 0.143        | 0.574        | 0.287         |
| <i>Rosa sericea</i>                          | 0.508         | 0.169        | 0.677        | 0.339         |
| <i>Rubus biflorus</i>                        | 0.122         | 0.041        | 0.162        | 0.081         |
| <i>Rubus foliolosus</i>                      | 0.298         | 0.099        | 0.398        | 0.199         |
| <i>Rubus hypargyryus</i>                     | 1.493         | 0.498        | 1.990        | 0.995         |
| <i>Salix denticulata</i>                     | 0.300         | 0.100        | 0.400        | 0.200         |
| <i>Skimmia laureola</i>                      | 0.521         | 0.174        | 0.695        | 0.347         |
| <i>Sorbaria tomentosa</i>                    | 0.173         | 0.058        | 0.230        | 0.115         |
| <i>Spiraea bella</i>                         | 0.510         | 0.170        | 0.681        | 0.340         |
| <i>Spiraea canescens</i>                     | 0.131         | 0.044        | 0.174        | 0.087         |
| <i>Strobilanthes atropurpureus</i>           | 0.134         | 0.045        | 0.179        | 0.089         |
| <i>Strobilanthes dalhousianus</i>            | 0.037         | 0.012        | 0.050        | 0.025         |



|                                   |               |              |              |              |
|-----------------------------------|---------------|--------------|--------------|--------------|
| <i>Thamnocalamus spathiflorus</i> | 0.461         | 0.154        | 0.614        | 0.307        |
| <i>Viburnum cotinifolium</i>      | 1.036         | 0.345        | 1.382        | 0.691        |
| <i>Viburnum foetens</i>           | 0.118         | 0.039        | 0.158        | 0.079        |
| <i>Viburnum mullaha</i>           | 0.363         | 0.121        | 0.484        | 0.242        |
| <i>Viburnum nervosum</i>          | 0.214         | 0.071        | 0.286        | 0.143        |
| <b>Total</b>                      | <b>14.175</b> | <b>4.725</b> | <b>18.90</b> | <b>9.450</b> |

Data presented in Table 56 reveals that among all the elevations of Kharsu Oak forests, at elevation E<sub>1</sub>, highest aboveground biomass (19.518 t/ha), belowground biomass (6.506 t/ha), total biomass (26.024 t/ha) and total carbon (13.017 t/ha) of shrubs was recorded. Which was followed by E<sub>2</sub> with aboveground shrub biomass as 16.876 t/ha, belowground shrub biomass as 5.625 t/ha, total shrub biomass as 22.502 t/ha and total shrub carbon as (11.251 t/ha). The least values of aboveground biomass (16.307 t/ha), belowground biomass (5.436 t/ha), total biomass (21.743 t/ha) and total carbon (10.871 t/ha) of shrubs was recorded at elevation E<sub>3</sub>.

At elevation E<sub>1</sub>, highest aboveground biomass (4.226 t/ha), belowground biomass (1.409 t/ha), total shrub biomass (5.635 t/ha) and total carbon (2.817 t/ha) among different shrubs was recorded for *Myrsine africana*, which was followed by *Prinsepia utilis* with aboveground biomass as 2.246 t/ha, belowground biomass as 0.749 t/ha, total biomass as 2.994 t/ha and total carbon as 1.497 t/ha. While lowest aboveground biomass (0.025 t/ha), belowground biomass (0.008 t/ha), total shrub biomass (0.033 t/ha) and total carbon (0.017 t/ha) was recorded for *Rabdosia rugosa*. At elevation E<sub>2</sub>, highest aboveground biomass (2.168 t/ha), belowground biomass (0.723 t/ha), total shrub biomass (2.890 t/ha) and total carbon (1.445 t/ha) was recorded for *Berberis aristata*, which was followed by *Rosa sericea* with aboveground biomass (1.962 t/ha), belowground biomass (0.654 t/ha), total shrub biomass (2.615 t/ha) and total carbon (1.31 t/ha) respectively. However, *Skimmia laureola* exhibited lowest aboveground biomass (0.040 t/ha), belowground biomass (0.013 t/ha), total shrub biomass (0.053 t/ha) and carbon (0.027 t/ha). At elevation E<sub>3</sub>, highest aboveground biomass (3.102 t/ha), belowground biomass (1.034 t/ha), total shrub biomass (4.136 t/ha) and total carbon (2.068 t/ha) was recorded for *Berberis aristata*, which was followed by *Rosa sericea* with aboveground biomass as 2.013 t/ha, belowground biomass as 0.671 t/ha, total shrub biomass as 2.683 and total carbon as 1.342 t/ha. Whereas, lowest total shrub biomass (0.477 t/ha) and carbon (0.238 t/ha) was recorded for *Spiraea bella* at elevation E<sub>3</sub> (Table 56).

At elevation E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.025 t/ha to 4.226 t/ha, 0.008 t/ha to 1.409 t/ha, 0.033 t/ha to 5.635 t/ha and 0.017 t/ha to 2.817 t/ha, respectively. At elevation E<sub>2</sub> aboveground biomass, belowground biomass, total biomass and total carbon varied from 0.040 t/ha to 2.168 t/ha, 0.013 t/ha to 0.723 t/ha, 0.053 t/ha to 2.890 t/ha and 0.027 t/ha to 1.445 t/ha, respectively while aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.358 t/ha to 3.102 t/ha, 0.119 t/ha to 1.034 t/ha, 0.477 t/ha to 4.136 t/ha and 0.238 t/ha to 2.068 t/ha respectively at elevation E<sub>3</sub> (Table 56).

**Table 56: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of shrubs in Kharsu Oak (*Q. semecarpifolia*) forests at different elevations**

| Shrub species                                 | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|-----------------------------------------------|-------------------|-------------------|------------|---------------|
|                                               | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation- E<sub>1</sub> (2300-2800 m)</b> |                   |                   |            |               |
| <i>Berberis aristata</i>                      | 0.256             | 0.085             | 0.342      | 0.171         |
| <i>Berberis lycium</i>                        | 1.829             | 0.610             | 2.438      | 1.219         |
| <i>Buddleja crispa</i>                        | 0.238             | 0.079             | 0.317      | 0.158         |
| <i>Cotoneaster bacillaris</i>                 | 0.148             | 0.049             | 0.197      | 0.098         |
| <i>Cotoneaster microphylla</i>                | 0.518             | 0.173             | 0.690      | 0.345         |
| <i>Daphne papyracea</i>                       | 0.177             | 0.059             | 0.236      | 0.118         |
| <i>Desmodium elegans</i>                      | 0.149             | 0.050             | 0.198      | 0.099         |
| <i>Deutzia compacta</i>                       | 0.171             | 0.057             | 0.227      | 0.114         |
| <i>Elaeagnus parvifolia</i>                   | 0.282             | 0.094             | 0.376      | 0.188         |
| <i>Elsholtzia fruticosa</i>                   | 0.065             | 0.022             | 0.087      | 0.044         |
| <i>Hypericum dyeri</i>                        | 0.871             | 0.290             | 1.161      | 0.581         |
| <i>Indigofera atropurpurea</i>                | 0.332             | 0.111             | 0.443      | 0.222         |
| <i>Indigofera dosua</i>                       | 0.047             | 0.016             | 0.062      | 0.031         |
| <i>Lespedeza juncea</i>                       | 0.223             | 0.074             | 0.297      | 0.149         |
| <i>Myrsine africana</i>                       | 4.226             | 1.409             | 5.635      | 2.817         |
| <i>Prinsepia utilis</i>                       | 2.246             | 0.749             | 2.994      | 1.497         |
| <i>Pteracanthus urticifolius</i>              | 0.499             | 0.166             | 0.666      | 0.333         |
| <i>Rabdosia rugosa</i>                        | 0.025             | 0.008             | 0.033      | 0.017         |
| <i>Rhamnus virgatus</i>                       | 0.054             | 0.018             | 0.072      | 0.036         |
| <i>Rosa macrophylla</i>                       | 1.660             | 0.553             | 2.214      | 1.107         |
| <i>Rubus biflorus</i>                         | 0.160             | 0.053             | 0.213      | 0.107         |
| <i>Salix denticulata</i>                      | 0.566             | 0.189             | 0.754      | 0.377         |
| <i>Sarcococca saligna</i>                     | 1.058             | 0.353             | 1.410      | 0.705         |
| <i>Skimmia laureola</i>                       | 0.492             | 0.164             | 0.656      | 0.328         |
| <i>Sorbaria tomentosa</i>                     | 0.274             | 0.091             | 0.365      | 0.183         |
| <i>Spiraea bella</i>                          | 0.045             | 0.015             | 0.060      | 0.030         |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Strobilanthes atropurpureus</i>            | 1.583         | 0.528        | 2.110         | 1.055         |
| <i>Thamnocalamus spathiflorus</i>             | 0.518         | 0.173        | 0.690         | 0.350         |
| <i>Viburnum cotinifolium</i>                  | 0.366         | 0.122        | 0.488         | 0.244         |
| <i>Viburnum foetens</i>                       | 0.444         | 0.148        | 0.592         | 0.296         |
| <b>Total</b>                                  | <b>19.518</b> | <b>6.506</b> | <b>26.024</b> | <b>13.017</b> |
| <b>Elevation- E<sub>2</sub> (2800-3200 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                      | 2.168         | 0.723        | 2.890         | 1.445         |
| <i>Cotoneaster bacillaris</i>                 | 0.936         | 0.312        | 1.247         | 0.624         |
| <i>Cotoneaster microphylla</i>                | 0.923         | 0.308        | 1.231         | 0.615         |
| <i>Deutzia compacta</i>                       | 0.286         | 0.095        | 0.382         | 0.191         |
| <i>Deutzia staminea</i>                       | 0.261         | 0.087        | 0.348         | 0.174         |
| <i>Elaeagnus parvifolia</i>                   | 0.134         | 0.045        | 0.178         | 0.089         |
| <i>Indigofera dosua</i>                       | 0.068         | 0.023        | 0.090         | 0.045         |
| <i>Indigofera heterantha</i>                  | 0.349         | 0.116        | 0.465         | 0.233         |
| <i>Lespedeza gerardiana</i>                   | 0.089         | 0.030        | 0.119         | 0.059         |
| <i>Lonicera quinquelocularis</i>              | 0.064         | 0.021        | 0.085         | 0.043         |
| <i>Pteracanthus urticifolius</i>              | 0.187         | 0.062        | 0.249         | 0.125         |
| <i>Ribes emodense</i>                         | 0.175         | 0.058        | 0.233         | 0.117         |
| <i>Rosa macrophylla</i>                       | 1.826         | 0.609        | 2.435         | 1.218         |
| <i>Rosa sericea</i>                           | 1.962         | 0.654        | 2.615         | 1.308         |
| <i>Rubus biflorus</i>                         | 1.289         | 0.430        | 1.718         | 0.859         |
| <i>Rubus foliolosus</i>                       | 0.499         | 0.166        | 0.665         | 0.333         |
| <i>Rubus hypargyris</i>                       | 1.459         | 0.486        | 1.945         | 0.973         |
| <i>Salix denticulata</i>                      | 0.943         | 0.314        | 1.257         | 0.628         |
| <i>Skimmia laureola</i>                       | 0.040         | 0.013        | 0.053         | 0.027         |
| <i>Sorbaria tomentosa</i>                     | 0.240         | 0.080        | 0.320         | 0.160         |
| <i>Spiraea bella</i>                          | 0.414         | 0.138        | 0.552         | 0.276         |
| <i>Strobilanthes atropurpureus</i>            | 0.445         | 0.148        | 0.593         | 0.296         |
| <i>Thamnocalamus spathiflorus</i>             | 0.945         | 0.315        | 1.260         | 0.630         |
| <i>Viburnum cotinifolium</i>                  | 0.288         | 0.096        | 0.383         | 0.192         |
| <i>Viburnum foetens</i>                       | 0.657         | 0.219        | 0.876         | 0.438         |
| <i>Wikstroemia canescens</i>                  | 0.234         | 0.078        | 0.312         | 0.156         |
| <b>Total</b>                                  | <b>16.876</b> | <b>5.625</b> | <b>22.502</b> | <b>11.251</b> |
| <b>Elevation- E<sub>3</sub> (3200-3600 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                      | 3.102         | 1.034        | 4.136         | 2.068         |
| <i>Cotoneaster microphylla</i>                | 1.590         | 0.530        | 2.120         | 1.060         |
| <i>Deutzia compacta</i>                       | 1.401         | 0.467        | 1.868         | 0.934         |
| <i>Lonicera quinquelocularis</i>              | 1.719         | 0.573        | 2.292         | 1.146         |
| <i>Ribes emodense</i>                         | 1.731         | 0.577        | 2.307         | 1.154         |
| <i>Rosa macrophylla</i>                       | 2.011         | 0.670        | 2.682         | 1.341         |
| <i>Rosa sericea</i>                           | 2.013         | 0.671        | 2.683         | 1.342         |
| <i>Salix denticulata</i>                      | 0.740         | 0.247        | 0.987         | 0.493         |
| <i>Spiraea bella</i>                          | 0.358         | 0.119        | 0.477         | 0.238         |
| <i>Viburnum mullaha</i>                       | 1.644         | 0.548        | 2.191         | 1.096         |
| <b>Total</b>                                  | <b>16.307</b> | <b>5.436</b> | <b>21.743</b> | <b>10.871</b> |

A perusal of the data presented in Table 57 reveals that in upper Oak-Fir forests among three elevations, E<sub>1</sub> showed highest aboveground biomass (15.613 t/ha), belowground biomass (5.204 t/ha), total biomass (20.817 t/ha) and total carbon (10.409 t/ha), followed by elevation E<sub>2</sub> with 13.523 t/ha as AGB, BGB as 4.508 t/ha, TB as 18.031 t/ha and TC as 9.016 t/ha. The least 11.954 t/ha (aboveground biomass), 3.985 t/ha (belowground biomass), 15.938 t/ha (total biomass) and 7.969 t/ha (total carbon) was recorded at elevation E<sub>3</sub>.

With respect to individual shrub species, maximum aboveground biomass (1.568 t/ha), belowground biomass (0.523 t/ha), total biomass (2.090 t/ha) and total carbon (1.045 t/ha) at elevation E<sub>1</sub> exhibited by *Berberis lycium*, followed by *Hypericum dyeri* with ABG (1.430 t/ha), BGB (0.477 t/ha), TB (1.907 t/ha) and TC (0.953 t/ha) Whereas least aboveground biomass (0.060 t/ha), belowground biomass (0.020 t/ha), total biomass (0.080 t/ha) and total carbon (0.040 t/ha) exhibited for *Ribes emodense*. At E<sub>2</sub>, maximum aboveground biomass (2.417 t/ha), belowground biomass (0.806 t/ha), total biomass (3.222 t/ha) and total carbon (1.611 t/ha) was observed for *Rosa sericea* while lowest AGB (0.002 t/ha), BGB (0.001 t/ha), TB (0.003 t/ha) and TC (0.001 t/ha) was recorded for *Lespedeza juncea*. At elevation E<sub>3</sub>, highest aboveground biomass (3.148 t/ha), belowground biomass (1.049 t/ha), total biomass (4.197 t/ha) and total carbon (2.098 t/ha) was observed for *Berberis aristata* whereas lowest values (ABG as 0.179, BGB as 0.060, TB as 0.239 t/ha and TC as 0.120 t/ha) occurred in *Lonicera quinquelocularis* (Table 57).

At E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.060 t/ha to 1.568 t/ha, 0.020 t/ha to 0.523 t/ha, 0.080 t/ha to 2.090 t/ha and 0.040 t/ha to 1.045 t/ha respectively. At E<sub>2</sub> aboveground biomass, belowground biomass total biomass varied from 0.002 t/ha to 2.417 t/ha, 0.001 t/ha to 0.806 t/ha, 0.003 t/ha to 3.222 t/ha and 0.001 t/ha to 1.611 t/ha, while aboveground biomass, belowground biomass, total tree biomass and total carbon ranged from 0.179 t/ha to 3.148 t/ha, 0.060 t/ha to 1.049 t/ha, 0.239 t/ha to 4.197 t/ha and 0.120 t/ha to 2.098 t/ha respectively at E<sub>3</sub> (Table 57).

**Table 57: Aboveground (AGB), belowground (BGB, total biomass (TB) and total carbon (TC) of shrubs in upper Oak-Fir forest at different elevations**

| Shrub Species                                  | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|------------------------------------------------|-------------------|-------------------|------------|---------------|
|                                                | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation - E<sub>1</sub> (2100-2600 m)</b> |                   |                   |            |               |
| <i>Andrachne cordifolia</i>                    | 0.288             | 0.096             | 0.383      | 0.192         |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Argyrolobium flaccidum</i>                  | 0.154         | 0.051        | 0.205         | 0.103         |
| <i>Berberis aristata</i>                       | 0.573         | 0.191        | 0.763         | 0.382         |
| <i>Berberis lycium</i>                         | 1.568         | 0.523        | 2.090         | 1.045         |
| <i>Buddleja crispa</i>                         | 0.368         | 0.123        | 0.490         | 0.245         |
| <i>Cotoneaster bacillaris</i>                  | 0.440         | 0.147        | 0.587         | 0.293         |
| <i>Cotoneaster microphylla</i>                 | 0.171         | 0.057        | 0.228         | 0.114         |
| <i>Daphne papyracea</i>                        | 0.325         | 0.108        | 0.433         | 0.217         |
| <i>Desmodium elegans</i>                       | 0.180         | 0.060        | 0.240         | 0.120         |
| <i>Deutzia compacta</i>                        | 0.314         | 0.105        | 0.418         | 0.209         |
| <i>Deutzia staminea</i>                        | 1.156         | 0.385        | 1.542         | 0.771         |
| <i>Elaeagnus parvifolia</i>                    | 0.157         | 0.052        | 0.209         | 0.104         |
| <i>Elsholtzia fruticosa</i>                    | 0.225         | 0.075        | 0.300         | 0.150         |
| <i>Hypericum dyeri</i>                         | 1.430         | 0.477        | 1.907         | 0.953         |
| <i>Indigofera atropurpurea</i>                 | 0.249         | 0.083        | 0.332         | 0.166         |
| <i>Indigofera dosua</i>                        | 0.073         | 0.024        | 0.098         | 0.049         |
| <i>Indigofera heterantha</i>                   | 0.124         | 0.041        | 0.166         | 0.083         |
| <i>Jasminum officinale</i>                     | 0.418         | 0.139        | 0.557         | 0.278         |
| <i>Lespedeza juncea</i>                        | 0.230         | 0.077        | 0.307         | 0.153         |
| <i>Myrsine africana</i>                        | 0.960         | 0.320        | 1.280         | 0.640         |
| <i>Prinsepia utilis</i>                        | 0.775         | 0.258        | 1.033         | 0.516         |
| <i>Pteracanthus urticifolius</i>               | 0.131         | 0.044        | 0.175         | 0.088         |
| <i>Rabdosia rugosa</i>                         | 0.124         | 0.041        | 0.166         | 0.083         |
| <i>Rhamnus virgatus</i>                        | 0.286         | 0.095        | 0.382         | 0.191         |
| <i>Ribes emodense</i>                          | 0.060         | 0.020        | 0.080         | 0.040         |
| <i>Rosa macrophylla</i>                        | 0.564         | 0.188        | 0.752         | 0.376         |
| <i>Rubus biflorus</i>                          | 1.310         | 0.437        | 1.747         | 0.873         |
| <i>Rubus hypargyryus</i>                       | 0.708         | 0.236        | 0.944         | 0.472         |
| <i>Salix denticulata</i>                       | 0.321         | 0.107        | 0.428         | 0.214         |
| <i>Sarcococca saligna</i>                      | 0.135         | 0.045        | 0.180         | 0.090         |
| <i>Skimmia laureola</i>                        | 0.248         | 0.083        | 0.330         | 0.165         |
| <i>Spiraea bella</i>                           | 0.176         | 0.059        | 0.235         | 0.118         |
| <i>Strobilanthes atropurpureus</i>             | 0.349         | 0.116        | 0.465         | 0.232         |
| <i>Viburnum foetens</i>                        | 0.835         | 0.278        | 1.113         | 0.557         |
| <i>Wikstroemia canescens</i>                   | 0.190         | 0.063        | 0.253         | 0.127         |
| <b>Total</b>                                   | <b>15.613</b> | <b>5.204</b> | <b>20.817</b> | <b>10.409</b> |
| <b>Elevation – E<sub>2</sub> (2600-3100 m)</b> |               |              |               |               |
| <i>Berberis aristata</i>                       | 0.648         | 0.216        | 0.864         | 0.432         |
| <i>Cotoneaster bacillaris</i>                  | 0.091         | 0.030        | 0.122         | 0.061         |
| <i>Cotoneaster microphylla</i>                 | 0.689         | 0.230        | 0.918         | 0.459         |
| <i>Deutzia compacta</i>                        | 0.169         | 0.056        | 0.225         | 0.113         |
| <i>Deutzia staminea</i>                        | 0.053         | 0.018        | 0.071         | 0.036         |
| <i>Elaeagnus parvifolia</i>                    | 0.286         | 0.095        | 0.382         | 0.191         |
| <i>Indigofera dosua</i>                        | 0.130         | 0.043        | 0.173         | 0.087         |
| <i>Indigofera heterantha</i>                   | 0.010         | 0.003        | 0.013         | 0.006         |
| <i>Lespedeza gerardiana</i>                    | 0.002         | 0.001        | 0.003         | 0.001         |
| <i>Lonicera quinquelocularis</i>               | 0.014         | 0.005        | 0.018         | 0.009         |
| <i>Pteracanthus urticifolius</i>               | 0.119         | 0.040        | 0.159         | 0.080         |
| <i>Ribes emodense</i>                          | 0.029         | 0.010        | 0.039         | 0.020         |

|                                                |               |              |               |              |
|------------------------------------------------|---------------|--------------|---------------|--------------|
| <i>Rosa macrophylla</i>                        | 0.608         | 0.203        | 0.810         | 0.405        |
| <i>Rosa sericea</i>                            | 2.417         | 0.806        | 3.222         | 1.611        |
| <i>Rubus biflorus</i>                          | 0.459         | 0.153        | 0.612         | 0.306        |
| <i>Rubus foliolosus</i>                        | 1.301         | 0.434        | 1.734         | 0.867        |
| <i>Rubus hypargyryus</i>                       | 2.203         | 0.734        | 2.937         | 1.469        |
| <i>Salix denticulata</i>                       | 0.987         | 0.329        | 1.316         | 0.658        |
| <i>Skimmia laureola</i>                        | 0.154         | 0.051        | 0.206         | 0.103        |
| <i>Sorbaria tomentosa</i>                      | 1.125         | 0.375        | 1.500         | 0.750        |
| <i>Spiraea bella</i>                           | 0.167         | 0.056        | 0.222         | 0.111        |
| <i>Strobilanthes atropurpureus</i>             | 0.054         | 0.018        | 0.072         | 0.036        |
| <i>Thamnocalamus spathiflorus</i>              | 0.162         | 0.054        | 0.216         | 0.108        |
| <i>Viburnum cotinifolium</i>                   | 0.709         | 0.236        | 0.945         | 0.473        |
| <i>Viburnum foetens</i>                        | 0.077         | 0.026        | 0.102         | 0.051        |
| <i>Wikstroemia canescens</i>                   | 0.864         | 0.288        | 1.152         | 0.576        |
| <b>Total</b>                                   | <b>13.523</b> | <b>4.508</b> | <b>18.031</b> | <b>9.016</b> |
| <b>Elevation – E<sub>3</sub> (3100-3500 m)</b> |               |              |               |              |
| <i>Berberis aristata</i>                       | 3.148         | 1.049        | 4.197         | 2.098        |
| <i>Cotoneaster microphylla</i>                 | 0.908         | 0.303        | 1.210         | 0.605        |
| <i>Deutzia compacta</i>                        | 1.649         | 0.550        | 2.198         | 1.099        |
| <i>Lonicera quinquelocularis</i>               | 0.179         | 0.060        | 0.239         | 0.120        |
| <i>Ribes emodense</i>                          | 1.440         | 0.480        | 1.920         | 0.960        |
| <i>Rosa macrophylla</i>                        | 0.955         | 0.318        | 1.273         | 0.637        |
| <i>Rosa sericea</i>                            | 1.735         | 0.578        | 2.313         | 1.157        |
| <i>Spiraea bella</i>                           | 0.308         | 0.103        | 0.410         | 0.205        |
| <i>Viburnum mullaha</i>                        | 1.633         | 0.544        | 2.177         | 1.089        |
| <b>Total</b>                                   | <b>11.954</b> | <b>3.985</b> | <b>15.938</b> | <b>7.969</b> |

Aboveground, belowground, total biomass and total carbon of shrubs in upper moist temperate deciduous forests exhibited difference at different elevations (Table 58). At elevation E<sub>1</sub> highest aboveground shrub biomass (12.179 t/ha), belowground biomass 4.060 t/ha, total biomass (16.239 t/ha) and total carbon (8.119 t/ha) was recorded followed by E<sub>2</sub> with aboveground biomass as 10.446 t/ha, belowground biomass as 3.485 t/ha, total biomass as 13.932 t/ha and total carbon as 7.42 t/ha while least aboveground biomass (9.723 t/ha), belowground biomass (3.241 t/ha), total biomass (12.964 t/ha) and total carbon (6.482 t/ha) was recorded at E<sub>3</sub>.

At elevation E<sub>1</sub>, highest values of aboveground biomass (2.396 t/ha), belowground biomass (0.799 t/ha), total shrub biomass (3.195 t/ha) and carbon (1.598 t/ha) was recorded for *Prinsepia utilis*, which was followed by *Myrsine africana* with aboveground biomass (1.343 t/ha), belowground biomass (0.448 t/ha), total biomass (1.790 t/ha) and carbon (0.895 t/ha). While lowest aboveground biomass (0.044 t/ha), belowground biomass (0.014 t/ha), total biomass (0.058 t/ha) and total carbon (0.029 t/ha) was recorded for *Buddleja crispa* at

E<sub>1</sub>. At elevation E<sub>2</sub>, highest aboveground biomass (2.438 t/ha), belowground biomass (0.813 t/ha), total biomass (3.251 t/ha) and total carbon (1.625 t/ha) was recorded for *Berberis aristata*, followed by *Rubus biflorus* with aboveground biomass (1.232 t/ha), belowground biomass (0.411 t/ha), total shrub biomass (1.643 t/ha) and carbon as (0.82 t/ha). Whereas *Indigofera dosua* exhibited lowest AGB, BGB, TB and TC as 0.036 t/ha, 0.012 t/ha, 0.048 t/ha and 0.024 t/ha respectively. At elevation E<sub>3</sub> highest aboveground biomass (2.083 t/ha), belowground biomass (0.694 t/ha), total biomass (2.777 t/ha) and total carbon (1.388 t/ha) was recorded for *Rosa macrophylla*, by *Viburnum mullaha* with AGB (1.913 t/ha), BGB(0.638 t/ha), TB (2.550 t/ha) and TC(1.275 t/ha) while lowest aboveground biomass (0.506 t/ha), belowground biomass (0.169 t/ha), total biomass (0.675 t/ha) and total carbon (0.338 t/ha) was observed for *Lonicera quinquelocularis* at elevation E<sub>3</sub> (Table 58).

**Table 58: Aboveground (AGB), belowground (BGB, total biomass (TB) and total carbon (TC) of shrubs in upper moist temperate deciduous forests at different elevation**

| Shrub Species                                  | Biomass (t/ha)    |                   |            | Carbon (t/ha) |
|------------------------------------------------|-------------------|-------------------|------------|---------------|
|                                                | Aboveground (AGB) | Belowground (BGB) | Total (TB) | Total (TC)    |
| <b>Elevation - E<sub>1</sub> (1700-2300 m)</b> |                   |                   |            |               |
| <i>Andrachne cordifolia</i>                    | 0.045             | 0.015             | 0.060      | 0.030         |
| <i>Argyrolobium flaccidum</i>                  | 0.071             | 0.024             | 0.095      | 0.048         |
| <i>Berberis lycium</i>                         | 0.516             | 0.172             | 0.688      | 0.344         |
| <i>Buddleja crispa</i>                         | 0.044             | 0.014             | 0.058      | 0.029         |
| <i>Cotoneaster bacillaris</i>                  | 0.368             | 0.123             | 0.490      | 0.245         |
| <i>Daphne papyracea</i>                        | 0.161             | 0.054             | 0.215      | 0.108         |
| <i>Deutzia staminea</i>                        | 0.138             | 0.046             | 0.183      | 0.092         |
| <i>Indigofera atropurpurea</i>                 | 0.264             | 0.088             | 0.352      | 0.176         |
| <i>Jasminum officinale</i>                     | 0.588             | 0.196             | 0.783      | 0.392         |
| <i>Lespedeza gerardiana</i>                    | 0.128             | 0.043             | 0.170      | 0.085         |
| <i>Lespedeza juncea</i>                        | 0.220             | 0.073             | 0.293      | 0.147         |
| <i>Myrsine africana</i>                        | 1.343             | 0.448             | 1.790      | 0.895         |
| <i>Prinsepia utilis</i>                        | 2.396             | 0.799             | 3.195      | 1.598         |
| <i>Pteracanthus urticifolius</i>               | 0.103             | 0.034             | 0.137      | 0.069         |
| <i>Rabdosia rugosa</i>                         | 0.468             | 0.156             | 0.624      | 0.312         |
| <i>Rhamnus virgatus</i>                        | 0.110             | 0.037             | 0.147      | 0.073         |
| <i>Ribes emodense</i>                          | 0.230             | 0.077             | 0.306      | 0.153         |
| <i>Rosa macrophylla</i>                        | 1.010             | 0.337             | 1.347      | 0.673         |
| <i>Rubus foliolosus</i>                        | 0.409             | 0.136             | 0.545      | 0.273         |
| <i>Rubus hypargyryus</i>                       | 0.675             | 0.225             | 0.900      | 0.450         |
| <i>Salix denticulata</i>                       | 0.623             | 0.208             | 0.830      | 0.415         |

|                                                 |               |              |               |              |
|-------------------------------------------------|---------------|--------------|---------------|--------------|
| <i>Sarcococca saligna</i>                       | 0.062         | 0.021        | 0.082         | 0.041        |
| <i>Skimmia laureola</i>                         | 0.248         | 0.083        | 0.330         | 0.165        |
| <i>Sorbaria tomentosa</i>                       | 0.090         | 0.030        | 0.120         | 0.060        |
| <i>Spiraea bella</i>                            | 0.083         | 0.028        | 0.110         | 0.055        |
| <i>Strobilanthes atropurpureus</i>              | 0.479         | 0.160        | 0.638         | 0.319        |
| <i>Thamnocalamus spathiflorus</i>               | 1.044         | 0.348        | 1.392         | 0.696        |
| <i>Viburnum foetens</i>                         | 0.093         | 0.031        | 0.123         | 0.062        |
| <i>Wikstroemia canescens</i>                    | 0.175         | 0.058        | 0.233         | 0.117        |
| <b>Total</b>                                    | <b>12.179</b> | <b>4.060</b> | <b>16.239</b> | <b>8.119</b> |
| <b>Elevation – E<sub>2</sub> (2300-2900 m)</b>  |               |              |               |              |
| <i>Berberis aristata</i>                        | 2.438         | 0.813        | 3.251         | 1.625        |
| <i>Cotoneaster bacillaris</i>                   | 0.581         | 0.194        | 0.775         | 0.388        |
| <i>Cotoneaster microphylla</i>                  | 0.128         | 0.043        | 0.170         | 0.085        |
| <i>Deutzia compacta</i>                         | 0.163         | 0.054        | 0.217         | 0.108        |
| <i>Deutzia staminea</i>                         | 0.146         | 0.049        | 0.194         | 0.097        |
| <i>Elaeagnus parvifolia</i>                     | 0.432         | 0.144        | 0.576         | 0.288        |
| <i>Indigofera dosua</i>                         | 0.036         | 0.012        | 0.048         | 0.024        |
| <i>Indigofera heterantha</i>                    | 0.164         | 0.055        | 0.219         | 0.110        |
| <i>Lepedeza gerardiana</i>                      | 0.096         | 0.032        | 0.127         | 0.064        |
| <i>Lonicera quinquelocularis</i>                | 0.162         | 0.054        | 0.216         | 0.108        |
| <i>Lotus corniculatus</i>                       | 0.080         | 0.030        | 0.110         | 0.510        |
| <i>Ribes emodense</i>                           | 0.324         | 0.108        | 0.432         | 0.216        |
| <i>Rosa macrophylla</i>                         | 0.281         | 0.094        | 0.375         | 0.188        |
| <i>Rosa sericea</i>                             | 0.398         | 0.133        | 0.530         | 0.265        |
| <i>Rubus biflorus</i>                           | 1.232         | 0.411        | 1.643         | 0.821        |
| <i>Rubus foliolosus</i>                         | 0.365         | 0.122        | 0.487         | 0.243        |
| <i>Rubus hypargyryus</i>                        | 0.626         | 0.209        | 0.835         | 0.418        |
| <i>Salix denticulata</i>                        | 0.420         | 0.140        | 0.560         | 0.280        |
| <i>Skimmia laureola</i>                         | 0.090         | 0.030        | 0.120         | 0.060        |
| <i>Sorbaria tomentosa</i>                       | 0.380         | 0.127        | 0.507         | 0.253        |
| <i>Spiraea bella</i>                            | 0.222         | 0.074        | 0.295         | 0.148        |
| <i>Strobilanthes atropurpureus</i>              | 0.068         | 0.023        | 0.091         | 0.045        |
| <i>Thamnocalamus spathiflorus</i>               | 0.735         | 0.245        | 0.980         | 0.490        |
| <i>Viburnum cotinifolium</i>                    | 0.483         | 0.161        | 0.644         | 0.322        |
| <i>Viburnum foetens</i>                         | 0.309         | 0.103        | 0.412         | 0.206        |
| <i>Wikstroemia canescens</i>                    | 0.090         | 0.030        | 0.120         | 0.060        |
| <b>Total</b>                                    | <b>10.446</b> | <b>3.485</b> | <b>13.932</b> | <b>6.966</b> |
| <b>Elevation – E<sub>3</sub> (2900 -3500 m)</b> |               |              |               |              |
| <i>Berberis aristata</i>                        | 0.788         | 0.263        | 1.050         | 0.525        |
| <i>Cotoneaster microphylla</i>                  | 1.221         | 0.407        | 1.627         | 0.814        |
| <i>Deutzia compacta</i>                         | 1.098         | 0.366        | 1.463         | 0.732        |
| <i>Lonicera quinquelocularis</i>                | 0.338         | 0.113        | 0.451         | 0.225        |
| <i>Ribes emodense</i>                           | 0.506         | 0.169        | 0.675         | 0.338        |
| <i>Rosa macrophylla</i>                         | 2.083         | 0.694        | 2.777         | 1.388        |



|                          |              |              |               |              |
|--------------------------|--------------|--------------|---------------|--------------|
| <i>Rosa sericea</i>      | 0.545        | 0.182        | 0.727         | 0.363        |
| <i>Salix denticulata</i> | 0.650        | 0.217        | 0.867         | 0.433        |
| <i>Spiraea bella</i>     | 0.583        | 0.194        | 0.778         | 0.389        |
| <i>Viburnum mullaha</i>  | 1.913        | 0.638        | 2.550         | 1.275        |
|                          | <b>9.723</b> | <b>3.241</b> | <b>12.964</b> | <b>6.482</b> |

At elevation E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.044 t/ha to 2.396 t/ha, 0.014 t/ha to 0.799 t/ha, 0.058 t/ha to 3.195 t/ha and 0.029 t/ha to 1.598 t/ha respectively. At E<sub>2</sub> aboveground biomass, belowground biomass total tree biomass varied from 0.0036 t/ha to 2.438 t/ha, 0.012 t/ha to 0.813 t/ha, 0.048 t/ha to 3.251 t/ha and 0.024 t/ha to 1.625 t/ha, while aboveground biomass, belowground biomass, total tree biomass and total carbon ranged from 0.338 t/ha to 2.083 t/ha, 0.113 t/ha to 0.694 t/ha, 0.451 t/ha to 2.777 t/ha and 0.225 t/ha to 1.388 t/ha respectively at elevation E<sub>3</sub> (Table 58).

Data presented in Table 59 reveal that among the nine different forest types shows that the change in shrub biomass among forests was statistically significant. Mean total biomass of shrubs in nine forests varies from 14.378 to 23.932 t/ha. Although, shrub biomass in moist temperate lower deciduous forests (23.932 t/ha) was highest but it was statistically at par with Ban Oak forests (23.887 t/ha) and Kharsu Oak forests (23.423 t/ha). There was significant decrease in mean total biomass of shrubs with increase in elevation with highest value (23.930 t/ha) at elevation E<sub>1</sub> followed by E<sub>2</sub> (20.913 t/ha) and least mean total biomass was observed at E<sub>3</sub> (18.032 t/ha). Forest types and elevation's interaction also influenced the total biomass of shrubs significantly. However, highest total biomass of shrubs was noted in Ban Oak (FT-1) forests as 27.844 t/ha at elevation E<sub>1</sub> which was at par with shrub biomass in moist temperate lower deciduous forests (FT-5) as 27.629 t/ha at elevation E<sub>1</sub>. Lowest biomass of shrubs was recorded in moist temperate upper deciduous forests (FT-9) as 12.964 t/ha at elevation E<sub>3</sub> which was however at par with shrub biomass in same forest at elevation E<sub>2</sub>.

Among different forest types (Table 59) change in total carbon in shrubs among forest types was also significant. Highest mean total carbon in shrubs was observed in moist temperate upper deciduous forests (11.966 t/ha) followed by 11.944 t/ha in Ban Oak forests, which were however at par. While lowest mean total carbon in shrubs was recorded in moist temperate upper deciduous forests as 7.199 t/ha. With respect to elevation, the change in shrub biomass (mean of different forests) was significant and it yielded highest total carbon

as 11.966 t/ha at elevation  $E_1$  followed by elevation  $E_2$  (10.460 t/ha) while least was recorded at  $E_3$  (9.017 t/ha). The interaction of forest types and elevation impacted shrub total carbon significantly. Highest total carbon in shrubs was recorded as 13.922 t/ha in Ban Oak forests (FT-1) at elevation  $E_1$  and lowest in moist temperate lower deciduous forests (FT-5) as 6.482 t/ha at elevation  $E_3$  which was however at par with total carbon in shrubs in the same forest at elevation  $E_2$  (6.996 t/ha).

**Table 59: Change in total biomass (TB) and total carbon (TC) of shrubs among forests (F) and elevations (E)**

| Forest Types (F) | Total Biomass (t/ha) at different elevations (E) |               |               | Mean          | Total Carbon (t/ha) at different elevations (E) |               |               | Mean          |
|------------------|--------------------------------------------------|---------------|---------------|---------------|-------------------------------------------------|---------------|---------------|---------------|
|                  | $E_1$                                            | $E_2$         | $E_3$         |               | $E_1$                                           | $E_2$         | $E_3$         |               |
| <b>FT-1</b>      | 27.844                                           | 23.096        | 20.721        | <b>23.887</b> | 13.922                                          | 11.548        | 10.361        | <b>11.944</b> |
| <b>FT-2</b>      | 25.250                                           | 23.587        | 19.219        | <b>22.685</b> | 12.625                                          | 11.799        | 9.610         | <b>11.345</b> |
| <b>FT-3</b>      | 22.693                                           | 21.715        | 14.556        | <b>19.655</b> | 11.347                                          | 10.857        | 7.278         | <b>9.827</b>  |
| <b>FT-4</b>      | 24.439                                           | 20.385        | 18.125        | <b>20.983</b> | 12.219                                          | 10.192        | 9.063         | <b>10.491</b> |
| <b>FT-5</b>      | 27.629                                           | 24.037        | 20.129        | <b>23.932</b> | 13.815                                          | 12.019        | 10.065        | <b>11.966</b> |
| <b>FT-6</b>      | 24.438                                           | 20.930        | 18.900        | <b>21.423</b> | 12.219                                          | 10.465        | 9.450         | <b>10.711</b> |
| <b>FT-7</b>      | 26.024                                           | 22.502        | 21.743        | <b>23.423</b> | 13.017                                          | 11.251        | 10.871        | <b>11.713</b> |
| <b>FT-8</b>      | 20.817                                           | 18.031        | 15.935        | <b>18.261</b> | 10.409                                          | 9.016         | 7.969         | <b>9.131</b>  |
| <b>FT-9</b>      | 16.239                                           | 13.932        | 12.964        | <b>14.378</b> | 8.119                                           | 6.996         | 6.482         | <b>7.199</b>  |
| <b>Mean</b>      | <b>23.930</b>                                    | <b>20.913</b> | <b>18.032</b> |               | <b>11.966</b>                                   | <b>10.460</b> | <b>9.017</b>  |               |
|                  | <b>C.D.</b> <sub>0.05</sub>                      |               |               |               | <b>C.D.</b> <sub>0.05</sub>                     |               |               |               |
|                  | <b>F</b>                                         | <b>C.D.</b>   | <b>SE (d)</b> |               | <b>F</b>                                        | <b>C.D.</b>   | <b>SE (d)</b> |               |
|                  | <b>E</b>                                         | 0.98          | 0.49          |               | <b>E</b>                                        | 0.56          | 0.28          |               |
|                  | <b>F x E</b>                                     | 0.56          | 0.29          |               | <b>F x E</b>                                    | 0.32          | 0.16          |               |
|                  |                                                  | 1.69          | 0.84          |               |                                                 | 0.97          | 0.48          |               |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in  $E_1$ ,  $E_2$  and  $E_3$  is different.

The shrub vegetation is an integral component of forest ecosystems, generally supports an important component of total plant floristic diversity (Gentry and Dodson 1987; Gentry and Emmons 1987; Mayfield and Daily 2005). Shrubs are of great significance to biophysical and biodynamic processes of different ecosystems and have a direct impact on ecosystem dynamics and function (Di Castri *et al.* 1981), and their role in the atmospheric carbon cycle (Waring and Running 1996). Shrub biomass is an important component of the total forest biomass, especially in natural stands.

It is evident from the results that in Himalayan moist temperate forest the biomass of shrubs varied with forest types and changed significantly along elevation. The primary reason for such variations is inevitable due to varying species composition, their growth behaviour and climatic variables. Beside this, in most temperate forests, competition for light is the main interaction between the understorey and overstorey. On the one hand, understorey competes with juvenile trees for light and can thus act as a filter for tree establishment. On the other hand, shading from the overstorey determines understorey composition and biomass. Thrippleton *et al* (2016) reported that varying overstorey–understorey interactions across the landscape and concluded that strongest effects are found at low to mid elevations, where tree establishment is substantially delayed; at high elevations, tree growth and establishment are more limited by low temperatures and said that it is largely due to reduced light availability under closed canopies, which reduces the growth rate and leads to lower biomass at shrub level. Many other factors affect the diversity of shrub layer. Among others these are environmental conditions (Hardtle *et al.* 2003; Kolb and Diekmann 2004), perturbations (Onaindia *et al.* 2004; Galhidy *et al.* 2006), litter layer (Dzwonko and Gawronski 2002) and intensity and type of former forest management (Graae and Heskjaer 1997). Open areas and tree species diversity had a positive relationship to shrub cover because a diverse overstorey generally created more canopy gaps (Gazol and Ibanez 2009). Canopy layer stand structure strongly influences understorey cover by resources, altering microsites and environmental conditions by light availability (Alaback 1982; Oliver and Larson 1996). Shrub cover is linked to habitat quality and a number of interconnected ecological processes (Carey 1995; Hagar *et al.* 1996). Ross and Walstad (1986) opined that biomass of shrubs regulated by the factors like age, size, origin, condition and habit of the species. Airi and Rawal (2015) expressed that canopy disturbance has impact on vegetation compositional attributes in west Himalayan and increased canopy disturbance leads to establishment and proliferation of non-native species in understorey.

Shrub composition usually varies considerably among different forest types at different elevation (Hart and Chen 2008). Several factors have been suggested to account for this variation including overstorey structure and composition (Hart and Chen 2008; Sangar *et al.* 2008), soil nutrient and moisture availability (Poulsen and Pendry 1995; Newbery *et al.* 1996), succession history (La Frankie *et al.* 2006), forest management strategies (Hart and Chen 2008; Ares *et al.* 2009), and fragmentation (Malvido and Ramos 2003; Rasingam and Parthasarathy 2009).

In the present study shrub biomass ranged from 12.96 (FT-9 at E<sub>3</sub>) to 27.84 t/ha (FT-1 at E<sub>1</sub>) in different forests at three elevations (Table 59). Results obtained in the present study got support from the finding of Ralhan *et al.* (1991) who reported shrub biomass to the tune of 14.86 to 18.1 t/ha in shrubland ecosystems of Himalaya and recorded species like, *Berberis vulgaris*, *Carissa spinarum*, *Murraya koenigii* in them. Biomass of shrubs recorded in the present study was appreciably higher than findings of Chaturvedi and Singh (1987) who reported shrub aboveground biomass from 0.56-0.82 t/ha in four areas of Himalayan Chir pine in Central Himalaya; 0.16 Mg ha<sup>-1</sup> in *Populus deltoides* forest to 2.36 Mg ha<sup>-1</sup> in *Pinus wallichiana* understory biomass and 0.08 to 1.18 Mg ha<sup>-1</sup> understorey carbon in seven forest types of Kashmir Himalaya (Dar and Sundarapandian 2015a); 0.52 t/ha (in blue pine-open canopy) to 1.22 t ha (in Fir-Spruce) shrub biomass and 0.17 ± 0.20 t/ha (in Deodar-open canopy) to 0.65 ± 0.48 t/ha (in Deodar-closed canopy) shrub biomass carbon in forests under different strata in temperate Kashmir Himalaya (Wani *et al.* 2016); 0.51 to 1.98 t/ha shrub biomass in differently managed Oak forests in north-west Himalaya (Pradeepan 2016); 2.63-4.68 t/ha mean aboveground biomass of shrubs of in Brazilian Cerrado (Linlienfein *et al.* 2001) and (Riberio *et al.* 2011); 2.16 to 8.6 t/ha shrub biomass in different forests of northwest Himalaya (Masoodi 2010) and 12.67t/ha shrub biomass in tropical dry deciduous forest of Madhya Pradesh (Salunkhe *et al.* 2014).

Adhikari *et al.* (1995) reported total biomass of shrubs under biotic interferences were least had comparatively higher different species in high altitude Himalayan forests as 0.25 t ha in Silver Fir, 1.71 t/ha in Horse Chestnut and 0.98 t/ha in Kharsu Oak forests. Although the biomass of shrubs in present study was higher than findings of Pradeepan (2016) for Oak forests in north-west Himalaya, but trend observed in shrub biomass change along elevation was similar who also found that it decreased from elevation E<sub>1</sub> as 0.83t/ha to 0.74 t/ha at elevation E<sub>2</sub> and 0.67 t/ha at elevation E<sub>3</sub>.

#### **4.6.3 Biomass and carbon in forbs**

Data presented in Table 60 reveals that among all three elevations in Ban Oak forests, highest aboveground biomass (236.68 g/m<sup>2</sup>), belowground biomass (78.89 g/m<sup>2</sup>), total biomass (315.57 g/m<sup>2</sup>) and total carbon (157.79 g/m<sup>2</sup>) of forbs existed at E<sub>1</sub> followed by E<sub>2</sub> with ABG as 211.42 g/m<sup>2</sup>, BGB as 52.86 g/m<sup>2</sup>, TB as 264.28 g/m<sup>2</sup> and TC as 132.14 g/m<sup>2</sup>. The least aboveground biomass (185.62 g/m<sup>2</sup>), belowground biomass (61.87 g/m<sup>2</sup>), total biomass (247.50 g/m<sup>2</sup>) and total carbon (123.75 g/m<sup>2</sup>) were recorded at E<sub>3</sub>. (Table 60)

Among individual forb species, at E<sub>1</sub>, maximum aboveground biomass (19.94 g/m<sup>2</sup>), belowground biomass (6.65 g/m<sup>2</sup>), total biomass (26.58 g/m<sup>2</sup>) and total carbon (13.29 g/m<sup>2</sup>) was recorded in *Anaphalis contorta*. Minimum aboveground biomass (0.65 g/m<sup>2</sup>), belowground biomass (0.22 g/m<sup>2</sup>), total biomass (0.86 g/m<sup>2</sup>) and total carbon (0.43 g/m<sup>2</sup>) at E<sub>1</sub> were observed in *Pteris cretica*. (Table 60)

At E<sub>2</sub>, *Themeda anathera* exhibited maximum aboveground biomass of 13.19 g/m<sup>2</sup>, belowground biomass of 3.30 g/m<sup>2</sup>, total biomass and total carbon of 16.49 g/m<sup>2</sup> and 8.24 g/m<sup>2</sup> respectively. Whereas, *Dioscorea deltoidea* exhibited lowest aboveground biomass (0.64 g/m<sup>2</sup>), belowground biomass (0.16 g/m<sup>2</sup>), total biomass (0.80 g/m<sup>2</sup>) and total carbon (0.40 g/m<sup>2</sup>). At E<sub>3</sub>, *Trifolium repens* had highest aboveground biomass (17.19 g/m<sup>2</sup>), belowground biomass (5.73 g/m<sup>2</sup>), total biomass (22.92 g/m<sup>2</sup>) and highest total carbon (11.46 g/m<sup>2</sup>). Lowest aboveground biomass (0.35 g/m<sup>2</sup>), belowground biomass (0.12 g/m<sup>2</sup>), total biomass (0.46 g/m<sup>2</sup>) and total carbon (0.23 g/m<sup>2</sup>) at E<sub>3</sub> were recorded in *Androsace sarmentosa*. (Table 60)

**Table 60: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Ban Oak (*Q. leucotrichophora*) forests at different elevations**

| Forb Species                                   | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|------------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                                | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation - E<sub>1</sub> (700 -1300 m)</b> |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                       | 1.29                        | 0.43              | 1.72               | 0.86                       |
| <i>Ainsliaea aptera</i>                        | 4.97                        | 1.66              | 6.63               | 3.31                       |
| <i>Ajuga bracteosa</i>                         | 9.45                        | 3.15              | 12.60              | 6.30                       |
| <i>Anaphalis contorta</i>                      | 19.94                       | 6.65              | 26.58              | 13.29                      |
| <i>Androsace lanuginosa</i>                    | 2.98                        | 0.99              | 3.97               | 1.99                       |
| <i>Androsace sarmentosa</i>                    | 2.83                        | 0.94              | 3.77               | 1.89                       |
| <i>Anemone obtusiloba</i>                      | 2.59                        | 0.86              | 3.46               | 1.73                       |
| <i>Angelica glauca</i>                         | 2.68                        | 0.89              | 3.57               | 1.79                       |
| <i>Arabis amplexicaulis</i>                    | 3.56                        | 1.19              | 4.75               | 2.37                       |
| <i>Artemisia roxburghiana</i>                  | 4.86                        | 1.62              | 6.48               | 3.24                       |
| <i>Bergenia stracheyi</i>                      | 5.83                        | 1.94              | 7.77               | 3.88                       |
| <i>Bistorta amplexicaulis</i>                  | 0.75                        | 0.25              | 1.00               | 0.50                       |
| <i>Bupleurum falcatum</i>                      | 5.52                        | 1.84              | 7.36               | 3.68                       |
| <i>Carex breviculmis</i>                       | 1.79                        | 0.60              | 2.38               | 1.19                       |
| <i>Carex cardiolepis</i>                       | 3.56                        | 1.19              | 4.75               | 2.37                       |
| <i>Chenopodium opulifolium</i>                 | 3.78                        | 1.26              | 5.03               | 2.52                       |
| <i>Clinopodium vulgare</i>                     | 2.85                        | 0.95              | 3.80               | 1.90                       |
| <i>Corydalis govaniana</i>                     | 3.03                        | 1.01              | 4.04               | 2.02                       |
| <i>Dioscorea deltoidea</i>                     | 0.74                        | 0.25              | 0.99               | 0.49                       |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Erigeron bellidioides</i>                   | 1.72          | 0.57         | 2.30          | 1.15          |
| <i>Fagopyrum dibotrys</i>                      | 1.95          | 0.65         | 2.59          | 1.30          |
| <i>Galium aparine</i>                          | 2.54          | 0.85         | 3.39          | 1.69          |
| <i>Geranium lucidum</i>                        | 2.98          | 0.99         | 3.98          | 1.99          |
| <i>Gypsophila cerastioides</i>                 | 4.31          | 1.44         | 5.75          | 2.88          |
| <i>Halenia elliptica</i>                       | 8.78          | 2.93         | 11.71         | 5.86          |
| <i>Impatiens scabrida</i>                      | 2.40          | 0.80         | 3.20          | 1.60          |
| <i>Iris nepalensis</i>                         | 12.33         | 4.11         | 16.44         | 8.22          |
| <i>Lotus corniculatus</i>                      | 4.54          | 1.51         | 6.05          | 3.03          |
| <i>Nepeta laevigata</i>                        | 9.05          | 3.02         | 12.07         | 6.03          |
| <i>Pedicularis hoffmeisteri</i>                | 2.03          | 0.68         | 2.70          | 1.35          |
| <i>Phragmites communis</i>                     | 1.09          | 0.36         | 1.45          | 0.73          |
| <i>Plantago depressa</i>                       | 3.23          | 1.08         | 4.30          | 2.15          |
| <i>Plectranthus japonicus</i>                  | 3.89          | 1.30         | 5.19          | 2.59          |
| <i>Podophyllum hexandrum</i>                   | 1.30          | 0.43         | 1.73          | 0.86          |
| <i>Polygonatum cirrhifolium</i>                | 3.89          | 1.30         | 5.19          | 2.59          |
| <i>Polygonatum multiflorum</i>                 | 6.51          | 2.17         | 8.68          | 4.34          |
| <i>Potentilla argyrophylla</i>                 | 3.22          | 1.07         | 4.29          | 2.15          |
| <i>Potentilla atrosanguinea</i>                | 1.83          | 0.61         | 2.44          | 1.22          |
| <i>Primula denticulata</i>                     | 13.65         | 4.55         | 18.20         | 9.10          |
| <i>Primula petiolaris</i>                      | 1.95          | 0.65         | 2.59          | 1.30          |
| <i>Pteris cretica</i>                          | 0.65          | 0.22         | 0.86          | 0.43          |
| <i>Ranunculus hirtellus</i>                    | 1.95          | 0.65         | 2.59          | 1.30          |
| <i>Roscoea purpurea</i>                        | 2.81          | 0.94         | 3.75          | 1.87          |
| <i>Salvia nubicola</i>                         | 6.50          | 2.17         | 8.67          | 4.33          |
| <i>Scrophularia himalensis</i>                 | 2.15          | 0.72         | 2.87          | 1.43          |
| <i>Selaginella spp.</i>                        | 3.25          | 1.08         | 4.33          | 2.17          |
| <i>Senecio chrysanthemoides</i>                | 4.02          | 1.34         | 5.37          | 2.68          |
| <i>Sibbaldia cuneata</i>                       | 4.54          | 1.51         | 6.05          | 3.03          |
| <i>Silene griffithii</i>                       | 2.16          | 0.72         | 2.88          | 1.44          |
| <i>Silene vulgaris</i>                         | 1.73          | 0.58         | 2.31          | 1.15          |
| <i>Smilacina purpurea</i>                      | 0.86          | 0.29         | 1.15          | 0.58          |
| <i>Stellaria media</i>                         | 2.89          | 0.96         | 3.86          | 1.93          |
| <i>Thymus linearis</i>                         | 3.91          | 1.30         | 5.22          | 2.61          |
| <i>Urtica ardens</i>                           | 2.15          | 0.72         | 2.87          | 1.43          |
| <i>Valeriana jatamansi</i>                     | 5.44          | 1.81         | 7.25          | 3.63          |
| <i>Valeriana pyrolaefolia</i>                  | 1.95          | 0.65         | 2.59          | 1.30          |
| <i>Verbascum thapsus</i>                       | 8.12          | 2.71         | 10.83         | 5.42          |
| <i>Vicatia coniiifolia</i>                     | 5.40          | 1.80         | 7.21          | 3.60          |
| <b>Total</b>                                   | <b>236.68</b> | <b>78.89</b> | <b>315.57</b> | <b>157.79</b> |
| <b>Elevation – E<sub>2</sub> (1300-1900 m)</b> |               |              |               |               |
| <i>Achyranthes aspera</i>                      | 2.67          | 0.67         | 3.33          | 1.67          |
| <i>Achyranthes bidentata</i>                   | 5.71          | 1.43         | 7.14          | 3.57          |
| <i>Ajuga bracteosa</i>                         | 4.40          | 1.10         | 5.50          | 2.75          |
| <i>Ajuga parviflora</i>                        | 3.82          | 0.95         | 4.77          | 2.39          |
| <i>Amaranthus blitum</i>                       | 3.46          | 0.87         | 4.33          | 2.17          |
| <i>Androsace lanuginosa</i>                    | 2.55          | 0.64         | 3.19          | 1.60          |
| <i>Arabis amplexicaulis</i>                    | 1.90          | 0.48         | 2.38          | 1.19          |

|                                |               |              |               |               |
|--------------------------------|---------------|--------------|---------------|---------------|
| <i>Arisaema flavum</i>         | 2.56          | 0.64         | 3.20          | 1.60          |
| <i>Artemisia roxburghiana</i>  | 1.30          | 0.33         | 1.63          | 0.81          |
| <i>Aster molliusculus</i>      | 7.32          | 1.83         | 9.15          | 4.57          |
| <i>Atylosia scarabaeoides</i>  | 2.69          | 0.67         | 3.37          | 1.68          |
| <i>Bidens biternata</i>        | 2.70          | 0.67         | 3.37          | 1.69          |
| <i>Bistorta amplexicaulis</i>  | 4.45          | 1.11         | 5.56          | 2.78          |
| <i>Clinopodium vulgare</i>     | 1.80          | 0.45         | 2.25          | 1.13          |
| <i>Cyathula tomentosa</i>      | 4.64          | 1.16         | 5.80          | 2.90          |
| <i>Datura stramonium</i>       | 4.05          | 1.01         | 5.06          | 2.53          |
| <i>Dicliptera bupleuroides</i> | 1.91          | 0.48         | 2.38          | 1.19          |
| <i>Dioscorea deltoidea</i>     | 0.64          | 0.16         | 0.80          | 0.40          |
| <i>Duchesnea indica</i>        | 3.41          | 0.85         | 4.26          | 2.13          |
| <i>Echinops niveus</i>         | 1.91          | 0.48         | 2.38          | 1.19          |
| <i>Fagopyrum dibotrys</i>      | 2.98          | 0.75         | 3.73          | 1.86          |
| <i>Fragaria nubicola</i>       | 9.87          | 2.47         | 12.33         | 6.17          |
| <i>Galium aparine</i>          | 5.44          | 1.36         | 6.80          | 3.40          |
| <i>Geranium lucidum</i>        | 1.92          | 0.48         | 2.40          | 1.20          |
| <i>Gerbera gossypina</i>       | 2.22          | 0.55         | 2.77          | 1.39          |
| <i>Habenaria intermedia</i>    | 1.55          | 0.39         | 1.94          | 0.97          |
| <i>Heracleum candicans</i>     | 2.67          | 0.67         | 3.33          | 1.67          |
| <i>Impatiens scabrida</i>      | 2.64          | 0.66         | 3.30          | 1.65          |
| <i>Iris nepalensis</i>         | 3.70          | 0.93         | 4.63          | 2.31          |
| <i>Leucas lanata</i>           | 11.08         | 2.77         | 13.85         | 6.93          |
| <i>Micromeria biflora</i>      | 3.01          | 0.75         | 3.77          | 1.88          |
| <i>Oenothera rosea</i>         | 12.32         | 3.08         | 15.40         | 7.70          |
| <i>Phragmites communis</i>     | 5.05          | 1.26         | 6.31          | 3.15          |
| <i>Plantago depressa</i>       | 6.84          | 1.71         | 8.55          | 4.28          |
| <i>Plantago erosa</i>          | 4.60          | 1.15         | 5.74          | 2.87          |
| <i>Plectranthus japonicus</i>  | 2.70          | 0.68         | 3.38          | 1.69          |
| <i>Polygonatum multiflorum</i> | 3.96          | 0.99         | 4.95          | 2.48          |
| <i>Potentilla argyrophylla</i> | 3.58          | 0.90         | 4.48          | 2.24          |
| <i>Primula floribunda</i>      | 1.88          | 0.47         | 2.35          | 1.18          |
| <i>Pteris cretica</i>          | 4.37          | 1.09         | 5.47          | 2.73          |
| <i>Rumex nepalensis</i>        | 1.06          | 0.26         | 1.32          | 0.66          |
| <i>Salvia lanata</i>           | 2.60          | 0.65         | 3.25          | 1.63          |
| <i>Scutellaria scandens</i>    | 3.00          | 0.75         | 3.75          | 1.88          |
| <i>Silene vulgaris</i>         | 7.56          | 1.89         | 9.45          | 4.73          |
| <i>Stellaria media</i>         | 1.19          | 0.30         | 1.48          | 0.74          |
| <i>Swertia cordata</i>         | 1.99          | 0.50         | 2.49          | 1.25          |
| <i>Thalictrum foliolosum</i>   | 4.44          | 1.11         | 5.55          | 2.78          |
| <i>Themeda anathera</i>        | 13.19         | 3.30         | 16.49         | 8.24          |
| <i>Trifolium repens</i>        | 2.15          | 0.54         | 2.69          | 1.34          |
| <i>Urtica ardens</i>           | 4.93          | 1.23         | 6.16          | 3.08          |
| <i>Urtica dioica</i>           | 0.92          | 0.23         | 1.15          | 0.58          |
| <i>Valeriana jatamansi</i>     | 2.69          | 0.67         | 3.36          | 1.68          |
| <i>Verbascum thapsus</i>       | 5.65          | 1.41         | 7.06          | 3.53          |
| <i>Viola canescens</i>         | 3.76          | 0.94         | 4.70          | 2.35          |
| <b>Total</b>                   | <b>211.42</b> | <b>52.86</b> | <b>264.28</b> | <b>132.14</b> |

| Elevation – E <sub>3</sub> (1900-2500 m) |       |      |       |       |
|------------------------------------------|-------|------|-------|-------|
| <i>Anaphalis contorta</i>                | 1.54  | 0.51 | 2.05  | 1.02  |
| <i>Androsace rotundifolia</i>            | 7.04  | 2.35 | 9.39  | 4.69  |
| <i>Androsace sarmentosa</i>              | 0.35  | 0.12 | 0.46  | 0.23  |
| <i>Arisaema flavum</i>                   | 1.37  | 0.46 | 1.82  | 0.91  |
| <i>Artemisia indica</i>                  | 6.31  | 2.10 | 8.42  | 4.21  |
| <i>Astilbe rivularis</i>                 | 1.58  | 0.53 | 2.11  | 1.05  |
| <i>Bupleurum hamiltonii</i>              | 14.02 | 4.67 | 18.69 | 9.35  |
| <i>Carex breviculmis</i>                 | 2.44  | 0.81 | 3.25  | 1.62  |
| <i>Carex remota</i>                      | 3.22  | 1.07 | 4.29  | 2.15  |
| <i>Chenopodium opulifolium</i>           | 1.40  | 0.47 | 1.87  | 0.94  |
| <i>Corydalis govaniana</i>               | 5.66  | 1.89 | 7.54  | 3.77  |
| <i>Crepis sancta</i>                     | 6.16  | 2.05 | 8.21  | 4.11  |
| <i>Dicliptera bupleuroides</i>           | 1.81  | 0.60 | 2.42  | 1.21  |
| <i>Dioscorea deltoidea</i>               | 4.02  | 1.34 | 5.35  | 2.68  |
| <i>Erigeron bellidioides</i>             | 4.99  | 1.66 | 6.65  | 3.33  |
| <i>Erigeron multicaulis</i>              | 2.89  | 0.96 | 3.85  | 1.93  |
| <i>Fagopyrum dibotrys</i>                | 3.34  | 1.11 | 4.45  | 2.22  |
| <i>Fragaria nubicola</i>                 | 7.43  | 2.48 | 9.90  | 4.95  |
| <i>Galium asperuloides</i>               | 1.52  | 0.51 | 2.03  | 1.02  |
| <i>Geranium lucidum</i>                  | 0.68  | 0.23 | 0.91  | 0.45  |
| <i>Gypsophila cerastioides</i>           | 1.62  | 0.54 | 2.16  | 1.08  |
| <i>Halenia elliptica</i>                 | 1.58  | 0.53 | 2.11  | 1.05  |
| <i>Iris nepalensis</i>                   | 2.11  | 0.70 | 2.82  | 1.41  |
| <i>Lamium album</i>                      | 2.40  | 0.80 | 3.19  | 1.60  |
| <i>Lotus corniculatus</i>                | 5.75  | 1.92 | 7.67  | 3.84  |
| <i>Myriactis nepalensis</i>              | 3.98  | 1.33 | 5.31  | 2.66  |
| <i>Nepeta laevigata</i>                  | 1.73  | 0.58 | 2.31  | 1.16  |
| <i>Phragmites communis</i>               | 3.46  | 1.15 | 4.61  | 2.30  |
| <i>Polygala abyssinica</i>               | 2.19  | 0.73 | 2.91  | 1.46  |
| <i>Polygonatum cirrhifolium</i>          | 1.41  | 0.47 | 1.88  | 0.94  |
| <i>Polygonatum multiflorum</i>           | 4.76  | 1.59 | 6.35  | 3.17  |
| <i>Potentilla argyrophylla</i>           | 3.94  | 1.31 | 5.25  | 2.63  |
| <i>Potentilla nepalensis</i>             | 3.35  | 1.12 | 4.47  | 2.24  |
| <i>Primula petiolaris</i>                | 2.88  | 0.96 | 3.84  | 1.92  |
| <i>Ranunculus hirtellus</i>              | 3.47  | 1.16 | 4.63  | 2.32  |
| <i>Ranunculus laetus</i>                 | 2.57  | 0.86 | 3.43  | 1.72  |
| <i>Rosularia rosulata</i>                | 3.45  | 1.15 | 4.61  | 2.30  |
| <i>Rumex nepalensis</i>                  | 1.45  | 0.48 | 1.93  | 0.97  |
| <i>Salvia nubicola</i>                   | 6.84  | 2.28 | 9.13  | 4.56  |
| <i>Scrophularia himalensis</i>           | 1.56  | 0.52 | 2.08  | 1.04  |
| <i>Smilax glaucophylla</i>               | 0.74  | 0.25 | 0.98  | 0.49  |
| <i>Stellaria media</i>                   | 1.76  | 0.59 | 2.35  | 1.17  |
| <i>Swertia cordata</i>                   | 8.33  | 2.78 | 11.11 | 5.55  |
| <i>Thymus linearis</i>                   | 3.07  | 1.02 | 4.09  | 2.05  |
| <i>Trifolium repens</i>                  | 17.19 | 5.73 | 22.92 | 11.46 |
| <i>Urtica ardens</i>                     | 0.87  | 0.29 | 1.16  | 0.58  |
| <i>Urtica dioica</i>                     | 1.16  | 0.39 | 1.54  | 0.77  |



|                               |               |              |               |               |
|-------------------------------|---------------|--------------|---------------|---------------|
| <i>Valeriana jatamansi</i>    | 2.35          | 0.78         | 3.13          | 1.57          |
| <i>Valeriana pyrolaefolia</i> | 5.23          | 1.74         | 6.97          | 3.49          |
| <i>Verbascum thapsus</i>      | 4.90          | 1.63         | 6.53          | 3.27          |
| <i>Vicatia coniifolia</i>     | 1.74          | 0.58         | 2.33          | 1.16          |
| <b>Total</b>                  | <b>185.62</b> | <b>61.87</b> | <b>247.50</b> | <b>123.75</b> |

At E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.65 to 19.94 g/m<sup>2</sup>, 0.22 to 6.65 g/m<sup>2</sup>, 0.86 to 26.58 g/m<sup>2</sup> and 0.43 to 13.29 g/m<sup>2</sup> respectively. At E<sub>2</sub> aboveground biomass, belowground biomass total biomass varied from 0.64 to 13.19 g/m<sup>2</sup>, 0.16 to 3.30 g/m<sup>2</sup>, 0.80 to 16.49 g/m<sup>2</sup> and 0.40 to 8.24 g/m<sup>2</sup> respectively. While aboveground biomass, belowground biomass, total tree biomass and total carbon ranged from 0.35 to 17.19 g/m<sup>2</sup>, 0.12 to 5.73 g/m<sup>2</sup>, 0.46 to 22.92 g/m<sup>2</sup> and 0.23 to 11.46 g/m<sup>2</sup> respectively. (Table 60)

Moru Oak forests among all the elevations, at E<sub>1</sub> highest aboveground biomass (250.47 g/m<sup>2</sup>), belowground biomass (83.49 g/m<sup>2</sup>), total biomass (333.96 g/m<sup>2</sup>) and total carbon (166.98 g/m<sup>2</sup>) was recorded, followed by E<sub>2</sub> with aboveground biomass of 225.22 g/m<sup>2</sup>, belowground biomass of 75.07 g/m<sup>2</sup>, total biomass of 300.03 g/m<sup>2</sup> and total carbon (150.15 g/m<sup>2</sup>). The least aboveground biomass (197.13 g/m<sup>2</sup>), belowground biomass (65.71 g/m<sup>2</sup>), total biomass (262.84 g/m<sup>2</sup>) and total carbon (131.42 g/m<sup>2</sup>) were recorded at E<sub>3</sub>. (Table 61).

At E<sub>1</sub> highest values of aboveground biomass (17.76 g/m<sup>2</sup>), belowground biomass (5.92 g/m<sup>2</sup>), total biomass (23.68 g/m<sup>2</sup>) and total carbon (11.84 g/m<sup>2</sup>) was recorded for *Stellaria media*, that descended in *Fragaria nubicola* with aboveground biomass (14.79 g/m<sup>2</sup>), belowground biomass (4.93 g/m<sup>2</sup>), total biomass (19.72 g/m<sup>2</sup>) and total carbon (9.86 g/m<sup>2</sup>). While least with aboveground biomass (0.46 g/m<sup>2</sup>), belowground biomass (0.15 g/m<sup>2</sup>), total biomass (0.62 g/m<sup>2</sup>) and total carbon (0.31 g/m<sup>2</sup>) was recorded for *Adiantum venustum* at E<sub>1</sub>. (Table 61)

At E<sub>2</sub> highest aboveground biomass (20.69 g/m<sup>2</sup>), belowground biomass (6.90 g/m<sup>2</sup>), total biomass (27.59 g/m<sup>2</sup>) and total carbon (13.80 g/m<sup>2</sup>) was recorded for *Vicatia coniifolia* followed by *Potentilla leschenaultiana* with aboveground biomass, belowground biomass, total biomass and carbon as 14.16 g/m<sup>2</sup>, 4.72 g/m<sup>2</sup>, 18.88 g/m<sup>2</sup> and 9.44 g/m<sup>2</sup> respectively. *Artemisia roxburghiana* was recorded for lowest aboveground biomass (0.79 g/m<sup>2</sup>),

belowground biomass (0.26 g/m<sup>2</sup>), total biomass (1.05 g/m<sup>2</sup>) and total carbon (0.53 g/m<sup>2</sup>). (Table 61).

At E<sub>3</sub> maximum aboveground biomass (a g/m<sup>2</sup>), belowground biomass (6.65 g/m<sup>2</sup>), total biomass (26.62 g/m<sup>2</sup>) and total carbon (13.31 g/m<sup>2</sup>) was recorded for *Thalictrum foliolosum*, followed by *Primula floribunda* with aboveground biomass, belowground biomass, total biomass and carbon as 14.58 g/m<sup>2</sup>, 4.86 g/m<sup>2</sup>, 19.44 g/m<sup>2</sup> and 9.72 g/m<sup>2</sup> respectively while lowest aboveground biomass (0.75 g/m<sup>2</sup>), belowground biomass (0.25 g/m<sup>2</sup>), total biomass (0.99 g/m<sup>2</sup>) and total carbon (0.50 g/m<sup>2</sup>) was recorded at E<sub>3</sub> for *Achyranthes aspera*. (Table 61).

**Table 61: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Moru Oak (*Q. floribunda*) forests at different elevations**

| Forb species                                  | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|-----------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                               | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation- E<sub>1</sub> (1800-2300 m)</b> |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                      | 0.46                        | 0.15              | 0.62               | 0.31                       |
| <i>Agrimonia pilosa</i>                       | 0.91                        | 0.30              | 1.21               | 0.61                       |
| <i>Ainsliaea aptera</i>                       | 4.55                        | 1.52              | 6.07               | 3.04                       |
| <i>Ajuga bracteosa</i>                        | 6.28                        | 2.09              | 8.37               | 4.18                       |
| <i>Anaphalis contorta</i>                     | 9.66                        | 3.22              | 12.88              | 6.44                       |
| <i>Androsace lanuginosa</i>                   | 7.05                        | 2.35              | 9.39               | 4.70                       |
| <i>Androsace rotundifolia</i>                 | 3.89                        | 1.30              | 5.19               | 2.59                       |
| <i>Arabis amplexicaulis</i>                   | 2.40                        | 0.80              | 3.20               | 1.60                       |
| <i>Bergenia ciliate</i>                       | 2.36                        | 0.79              | 3.15               | 1.57                       |
| <i>Bergenia stracheyi</i>                     | 5.23                        | 1.74              | 6.98               | 3.49                       |
| <i>Bistorta amplexicaulis</i>                 | 4.22                        | 1.41              | 5.62               | 2.81                       |
| <i>Bupleurum falcatum</i>                     | 5.10                        | 1.70              | 6.79               | 3.40                       |
| <i>Carex cardiolepis</i>                      | 2.25                        | 0.75              | 3.00               | 1.50                       |
| <i>Carex remota</i>                           | 2.25                        | 0.75              | 3.00               | 1.50                       |
| <i>Chenopodium opulifolium</i>                | 4.02                        | 1.34              | 5.35               | 2.68                       |
| <i>Clinopodium vulgare</i>                    | 6.19                        | 2.06              | 8.25               | 4.13                       |
| <i>Corydalis govaniana</i>                    | 9.53                        | 3.18              | 12.70              | 6.35                       |
| <i>Dioscorea deltoidea</i>                    | 5.46                        | 1.82              | 7.28               | 3.64                       |
| <i>Erigeron bellidioides</i>                  | 6.72                        | 2.24              | 8.96               | 4.48                       |
| <i>Fragaria nubicola</i>                      | 14.79                       | 4.93              | 19.72              | 9.86                       |
| <i>Gypsophila cerastioides</i>                | 6.65                        | 2.22              | 8.87               | 4.44                       |
| <i>Halenia elliptica</i>                      | 2.86                        | 0.95              | 3.82               | 1.91                       |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Heracleum candicans</i>                    | 4.47          | 1.49         | 5.96          | 2.98          |
| <i>Iris nepalensis</i>                        | 1.90          | 0.63         | 2.54          | 1.27          |
| <i>Lotus corniculatus</i>                     | 2.37          | 0.79         | 3.16          | 1.58          |
| <i>Origanum vulgare</i>                       | 4.54          | 1.51         | 6.05          | 3.03          |
| <i>Pedicularis hoffmeisteri</i>               | 2.55          | 0.85         | 3.39          | 1.70          |
| <i>Plantago depressa</i>                      | 5.10          | 1.70         | 6.79          | 3.40          |
| <i>Plectranthus japonicus</i>                 | 7.21          | 2.40         | 9.61          | 4.80          |
| <i>Podophyllum hexandrum</i>                  | 1.18          | 0.39         | 1.57          | 0.79          |
| <i>Polygonatum cirrhifolium</i>               | 3.25          | 1.08         | 4.33          | 2.16          |
| <i>Polygonatum verticillatum</i>              | 5.44          | 1.81         | 7.25          | 3.62          |
| <i>Potentilla argyrophylla</i>                | 10.48         | 3.49         | 13.98         | 6.99          |
| <i>Potentilla leschenaultiana</i>             | 7.35          | 2.45         | 9.80          | 4.90          |
| <i>Primula denticulata</i>                    | 8.93          | 2.98         | 11.91         | 5.95          |
| <i>Primula petiolaris</i>                     | 1.93          | 0.64         | 2.57          | 1.28          |
| <i>Roscoeia purpurea</i>                      | 2.25          | 0.75         | 3.00          | 1.50          |
| <i>Rumex nepalensis</i>                       | 1.74          | 0.58         | 2.32          | 1.16          |
| <i>Salvia nubicola</i>                        | 3.22          | 1.07         | 4.29          | 2.14          |
| <i>Scrophularia himalensis</i>                | 8.43          | 2.81         | 11.24         | 5.62          |
| <i>Selaginella spp.</i>                       | 8.64          | 2.88         | 11.52         | 5.76          |
| <i>Selinum candollii</i>                      | 6.72          | 2.24         | 8.96          | 4.48          |
| <i>Senecio chrysanthemoides</i>               | 2.46          | 0.82         | 3.29          | 1.64          |
| <i>Sibbaldia cuneata</i>                      | 3.90          | 1.30         | 5.20          | 2.60          |
| <i>Silene griffithii</i>                      | 9.73          | 3.24         | 12.97         | 6.48          |
| <i>Stellaria media</i>                        | 17.76         | 5.92         | 23.68         | 11.84         |
| <i>Urtica dioica</i>                          | 1.15          | 0.38         | 1.53          | 0.76          |
| <i>Valeriana jatamansi</i>                    | 3.21          | 1.07         | 4.27          | 2.14          |
| <i>Valeriana pyrolaefolia</i>                 | 1.78          | 0.59         | 2.37          | 1.18          |
| <b>Total</b>                                  | <b>250.47</b> | <b>83.49</b> | <b>333.96</b> | <b>166.98</b> |
| <b>Elevation- E<sub>2</sub> (2300-2800 m)</b> |               |              |               |               |
| <i>Ainsliaea aptera</i>                       | 1.43          | 0.48         | 1.91          | 0.96          |
| <i>Ajuga bracteosa</i>                        | 1.58          | 0.53         | 2.10          | 1.05          |
| <i>Anaphalis contorta</i>                     | 7.22          | 2.41         | 9.63          | 4.81          |
| <i>Androsace lanuginosa</i>                   | 2.81          | 0.94         | 3.75          | 1.88          |
| <i>Androsace rotundifolia</i>                 | 2.72          | 0.91         | 3.62          | 1.81          |
| <i>Arisaema flavum</i>                        | 3.00          | 1.00         | 4.00          | 2.00          |
| <i>Artemisia indica</i>                       | 2.41          | 0.80         | 3.21          | 1.61          |
| <i>Artemisia roxburghiana</i>                 | 0.79          | 0.26         | 1.05          | 0.53          |
| <i>Bergenia ciliata</i>                       | 3.64          | 1.21         | 4.86          | 2.43          |
| <i>Bupleurum falcatum</i>                     | 2.86          | 0.95         | 3.82          | 1.91          |
| <i>Carex breviculmis</i>                      | 4.74          | 1.58         | 6.32          | 3.16          |
| <i>Carex remota</i>                           | 2.85          | 0.95         | 3.80          | 1.90          |
| <i>Chenopodium opulifolium</i>                | 2.01          | 0.67         | 2.68          | 1.34          |
| <i>Crepis sancta</i>                          | 1.61          | 0.54         | 2.15          | 1.08          |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Dioscorea deltoidea</i>                    | 5.03          | 1.68         | 6.70          | 3.35          |
| <i>Erigeron multicaulis</i>                   | 2.03          | 0.68         | 2.71          | 1.35          |
| <i>Fagopyrum dibotrys</i>                     | 2.09          | 0.70         | 2.78          | 1.39          |
| <i>Galium asperuloides</i>                    | 10.09         | 3.36         | 13.45         | 6.73          |
| <i>Girardinia diversifolia</i>                | 3.17          | 1.06         | 4.23          | 2.12          |
| <i>Habenaria intermedia</i>                   | 3.67          | 1.22         | 4.89          | 2.44          |
| <i>Heracleum candicans</i>                    | 8.28          | 2.76         | 11.04         | 5.52          |
| <i>Lamium album</i>                           | 8.90          | 2.97         | 11.87         | 5.94          |
| <i>Myriactis nepalensis</i>                   | 2.41          | 0.80         | 3.22          | 1.61          |
| <i>Origanum vulgare</i>                       | 3.31          | 1.10         | 4.42          | 2.21          |
| <i>Phragmites communis</i>                    | 2.87          | 0.96         | 3.82          | 1.91          |
| <i>Plantago erosa</i>                         | 5.37          | 1.79         | 7.16          | 3.58          |
| <i>Polygala abyssinica</i>                    | 2.77          | 0.92         | 3.69          | 1.84          |
| <i>Polygonatum multiflorum</i>                | 2.87          | 0.96         | 3.82          | 1.91          |
| <i>Polygonatum verticillatum</i>              | 4.05          | 1.35         | 5.40          | 2.70          |
| <i>Potentilla fragarioides</i>                | 2.96          | 0.99         | 3.94          | 1.97          |
| <i>Potentilla leschenaultiana</i>             | 14.16         | 4.72         | 18.88         | 9.44          |
| <i>Primula denticulata</i>                    | 12.06         | 4.02         | 16.08         | 8.04          |
| <i>Primula petiolaris</i>                     | 3.79          | 1.26         | 5.06          | 2.53          |
| <i>Pteris cretica</i>                         | 4.61          | 1.54         | 6.14          | 3.07          |
| <i>Ranunculus laetus</i>                      | 4.81          | 1.60         | 6.41          | 3.21          |
| <i>Roscoeia purpurea</i>                      | 1.60          | 0.53         | 2.14          | 1.07          |
| <i>Rosularia rosulata</i>                     | 3.40          | 1.13         | 4.54          | 2.27          |
| <i>Rumex nepalensis</i>                       | 1.91          | 0.64         | 2.55          | 1.27          |
| <i>Salvia nubicola</i>                        | 2.40          | 0.80         | 3.20          | 1.60          |
| <i>Scrophularia himalensis</i>                | 2.76          | 0.92         | 3.68          | 1.84          |
| <i>Senecio nudicaulis</i>                     | 5.10          | 1.70         | 6.80          | 3.40          |
| <i>Silene griffithii</i>                      | 2.40          | 0.80         | 3.20          | 1.60          |
| <i>Smilax vaginata</i>                        | 2.40          | 0.80         | 3.20          | 1.60          |
| <i>Stellaria media</i>                        | 2.41          | 0.80         | 3.21          | 1.60          |
| <i>Swertia cordata</i>                        | 4.42          | 1.47         | 5.89          | 2.94          |
| <i>Thalictrum foliolosum</i>                  | 10.26         | 3.42         | 13.68         | 6.84          |
| <i>Trifolium pratense</i>                     | 3.52          | 1.17         | 4.69          | 2.34          |
| <i>Thymus linearis</i>                        | 9.13          | 3.04         | 12.18         | 6.09          |
| <i>Valeriana pyrolaefolia</i>                 | 3.83          | 1.28         | 5.11          | 2.55          |
| <i>Vicatia coniiifolia</i>                    | 20.69         | 6.90         | 27.59         | 13.80         |
| <b>Total</b>                                  | <b>225.22</b> | <b>75.07</b> | <b>300.30</b> | <b>150.15</b> |
| <b>Elevation- E<sub>3</sub> (2800-3300 m)</b> |               |              |               |               |
| <i>Achyranthes aspera</i>                     | 0.75          | 0.25         | 0.99          | 0.50          |
| <i>Agrimonia pilosa</i>                       | 0.78          | 0.26         | 1.04          | 0.52          |
| <i>Ajuga parviflora</i>                       | 0.80          | 0.27         | 1.06          | 0.53          |
| <i>Apluda mutica</i>                          | 7.60          | 2.53         | 10.14         | 5.07          |
| <i>Arabis amplexicaulis</i>                   | 1.84          | 0.61         | 2.45          | 1.22          |

|                                  |               |              |               |               |
|----------------------------------|---------------|--------------|---------------|---------------|
| <i>Arctium lappa</i>             | 2.04          | 0.68         | 2.72          | 1.36          |
| <i>Arisaema flavum</i>           | 0.74          | 0.25         | 0.98          | 0.49          |
| <i>Artemisia indica</i>          | 1.58          | 0.53         | 2.10          | 1.05          |
| <i>Aster molliusculus</i>        | 4.68          | 1.56         | 6.24          | 3.12          |
| <i>Atylosia scarabaeoides</i>    | 0.84          | 0.28         | 1.12          | 0.56          |
| <i>Bergenia ciliata</i>          | 3.07          | 1.02         | 4.09          | 2.04          |
| <i>Bidens biternata</i>          | 10.16         | 3.39         | 13.55         | 6.77          |
| <i>Bupleurum falcatum</i>        | 0.89          | 0.30         | 1.18          | 0.59          |
| <i>Cheilanthes albomarginata</i> | 6.72          | 2.24         | 8.96          | 4.48          |
| <i>Clinopodium vulgare</i>       | 0.63          | 0.21         | 0.84          | 0.42          |
| <i>Datura stramonium</i>         | 2.05          | 0.68         | 2.74          | 1.37          |
| <i>Dicliptera bupleuroides</i>   | 1.08          | 0.36         | 1.43          | 0.72          |
| <i>Dioscorea deltoidea</i>       | 4.61          | 1.54         | 6.15          | 3.07          |
| <i>Echinops niveus</i>           | 10.50         | 3.50         | 14.00         | 7.00          |
| <i>Erigeron multicaulis</i>      | 1.58          | 0.53         | 2.11          | 1.05          |
| <i>Fragaria nubicola</i>         | 1.88          | 0.63         | 2.50          | 1.25          |
| <i>Galium aparine</i>            | 4.53          | 1.51         | 6.04          | 3.02          |
| <i>Girardinia diversifolia</i>   | 2.82          | 0.94         | 3.75          | 1.88          |
| <i>Habenaria intermedia</i>      | 0.95          | 0.32         | 1.27          | 0.63          |
| <i>Leucas lanata</i>             | 0.96          | 0.32         | 1.27          | 0.64          |
| <i>Lotus corniculatus</i>        | 1.91          | 0.64         | 2.55          | 1.27          |
| <i>Micromeria biflora</i>        | 4.15          | 1.38         | 5.53          | 2.77          |
| <i>Myriactis nepalensis</i>      | 2.15          | 0.72         | 2.86          | 1.43          |
| <i>Plantago erosa</i>            | 8.77          | 2.92         | 11.70         | 5.85          |
| <i>Plectranthus japonicus</i>    | 4.97          | 1.66         | 6.63          | 3.31          |
| <i>Polygala abyssinica</i>       | 3.40          | 1.13         | 4.54          | 2.27          |
| <i>Potentilla argyrophylla</i>   | 6.65          | 2.22         | 8.87          | 4.43          |
| <i>Primula floribunda</i>        | 14.58         | 4.86         | 19.44         | 9.72          |
| <i>Pteris cretica</i>            | 7.16          | 2.39         | 9.55          | 4.77          |
| <i>Roscoeia purpurea</i>         | 10.63         | 3.54         | 14.17         | 7.09          |
| <i>Rumex nepalensis</i>          | 5.87          | 1.96         | 7.82          | 3.91          |
| <i>Saccharum filifolium</i>      | 8.38          | 2.79         | 11.18         | 5.59          |
| <i>Silene vulgaris</i>           | 2.56          | 0.85         | 3.41          | 1.71          |
| <i>Smilax glaucophylla</i>       | 4.10          | 1.37         | 5.47          | 2.73          |
| <i>Thalictrum foliolosum</i>     | 19.96         | 6.65         | 26.62         | 13.31         |
| <i>Trifolium pratense</i>        | 1.66          | 0.55         | 2.21          | 1.11          |
| <i>Urtica dioica</i>             | 2.51          | 0.84         | 3.34          | 1.67          |
| <i>Valeriana jatamansi</i>       | 1.96          | 0.65         | 2.61          | 1.31          |
| <i>Viola canescens</i>           | 11.70         | 3.90         | 15.61         | 7.80          |
| <b>Total</b>                     | <b>197.13</b> | <b>65.71</b> | <b>262.84</b> | <b>131.42</b> |

Range of aboveground biomass, belowground biomass, total biomass and total carbon at E<sub>1</sub> varied from 0.46 g/m<sup>2</sup> to 17.76 g/m<sup>2</sup>, 0.15 g/m<sup>2</sup> to 5.92 g/m<sup>2</sup>, 0.62 g/m<sup>2</sup> to 23.68 g/m<sup>2</sup>

and 0.31 g/m<sup>2</sup> to 11.84 g/m<sup>2</sup> respectively. At E<sub>2</sub> range of aboveground biomass as 0.79 g/m<sup>2</sup> to 20.69 g/m<sup>2</sup>, belowground biomass as 0.26 g/m<sup>2</sup> to 6.90 g/m<sup>2</sup>, total biomass as 1.05 g/m<sup>2</sup> to 27.59 g/m<sup>2</sup> and total carbon as 0.53 g/m<sup>2</sup> to 13.80 g/m<sup>2</sup> while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.75 g/m<sup>2</sup> to 19.96 g/m<sup>2</sup>, 0.25 g/m<sup>2</sup> to 6.65 g/m<sup>2</sup>, 0.99 g/m<sup>2</sup> to 26.62 g/m<sup>2</sup> and 0.50 g/m<sup>2</sup> to 13.31 g/m<sup>2</sup> respectively. (Table 61).

It is evident from the data exhibited in Table 62 that Deodar forests among all the elevations, highest aboveground biomass (347.28 g/m<sup>2</sup>), belowground biomass (115.76 g/m<sup>2</sup>), total biomass (463.04 g/m<sup>2</sup>) and total carbon (231.52 g/m<sup>2</sup>) exhibited at E<sub>1</sub> followed by E<sub>2</sub> with ABG as 332.77 g/m<sup>2</sup>, BGB as 110.92 g/m<sup>2</sup>, TB as 443.70 g/m<sup>2</sup> and TC as 221.85 g/m<sup>2</sup>. The least values of aboveground biomass (240.54 g/m<sup>2</sup>), belowground biomass (80.18 g/m<sup>2</sup>), total biomass (320.73 g/m<sup>2</sup>) and total carbon (160.36 g/m<sup>2</sup>) were observed at E<sub>3</sub> (Table 62).

Among individual forb species, at E<sub>1</sub>, maximum values of aboveground biomass (17.22 g/m<sup>2</sup>), belowground biomass (5.74 g/m<sup>2</sup>), total biomass (22.96 g/m<sup>2</sup>) and total carbon (11.48 g/m<sup>2</sup>) were recorded in *Anemone vitifolia*. Minimum values of aboveground biomass (1.33 g/m<sup>2</sup>), belowground biomass (0.44 g/m<sup>2</sup>), total biomass (1.77 g/m<sup>2</sup>) and total carbon (0.89 g/m<sup>2</sup>) at E<sub>1</sub> were observed in *Pteris cretica*. At E<sub>2</sub>, *Androsace rotundifolia* showed maximum aboveground biomass of 28.36 g/m<sup>2</sup>, belowground biomass of 9.45 g/m<sup>2</sup>, total biomass of 37.81 g/m<sup>2</sup> and total carbon of 18.90 g/m<sup>2</sup>. Whereas *Pteris cretica* exhibited lowest aboveground biomass (1.56 g/m<sup>2</sup>), belowground biomass (0.52 g/m<sup>2</sup>), total biomass (2.08 g/m<sup>2</sup>) and total carbon (1.04 g/m<sup>2</sup>) at E<sub>2</sub>. At E<sub>3</sub>, *Dichanthium annulatum* recorded with maximum aboveground biomass (34.52 g/m<sup>2</sup>), belowground biomass (11.51 g/m<sup>2</sup>), total biomass (46.03 g/m<sup>2</sup>) and total carbon (23.02 g/m<sup>2</sup>). Lowest aboveground biomass of 1.17 g/m<sup>2</sup>, belowground biomass of 0.39 g/m<sup>2</sup>, total biomass of 1.56 g/m<sup>2</sup> and total carbon of 0.78 g/m<sup>2</sup> exhibited in *Polygonum nepalense* at E<sub>3</sub> (Table 62).

At E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 1.33 g/m<sup>2</sup> to 17.22 g/m<sup>2</sup>, 0.44 g/m<sup>2</sup> to 5.74 g/m<sup>2</sup>, 1.77 g/m<sup>2</sup> to 22.96 g/m<sup>2</sup> and 0.89 g/m<sup>2</sup> to 11.48 g/m<sup>2</sup> respectively. At E<sub>2</sub> aboveground biomass, belowground biomass total biomass varied from 1.56 g/m<sup>2</sup> to 28.36 g/m<sup>2</sup>, 0.52 g/m<sup>2</sup> to 9.45 g/m<sup>2</sup>, 2.08 g/m<sup>2</sup> to 37.81 g/m<sup>2</sup> and 1.04 g/m<sup>2</sup> to 18.90 g/m<sup>2</sup>, while aboveground biomass, belowground biomass, total forb biomass and total carbon ranged from 1.17 g/m<sup>2</sup> to 34.52 g/m<sup>2</sup>, 0.39 g/m<sup>2</sup> to 11.51 g/m<sup>2</sup>, 1.56 g/m<sup>2</sup> to 46.03 g/m<sup>2</sup> and 0.78 g/m<sup>2</sup> to 23.02 g/m<sup>2</sup> respectively at E<sub>3</sub> (Table 62).

**Table 62: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Deodar (*Cedrus deodara*) forests at different elevations**

| Forb Species                                  | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|-----------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                               | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation - E<sub>1</sub> (900-1800 m)</b> |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                      | 6.20                        | 2.07              | 8.27               | 4.14                       |
| <i>Agrimonia pilosa</i>                       | 5.83                        | 1.94              | 7.77               | 3.89                       |
| <i>Ainsliaea aptera</i>                       | 7.92                        | 2.64              | 10.56              | 5.28                       |
| <i>Ajuga bracteosa</i>                        | 10.95                       | 3.65              | 14.60              | 7.30                       |
| <i>Anaphalis busua</i>                        | 4.65                        | 1.55              | 6.20               | 3.10                       |
| <i>Anemone vitifolia</i>                      | 17.22                       | 5.74              | 22.96              | 11.48                      |
| <i>Angelica glauca</i>                        | 3.16                        | 1.05              | 4.21               | 2.11                       |
| <i>Artemisia roxburghiana</i>                 | 5.66                        | 1.89              | 7.55               | 3.77                       |
| <i>Carex cardiolepis</i>                      | 3.36                        | 1.12              | 4.48               | 2.24                       |
| <i>Cheilanthes dalhousiae</i>                 | 4.99                        | 1.66              | 6.65               | 3.32                       |
| <i>Chenopodium opulifolium</i>                | 4.78                        | 1.59              | 6.37               | 3.18                       |
| <i>Corydalis govaniana</i>                    | 5.79                        | 1.93              | 7.72               | 3.86                       |
| <i>Delphinium nudatum</i>                     | 14.98                       | 4.99              | 19.98              | 9.99                       |
| <i>Dicliptera bupleuroides</i>                | 9.68                        | 3.23              | 12.91              | 6.45                       |
| <i>Eriophorum comosum</i>                     | 2.60                        | 0.87              | 3.46               | 1.73                       |
| <i>Fagopyrum dibotry</i>                      | 9.60                        | 3.20              | 12.80              | 6.40                       |
| <i>Fragaria nubicola</i>                      | 6.52                        | 2.17              | 8.70               | 4.35                       |
| <i>Fumaria indica</i>                         | 11.17                       | 3.72              | 14.89              | 7.44                       |
| <i>Galium aparine</i>                         | 5.16                        | 1.72              | 6.88               | 3.44                       |
| <i>Girardinia diversifolia</i>                | 7.55                        | 2.52              | 10.07              | 5.03                       |
| <i>Impatiens scabrida</i>                     | 5.60                        | 1.87              | 7.47               | 3.73                       |
| <i>Iris nepalensis</i>                        | 5.55                        | 1.85              | 7.39               | 3.70                       |
| <i>Malvastrum coromandelianum</i>             | 11.57                       | 3.86              | 15.42              | 7.71                       |
| <i>Oxalis corniculata</i>                     | 11.22                       | 3.74              | 14.96              | 7.48                       |
| <i>Pennisetum flaccidum</i>                   | 7.52                        | 2.51              | 10.03              | 5.02                       |
| <i>Phragmites communis</i>                    | 6.82                        | 2.27              | 9.09               | 4.55                       |
| <i>Plantago depressa</i>                      | 4.14                        | 1.38              | 5.52               | 2.76                       |
| <i>Polygala abyssinica</i>                    | 6.84                        | 2.28              | 9.12               | 4.56                       |
| <i>Polygonatum multiflorum</i>                | 4.82                        | 1.61              | 6.42               | 3.21                       |
| <i>Polygonum nepalense</i>                    | 8.36                        | 2.79              | 11.15              | 5.57                       |
| <i>Potentilla fragarioides</i>                | 6.20                        | 2.07              | 8.26               | 4.13                       |
| <i>Primula petiolaris</i>                     | 7.70                        | 2.57              | 10.26              | 5.13                       |
| <i>Pteris cretica</i>                         | 1.33                        | 0.44              | 1.77               | 0.89                       |
| <i>Ranunculus hirtellus</i>                   | 4.63                        | 1.54              | 6.18               | 3.09                       |
| <i>Roscoeia purpurea</i>                      | 4.83                        | 1.61              | 6.44               | 3.22                       |
| <i>Rubia cordifolia</i>                       | 7.83                        | 2.61              | 10.44              | 5.22                       |
| <i>Rumex nepalensis</i>                       | 10.09                       | 3.36              | 13.45              | 6.73                       |

|                                                |               |               |               |               |
|------------------------------------------------|---------------|---------------|---------------|---------------|
| <i>Salvia nubicola</i>                         | 11.07         | 3.69          | 14.76         | 7.38          |
| <i>Scutellaria scandens</i>                    | 6.41          | 2.14          | 8.55          | 4.28          |
| <i>Selinum candollii</i>                       | 4.61          | 1.54          | 6.15          | 3.08          |
| <i>Silene vulgaris</i>                         | 2.26          | 0.75          | 3.01          | 1.51          |
| <i>Smilax aspera</i>                           | 2.50          | 0.83          | 3.34          | 1.67          |
| <i>Thalictrum foliolosum</i>                   | 3.89          | 1.30          | 5.18          | 2.59          |
| <i>Themeda anathera</i>                        | 4.87          | 1.62          | 6.50          | 3.25          |
| <i>Thymus linearis</i>                         | 8.55          | 2.85          | 11.40         | 5.70          |
| <i>Trifolium repens</i>                        | 13.39         | 4.46          | 17.85         | 8.92          |
| <i>Urtica ardens</i>                           | 2.33          | 0.78          | 3.11          | 1.55          |
| <i>Urtica dioica</i>                           | 12.82         | 4.27          | 17.09         | 8.55          |
| <i>Valeriana jatamansi</i>                     | 1.65          | 0.55          | 2.20          | 1.10          |
| <i>Verbascum thapsus</i>                       | 2.65          | 0.88          | 3.53          | 1.77          |
| <i>Viola canescens</i>                         | 7.47          | 2.49          | 9.96          | 4.98          |
| <b>Total</b>                                   | <b>347.28</b> | <b>115.76</b> | <b>463.04</b> | <b>231.52</b> |
| <b>Elevation – E<sub>2</sub> (1800-2700 m)</b> |               |               |               |               |
| <i>Adiantum venustum</i>                       | 5.30          | 1.77          | 7.06          | 3.53          |
| <i>Agrimonia pilosa</i>                        | 3.21          | 1.07          | 4.28          | 2.14          |
| <i>Ainsliaea aptera</i>                        | 4.14          | 1.38          | 5.52          | 2.76          |
| <i>Ajuga bracteosa</i>                         | 4.60          | 1.53          | 6.14          | 3.07          |
| <i>Androsace rotundifolia</i>                  | 28.36         | 9.45          | 37.81         | 18.90         |
| <i>Anemone vitifolia</i>                       | 7.05          | 2.35          | 9.40          | 4.70          |
| <i>Angelica glauca</i>                         | 10.33         | 3.44          | 13.78         | 6.89          |
| <i>Artemisia vestita</i>                       | 2.81          | 0.94          | 3.74          | 1.87          |
| <i>Bergenia stracheyi</i>                      | 3.94          | 1.31          | 5.26          | 2.63          |
| <i>Bistorta amplexicaulis</i>                  | 5.30          | 1.77          | 7.07          | 3.53          |
| <i>Bromus mollis</i>                           | 9.56          | 3.19          | 12.74         | 6.37          |
| <i>Carex cardiolepis</i>                       | 9.72          | 3.24          | 12.96         | 6.48          |
| <i>Eriophorum comosum</i>                      | 9.13          | 3.04          | 12.18         | 6.09          |
| <i>Fagopyrum dibotry</i>                       | 7.24          | 2.41          | 9.65          | 4.82          |
| <i>Fragaria nubicola</i>                       | 12.86         | 4.29          | 17.15         | 8.58          |
| <i>Galium aparine</i>                          | 3.97          | 1.32          | 5.29          | 2.65          |
| <i>Halenia elliptica</i>                       | 5.88          | 1.96          | 7.84          | 3.92          |
| <i>Impatiens scabrida</i>                      | 18.41         | 6.14          | 24.54         | 12.27         |
| <i>Iris nepalensis</i>                         | 9.62          | 3.21          | 12.83         | 6.41          |
| <i>Malva verticillata</i>                      | 7.70          | 2.57          | 10.27         | 5.14          |
| <i>Pedicularis hoffmeisteri</i>                | 5.86          | 1.95          | 7.81          | 3.90          |
| <i>Pennisetum flaccidum</i>                    | 10.71         | 3.57          | 14.28         | 7.14          |
| <i>Phragmites communis</i>                     | 3.98          | 1.33          | 5.30          | 2.65          |
| <i>Plantago depressa</i>                       | 5.40          | 1.80          | 7.20          | 3.60          |
| <i>Polygonatum multiflorum</i>                 | 10.20         | 3.40          | 13.60         | 6.80          |
| <i>Polygonum nepalense</i>                     | 11.34         | 3.78          | 15.13         | 7.56          |
| <i>Potentilla nepalensis</i>                   | 4.27          | 1.42          | 5.70          | 2.85          |
| <i>Primula petiolaris</i>                      | 14.13         | 4.71          | 18.84         | 9.42          |



|                                                |               |               |               |               |
|------------------------------------------------|---------------|---------------|---------------|---------------|
| <i>Pteris cretica</i>                          | 1.56          | 0.52          | 2.08          | 1.04          |
| <i>Ranunculus hirtellus</i>                    | 8.72          | 2.91          | 11.62         | 5.81          |
| <i>Rumex nepalensis</i>                        | 9.81          | 3.27          | 13.08         | 6.54          |
| <i>Salvia nubicola</i>                         | 10.81         | 3.60          | 14.41         | 7.21          |
| <i>Scirpus roylei</i>                          | 3.82          | 1.27          | 5.10          | 2.55          |
| <i>Silene griffithii</i>                       | 6.03          | 2.01          | 8.05          | 4.02          |
| <i>Silene vulgaris</i>                         | 7.26          | 2.42          | 9.67          | 4.84          |
| <i>Smilacina purpurea</i>                      | 5.01          | 1.67          | 6.69          | 3.34          |
| <i>Thalictrum foliolosum</i>                   | 5.54          | 1.85          | 7.39          | 3.70          |
| <i>Thymus linearis</i>                         | 9.66          | 3.22          | 12.88         | 6.44          |
| <i>Urtica ardens</i>                           | 9.84          | 3.28          | 13.12         | 6.56          |
| <i>Valeriana jatamansi</i>                     | 16.17         | 5.39          | 21.56         | 10.78         |
| <i>Verbascum thapsus</i>                       | 3.51          | 1.17          | 4.67          | 2.34          |
| <b>Total</b>                                   | <b>332.77</b> | <b>110.92</b> | <b>443.70</b> | <b>221.85</b> |
| <b>Elevation – E<sub>3</sub> (2700-3600 m)</b> |               |               |               |               |
| <i>Achyranthes bidentata</i>                   | 2.68          | 0.89          | 3.58          | 1.79          |
| <i>Agrimonia pilosa</i>                        | 14.62         | 4.87          | 19.50         | 9.75          |
| <i>Ajuga bracteosa</i>                         | 14.10         | 4.70          | 18.79         | 9.40          |
| <i>Anaphalis busua</i>                         | 6.97          | 2.32          | 9.30          | 4.65          |
| <i>Apluda mutica</i>                           | 8.02          | 2.67          | 10.70         | 5.35          |
| <i>Artemisia vestita</i>                       | 2.83          | 0.94          | 3.77          | 1.89          |
| <i>Bergenia ciliata</i>                        | 5.90          | 1.97          | 7.87          | 3.94          |
| <i>Cheilanthes albomarginata</i>               | 2.65          | 0.88          | 3.53          | 1.77          |
| <i>Cheilanthes brevifrons</i>                  | 1.79          | 0.60          | 2.39          | 1.20          |
| <i>Chenopodium ambrosioides</i>                | 9.15          | 3.05          | 12.20         | 6.10          |
| <i>Cissampelos pareira</i>                     | 2.03          | 0.68          | 2.71          | 1.36          |
| <i>Cynodon dactylon</i>                        | 3.30          | 1.10          | 4.40          | 2.20          |
| <i>Dichanthium annulatum</i>                   | 34.52         | 11.51         | 46.03         | 23.02         |
| <i>Digitaria sanguinalis</i>                   | 29.03         | 9.68          | 38.71         | 19.36         |
| <i>Dryopteris caroli-hopei</i>                 | 2.01          | 0.67          | 2.67          | 1.34          |
| <i>Echinochloa crus-galli</i>                  | 4.36          | 1.45          | 5.81          | 2.91          |
| <i>Eriophorum comosum</i>                      | 3.28          | 1.09          | 4.37          | 2.19          |
| <i>Fumaria indica</i>                          | 2.81          | 0.94          | 3.74          | 1.87          |
| <i>Galinsoga parviflora</i>                    | 1.77          | 0.59          | 2.36          | 1.18          |
| <i>Galium aparine</i>                          | 2.62          | 0.87          | 3.49          | 1.75          |
| <i>Girardinia diversifolia</i>                 | 8.58          | 2.86          | 11.44         | 5.72          |
| <i>Malvastrum coromandelianum</i>              | 8.19          | 2.73          | 10.92         | 5.46          |
| <i>Oxalis corniculata</i>                      | 5.63          | 1.88          | 7.51          | 3.76          |
| <i>Phalaris paradoxa</i>                       | 1.66          | 0.55          | 2.22          | 1.11          |
| <i>Plantago depressa</i>                       | 9.38          | 3.13          | 12.51         | 6.26          |
| <i>Polygala abyssinica</i>                     | 7.16          | 2.39          | 9.55          | 4.78          |
| <i>Polygonum nepalense</i>                     | 1.17          | 0.39          | 1.56          | 0.78          |
| <i>Rumex nepalensis</i>                        | 5.84          | 1.95          | 7.79          | 3.90          |
| <i>Thalictrum foliolosum</i>                   | 5.39          | 1.80          | 7.19          | 3.60          |
| <i>Themeda anathera</i>                        | 1.77          | 0.59          | 2.36          | 1.18          |

|                          |               |              |               |               |
|--------------------------|---------------|--------------|---------------|---------------|
| <i>Urtica dioica</i>     | 10.18         | 3.39         | 13.58         | 6.79          |
| <i>Verbascum thapsus</i> | 15.30         | 5.10         | 20.40         | 10.20         |
| <i>Viola canescens</i>   | 5.82          | 1.94         | 7.76          | 3.88          |
| <b>Total</b>             | <b>240.54</b> | <b>80.18</b> | <b>320.73</b> | <b>160.36</b> |

Details pertaining to aboveground, belowground, total biomass, and total carbon of forbs in western mixed coniferous forests at different elevations are presented in Table 63. Among all the elevations, highest aboveground biomass ( $302.53 \text{ g/m}^2$ ), belowground biomass ( $100.84 \text{ g/m}^2$ ), total biomass ( $403.38 \text{ g/m}^2$ ) and total carbon ( $201.69 \text{ g/m}^2$ ) was observed at  $E_1$ , followed by  $E_2$  with ABG as  $251.87 \text{ g/m}^2$ , BGB as  $83.96 \text{ g/m}^2$ , TB as  $335.83 \text{ g/m}^2$  and TC as  $167.92 \text{ g/m}^2$ . The least aboveground biomass ( $233.67 \text{ g/m}^2$ ), belowground biomass ( $77.89 \text{ g/m}^2$ ), total biomass ( $311.55 \text{ g/m}^2$ ) and total carbon ( $155.78 \text{ g/m}^2$ ) were observed at  $E_3$ .

Among individual forb species, at  $E_1$ , maximum aboveground biomass ( $26.11 \text{ g/m}^2$ ), belowground biomass ( $8.70 \text{ g/m}^2$ ), total biomass ( $34.82 \text{ g/m}^2$ ) and total carbon ( $17.41 \text{ g/m}^2$ ) exhibited by *Fragaria nubicola*. Minimum aboveground biomass, belowground biomass, total biomass and total carbon at  $E_1$  was observed in *Sonchus asper* as  $0.81 \text{ g/m}^2$ ,  $0.27 \text{ g/m}^2$ ,  $1.08 \text{ g/m}^2$  and  $0.54 \text{ g/m}^2$  respectively. At  $E_2$ , *Plectranthus japonicus* exhibited maximum aboveground biomass, belowground biomass, total biomass and total carbon of  $14.43 \text{ g/m}^2$ ,  $4.81 \text{ g/m}^2$ ,  $19.24 \text{ g/m}^2$  and  $9.62 \text{ g/m}^2$  respectively. Whereas *Dioscorea melanophyma* exhibited lowest aboveground biomass ( $0.69 \text{ g/m}^2$ ), belowground biomass ( $0.23 \text{ g/m}^2$ ), total biomass ( $0.92 \text{ g/m}^2$ ) and total carbon ( $0.46 \text{ g/m}^2$ ) at  $E_2$ . At  $E_3$ , *Thalictrum foliolosum* exhibited maximum aboveground biomass ( $13.48 \text{ g/m}^2$ ), belowground biomass ( $4.49 \text{ g/m}^2$ ), total biomass ( $17.97 \text{ g/m}^2$ ) and highest total carbon ( $8.98 \text{ g/m}^2$ ). Lowest AGB ( $0.69 \text{ g/m}^2$ ), BGB ( $0.23 \text{ g/m}^2$ ), TB ( $0.93 \text{ g/m}^2$ ) and TC ( $0.46 \text{ g/m}^2$ ) were exhibited in *Rumex nepalensis* (Table 63)

Range of aboveground biomass, belowground biomass, total biomass and total carbon at  $E_1$  varied from  $0.81 \text{ g/m}^2$  to  $26.11 \text{ g/m}^2$ ,  $0.27 \text{ g/m}^2$  to  $8.70 \text{ g/m}^2$ ,  $1.08 \text{ g/m}^2$  to  $34.82 \text{ g/m}^2$  and  $0.54 \text{ g/m}^2$  to  $17.41 \text{ g/m}^2$  respectively. At  $E_2$  range of aboveground biomass as  $0.69 \text{ g/m}^2$  to  $14.43 \text{ g/m}^2$ , belowground biomass as  $0.23 \text{ g/m}^2$  to  $4.81 \text{ g/m}^2$ , total biomass as  $0.92 \text{ g/m}^2$  to  $19.24 \text{ g/m}^2$  and total carbon as  $0.46 \text{ g/m}^2$  to  $9.62 \text{ g/m}^2$  while at  $E_3$  aboveground biomass, belowground biomass, total biomass and total carbon ranged from  $0.69 \text{ g/m}^2$  to  $13.48 \text{ g/m}^2$ ,  $0.23 \text{ g/m}^2$  to  $4.49 \text{ g/m}^2$ ,  $0.93 \text{ g/m}^2$  to  $17.97 \text{ g/m}^2$  and  $0.46 \text{ g/m}^2$  to  $8.98 \text{ g/m}^2$  respectively (Table 63)

**Table 63: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Western mixed coniferous forests at different elevations**

| Forb Species                                   | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|------------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                                | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation - E<sub>1</sub> (1200-2100 m)</b> |                             |                   |                    |                            |
| <i>Achyranthes bidentata</i>                   | 2.28                        | 0.76              | 3.04               | 1.52                       |
| <i>Agrimonia pilosa</i>                        | 2.75                        | 0.92              | 3.67               | 1.83                       |
| <i>Ajuga bracteosa</i>                         | 2.11                        | 0.70              | 2.81               | 1.41                       |
| <i>Androsace lanuginosa</i>                    | 4.27                        | 1.42              | 5.69               | 2.85                       |
| <i>Apluda mutica</i>                           | 3.72                        | 1.24              | 4.96               | 2.48                       |
| <i>Arisaema flavum</i>                         | 3.58                        | 1.19              | 4.78               | 2.39                       |
| <i>Artemisia indica</i>                        | 4.23                        | 1.41              | 5.64               | 2.82                       |
| <i>Artemisia roxburghiana</i>                  | 2.54                        | 0.85              | 3.39               | 1.69                       |
| <i>Artemisia vestita</i>                       | 11.55                       | 3.85              | 15.40              | 7.70                       |
| <i>Asplenium dalhousiae</i>                    | 6.75                        | 2.25              | 9.00               | 4.50                       |
| <i>Astilbe rivularis</i>                       | 3.45                        | 1.15              | 4.60               | 2.30                       |
| <i>Bergenia ciliata</i>                        | 2.85                        | 0.95              | 3.80               | 1.90                       |
| <i>Bupleurum falcatum</i>                      | 3.14                        | 1.05              | 4.19               | 2.09                       |
| <i>Capillipedium assimile</i>                  | 4.08                        | 1.36              | 5.44               | 2.72                       |
| <i>Cirsium wallichii</i>                       | 5.37                        | 1.79              | 7.15               | 3.58                       |
| <i>Cynoglossum glochidiatum</i>                | 3.22                        | 1.07              | 4.30               | 2.15                       |
| <i>Dioscorea deltoidea</i>                     | 0.92                        | 0.31              | 1.22               | 0.61                       |
| <i>Dioscorea melanophyma</i>                   | 1.21                        | 0.40              | 1.62               | 0.81                       |
| <i>Duchesnea indica</i>                        | 4.64                        | 1.55              | 6.19               | 3.10                       |
| <i>Erigeron bellidioides</i>                   | 6.12                        | 2.04              | 8.16               | 4.08                       |
| <i>Erigeron multicaulis</i>                    | 1.38                        | 0.46              | 1.83               | 0.92                       |
| <i>Eriophorum comosum</i>                      | 3.12                        | 1.04              | 4.16               | 2.08                       |
| <i>Fagopyrum dibotrys</i>                      | 12.83                       | 4.28              | 17.11              | 8.55                       |
| <i>Fragaria nubicola</i>                       | 26.11                       | 8.70              | 34.82              | 17.41                      |
| <i>Galium aparine</i>                          | 15.98                       | 5.33              | 21.30              | 10.65                      |
| <i>Geranium lucidum</i>                        | 4.53                        | 1.51              | 6.03               | 3.02                       |
| <i>Girardinia diversifolia</i>                 | 4.22                        | 1.41              | 5.62               | 2.81                       |
| <i>Habenaria intermedia</i>                    | 2.03                        | 0.68              | 2.71               | 1.35                       |
| <i>Halenia elliptica</i>                       | 2.55                        | 0.85              | 3.40               | 1.70                       |
| <i>Iris nepalensis</i>                         | 6.83                        | 2.28              | 9.10               | 4.55                       |
| <i>Koeleria cristata</i>                       | 5.34                        | 1.78              | 7.12               | 3.56                       |
| <i>Lamium album</i>                            | 7.31                        | 2.44              | 9.75               | 4.88                       |
| <i>Lotus corniculatus</i>                      | 3.44                        | 1.15              | 4.59               | 2.30                       |
| <i>Malvastrum coromandelianum</i>              | 4.54                        | 1.51              | 6.06               | 3.03                       |
| <i>Mentha longifolia</i>                       | 4.05                        | 1.35              | 5.40               | 2.70                       |
| <i>Nasturtium officinale</i>                   | 6.17                        | 2.06              | 8.23               | 4.11                       |

|                                                |               |               |               |               |
|------------------------------------------------|---------------|---------------|---------------|---------------|
| <i>Nepeta laevigata</i>                        | 3.27          | 1.09          | 4.36          | 2.18          |
| <i>Oenothera rosea</i>                         | 3.65          | 1.22          | 4.86          | 2.43          |
| <i>Origanum vulgare</i>                        | 5.24          | 1.75          | 6.99          | 3.50          |
| <i>Oxalis corniculata</i>                      | 9.47          | 3.16          | 12.63         | 6.31          |
| <i>Pennisetum flaccidum</i>                    | 4.82          | 1.61          | 6.43          | 3.21          |
| <i>Phragmites communis</i>                     | 4.88          | 1.63          | 6.51          | 3.25          |
| <i>Pimpinella diversifolia</i>                 | 4.43          | 1.48          | 5.91          | 2.96          |
| <i>Plantago erosa</i>                          | 3.77          | 1.26          | 5.03          | 2.52          |
| <i>Plectranthus japonicus</i>                  | 2.84          | 0.95          | 3.79          | 1.89          |
| <i>Polygala abyssinica</i>                     | 4.63          | 1.54          | 6.18          | 3.09          |
| <i>Polygonatum cirrhifolium</i>                | 11.12         | 3.71          | 14.83         | 7.41          |
| <i>Polygonatum multiflorum</i>                 | 2.48          | 0.83          | 3.31          | 1.66          |
| <i>Polygonum nepalense</i>                     | 2.99          | 1.00          | 3.98          | 1.99          |
| <i>Polystichum neolobatum</i>                  | 5.50          | 1.83          | 7.33          | 3.67          |
| <i>Potentilla nepalensis</i>                   | 3.69          | 1.23          | 4.92          | 2.46          |
| <i>Pteris cretica</i>                          | 1.03          | 0.34          | 1.37          | 0.68          |
| <i>Ranunculus laetus</i>                       | 4.12          | 1.37          | 5.50          | 2.75          |
| <i>Rumex nepalensis</i>                        | 1.37          | 0.46          | 1.82          | 0.91          |
| <i>Salvia lanata</i>                           | 3.05          | 1.02          | 4.07          | 2.03          |
| <i>Smilax aspera</i>                           | 1.46          | 0.49          | 1.95          | 0.97          |
| <i>Sonchus asper</i>                           | 0.81          | 0.27          | 1.08          | 0.54          |
| <i>Stellaria media</i>                         | 2.56          | 0.85          | 3.41          | 1.71          |
| <i>Thalictrum foliolosum</i>                   | 7.33          | 2.44          | 9.78          | 4.89          |
| <i>Themeda anathera</i>                        | 1.39          | 0.46          | 1.85          | 0.92          |
| <i>Thymus linearis</i>                         | 3.07          | 1.02          | 4.09          | 2.05          |
| <i>Trichosanthes bracteata</i>                 | 1.42          | 0.47          | 1.89          | 0.94          |
| <i>Trifolium repens</i>                        | 2.62          | 0.87          | 3.50          | 1.75          |
| <i>Urtica ardens</i>                           | 2.22          | 0.74          | 2.96          | 1.48          |
| <i>Urtica dioica</i>                           | 1.44          | 0.48          | 1.92          | 0.96          |
| <i>Verbascum thapsus</i>                       | 2.70          | 0.90          | 3.60          | 1.80          |
| <i>Viola canescens</i>                         | 3.93          | 1.31          | 5.24          | 2.62          |
| <b>Total</b>                                   | <b>302.53</b> | <b>100.84</b> | <b>403.38</b> | <b>201.69</b> |
| <b>Elevation – E<sub>2</sub> (2100-3000 m)</b> |               |               |               |               |
| <i>Adiantum venustum</i>                       | 7.02          | 2.34          | 9.36          | 4.68          |
| <i>Agrimonia pilosa</i>                        | 3.88          | 1.29          | 5.17          | 2.58          |
| <i>Ainsliaea aptera</i>                        | 4.96          | 1.65          | 6.61          | 3.30          |
| <i>Ajuga bracteosa</i>                         | 3.83          | 1.28          | 5.10          | 2.55          |
| <i>Androsace sarmentosa</i>                    | 2.94          | 0.98          | 3.92          | 1.96          |
| <i>Anemone obtusiloba</i>                      | 2.82          | 0.94          | 3.77          | 1.88          |
| <i>Angelica glauca</i>                         | 3.26          | 1.09          | 4.35          | 2.18          |
| <i>Arisaema flavum</i>                         | 2.78          | 0.93          | 3.70          | 1.85          |
| <i>Artemisia indica</i>                        | 6.17          | 2.06          | 8.23          | 4.12          |
| <i>Artemisia roxburghiana</i>                  | 3.37          | 1.12          | 4.49          | 2.25          |
| <i>Asplenium dalhousiae</i>                    | 2.15          | 0.72          | 2.87          | 1.43          |

|                                 |       |      |       |      |
|---------------------------------|-------|------|-------|------|
| <i>Astilbe rivularis</i>        | 2.91  | 0.97 | 3.88  | 1.94 |
| <i>Bergenia ciliata</i>         | 4.36  | 1.45 | 5.81  | 2.90 |
| <i>Bromus mollis</i>            | 2.25  | 0.75 | 3.01  | 1.50 |
| <i>Carduus nutans</i>           | 3.73  | 1.24 | 4.97  | 2.48 |
| <i>Carex remota</i>             | 3.18  | 1.06 | 4.24  | 2.12 |
| <i>Clinopodium vulgare</i>      | 2.90  | 0.97 | 3.86  | 1.93 |
| <i>Corydalis govaniana</i>      | 4.07  | 1.36 | 5.42  | 2.71 |
| <i>Dioscorea deltoidea</i>      | 1.60  | 0.53 | 2.14  | 1.07 |
| <i>Dioscorea melanophyma</i>    | 0.69  | 0.23 | 0.92  | 0.46 |
| <i>Erigeron bellidioides</i>    | 2.30  | 0.77 | 3.06  | 1.53 |
| <i>Erigeron multicaulis</i>     | 3.99  | 1.33 | 5.32  | 2.66 |
| <i>Eriophorum comosum</i>       | 3.73  | 1.24 | 4.98  | 2.49 |
| <i>Fagopyrum dibotrys</i>       | 2.43  | 0.81 | 3.24  | 1.62 |
| <i>Fragaria nubicola</i>        | 8.34  | 2.78 | 11.12 | 5.56 |
| <i>Geranium wallichianum</i>    | 3.77  | 1.26 | 5.03  | 2.51 |
| <i>Girardinia diversifolia</i>  | 2.31  | 0.77 | 3.08  | 1.54 |
| <i>Habenaria intermedia</i>     | 2.12  | 0.71 | 2.83  | 1.41 |
| <i>Halenia elliptica</i>        | 9.71  | 3.24 | 12.95 | 6.47 |
| <i>Heracleum candicans</i>      | 4.08  | 1.36 | 5.44  | 2.72 |
| <i>Iris nepalensis</i>          | 3.00  | 1.00 | 4.00  | 2.00 |
| <i>Koeleria cristata</i>        | 2.53  | 0.84 | 3.38  | 1.69 |
| <i>Lamium album</i>             | 5.58  | 1.86 | 7.44  | 3.72 |
| <i>Mentha longifolia</i>        | 6.05  | 2.02 | 8.06  | 4.03 |
| <i>Nepeta laevigata</i>         | 10.39 | 3.46 | 13.86 | 6.93 |
| <i>Origanum vulgare</i>         | 2.67  | 0.89 | 3.56  | 1.78 |
| <i>Oxalis corniculata</i>       | 3.38  | 1.13 | 4.50  | 2.25 |
| <i>Pennisetum flaccidum</i>     | 3.07  | 1.02 | 4.09  | 2.05 |
| <i>Plantago erosa</i>           | 4.78  | 1.59 | 6.37  | 3.19 |
| <i>Plectranthus japonicus</i>   | 14.43 | 4.81 | 19.24 | 9.62 |
| <i>Podophyllum hexandrum</i>    | 1.63  | 0.54 | 2.18  | 1.09 |
| <i>Polygonatum cirrhifolium</i> | 3.93  | 1.31 | 5.25  | 2.62 |
| <i>Potentilla argyrophylla</i>  | 2.94  | 0.98 | 3.92  | 1.96 |
| <i>Potentilla nepalensis</i>    | 3.45  | 1.15 | 4.60  | 2.30 |
| <i>Pteris cretica</i>           | 2.40  | 0.80 | 3.19  | 1.60 |
| <i>Ranunculus hirtellus</i>     | 8.13  | 2.71 | 10.84 | 5.42 |
| <i>Roscoeia purpurea</i>        | 5.02  | 1.67 | 6.69  | 3.35 |
| <i>Rumex nepalensis</i>         | 1.94  | 0.65 | 2.59  | 1.30 |
| <i>Salvia nubicola</i>          | 3.38  | 1.13 | 4.51  | 2.25 |
| <i>Selinum vaginatum</i>        | 3.36  | 1.12 | 4.48  | 2.24 |
| <i>Smilacina purpurea</i>       | 5.74  | 1.91 | 7.66  | 3.83 |
| <i>Smilax vaginata</i>          | 2.03  | 0.68 | 2.71  | 1.35 |
| <i>Sonchus asper</i>            | 1.53  | 0.51 | 2.04  | 1.02 |
| <i>Stellaria media</i>          | 5.14  | 1.71 | 6.86  | 3.43 |
| <i>Thalictrum foliolosum</i>    | 4.83  | 1.61 | 6.44  | 3.22 |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Thymus linearis</i>                         | 3.89          | 1.30         | 5.18          | 2.59          |
| <i>Trifolium repens</i>                        | 7.16          | 2.39         | 9.54          | 4.77          |
| <i>Urtica ardens</i>                           | 1.65          | 0.55         | 2.21          | 1.10          |
| <i>Verbascum thapsus</i>                       | 2.19          | 0.73         | 2.92          | 1.46          |
| <i>Viola canescens</i>                         | 14.01         | 4.67         | 18.67         | 9.34          |
| <b>Total</b>                                   | <b>251.87</b> | <b>83.96</b> | <b>335.83</b> | <b>167.92</b> |
| <b>Elevation – E<sub>3</sub> (3000-3900 m)</b> |               |              |               |               |
| <i>Androsace sarmentosa</i>                    | 1.42          | 0.47         | 1.90          | 0.95          |
| <i>Angelica glauca</i>                         | 2.01          | 0.67         | 2.67          | 1.34          |
| <i>Aquilegia fragrans</i>                      | 1.71          | 0.57         | 2.29          | 1.14          |
| <i>Artemisia roxburghiana</i>                  | 2.97          | 0.99         | 3.96          | 1.98          |
| <i>Asplenium dalhousiae</i>                    | 9.02          | 3.01         | 12.03         | 6.02          |
| <i>Bergenia stracheyi</i>                      | 9.57          | 3.19         | 12.77         | 6.38          |
| <i>Bistorta amplexicaulis</i>                  | 0.95          | 0.32         | 1.27          | 0.63          |
| <i>Bromus mollis</i>                           | 3.17          | 1.06         | 4.23          | 2.11          |
| <i>Carduus nutans</i>                          | 10.43         | 3.48         | 13.91         | 6.95          |
| <i>Carex breviculmis</i>                       | 11.72         | 3.91         | 15.63         | 7.81          |
| <i>Carex cardiolepis</i>                       | 6.44          | 2.15         | 8.59          | 4.29          |
| <i>Carex remota</i>                            | 2.65          | 0.88         | 3.53          | 1.76          |
| <i>Clinopodium vulgare</i>                     | 3.96          | 1.32         | 5.27          | 2.64          |
| <i>Corydalis govaniana</i>                     | 3.00          | 1.00         | 4.00          | 2.00          |
| <i>Dioscorea deltoidea</i>                     | 2.16          | 0.72         | 2.88          | 1.44          |
| <i>Eriophorum comosum</i>                      | 4.33          | 1.44         | 5.78          | 2.89          |
| <i>Fagopyrum dibotrys</i>                      | 1.44          | 0.48         | 1.91          | 0.96          |
| <i>Fragaria nubicola</i>                       | 6.44          | 2.15         | 8.58          | 4.29          |
| <i>Galium aparine</i>                          | 7.50          | 2.50         | 10.00         | 5.00          |
| <i>Gypsophila cerastioides</i>                 | 1.04          | 0.35         | 1.39          | 0.70          |
| <i>Halenia elliptica</i>                       | 4.27          | 1.42         | 5.69          | 2.84          |
| <i>Heracleum candicans</i>                     | 1.17          | 0.39         | 1.56          | 0.78          |
| <i>Impatiens scabrida</i>                      | 2.00          | 0.67         | 2.66          | 1.33          |
| <i>Koeleria cristata</i>                       | 4.80          | 1.60         | 6.40          | 3.20          |
| <i>Lotus corniculatus</i>                      | 6.79          | 2.26         | 9.05          | 4.53          |
| <i>Mentha longifolia</i>                       | 5.44          | 1.81         | 7.25          | 3.63          |
| <i>Origanum vulgare</i>                        | 2.55          | 0.85         | 3.40          | 1.70          |
| <i>Pedicularis hoffmeister</i>                 | 4.65          | 1.55         | 6.20          | 3.10          |
| <i>Pennisetum flaccidum</i>                    | 5.66          | 1.89         | 7.54          | 3.77          |
| <i>Phragmites communis</i>                     | 2.33          | 0.78         | 3.11          | 1.55          |
| <i>Plantago erosa</i>                          | 14.81         | 4.94         | 19.74         | 9.87          |
| <i>Podophyllum hexandrum</i>                   | 0.58          | 0.19         | 0.78          | 0.39          |
| <i>Polygonatum cirrhifolium</i>                | 2.92          | 0.97         | 3.90          | 1.95          |
| <i>Polygonatum verticillatum</i>               | 5.66          | 1.89         | 7.55          | 3.78          |
| <i>Polygonum nepalense</i>                     | 2.41          | 0.80         | 3.21          | 1.61          |
| <i>Primula denticulata</i>                     | 1.93          | 0.64         | 2.57          | 1.29          |
| <i>Primula petiolaris</i>                      | 4.45          | 1.48         | 5.93          | 2.96          |

|                                   |               |              |               |               |
|-----------------------------------|---------------|--------------|---------------|---------------|
| <i>Ranunculus hirtellus</i>       | 3.54          | 1.18         | 4.72          | 2.36          |
| <i>Roscoea purpurea</i>           | 2.08          | 0.69         | 2.77          | 1.39          |
| <i>Rumex nepalensis</i>           | 0.69          | 0.23         | 0.93          | 0.46          |
| <i>Salvia nubicola</i>            | 2.86          | 0.95         | 3.81          | 1.91          |
| <i>Selinum candollii</i>          | 1.31          | 0.44         | 1.74          | 0.87          |
| <i>Selinum vaginatum</i>          | 3.77          | 1.26         | 5.02          | 2.51          |
| <i>Senecio chrysanthemoides</i>   | 1.03          | 0.34         | 1.38          | 0.69          |
| <i>Sibbaldia cuneata</i>          | 10.28         | 3.43         | 13.70         | 6.85          |
| <i>Smilacina purpurea</i>         | 2.30          | 0.77         | 3.07          | 1.54          |
| <i>Sonchus asper</i>              | 4.92          | 1.64         | 6.56          | 3.28          |
| <i>Stellaria media</i>            | 2.05          | 0.68         | 2.74          | 1.37          |
| <i>Thalictrum foliolosum</i>      | 13.48         | 4.49         | 17.97         | 8.98          |
| <i>Thamnocalamus spathiflorus</i> | 1.45          | 0.48         | 1.94          | 0.97          |
| <i>Thymus linearis</i>            | 2.79          | 0.93         | 3.72          | 1.86          |
| <i>Urtica ardens</i>              | 2.18          | 0.73         | 2.91          | 1.45          |
| <i>Verbascum thapsus</i>          | 4.20          | 1.40         | 5.61          | 2.80          |
| <i>Vicatia coniiifolia</i>        | 10.38         | 3.46         | 13.84         | 6.92          |
| <b>Total</b>                      | <b>233.67</b> | <b>77.89</b> | <b>311.55</b> | <b>155.78</b> |

Moist temperate lower deciduous forests among all the elevations, at E<sub>1</sub> highest aboveground biomass (287.07 g/m<sup>2</sup>), belowground biomass (95.69 g/m<sup>2</sup>), total biomass (382.76 g/m<sup>2</sup>) and total carbon (191.38 g/m<sup>2</sup>) was recorded, followed by E<sub>2</sub> with aboveground biomass as 254.29 g/m<sup>2</sup>, belowground biomass as 84.76 g/m<sup>2</sup>, total biomass as 339.05 g/m<sup>2</sup> and total carbon as (169.52 g/m<sup>2</sup>). The least values of aboveground biomass (183.74 g/m<sup>2</sup>), belowground biomass (61.25 g/m<sup>2</sup>), total biomass (244.99 g/m<sup>2</sup>) and total carbon (122.50 g/m<sup>2</sup>) were recorded at E<sub>3</sub>. At E<sub>1</sub> highest values of aboveground biomass (21.29 g/m<sup>2</sup>), belowground biomass (7.13 g/m<sup>2</sup>), total biomass (28.52 g/m<sup>2</sup>) and carbon (14.26 g/m<sup>2</sup>) was recorded for *Ainsliaea aptera*, which was followed by *Ranunculus laetus* with aboveground biomass (18.61 g/m<sup>2</sup>), belowground biomass (6.20 g/m<sup>2</sup>), total forb biomass (24.81 g/m<sup>2</sup>) and carbon (12.41 g/m<sup>2</sup>) while lowest AGB (0.49 g/m<sup>2</sup>), BGB (0.16 g/m<sup>2</sup>), TB (0.65 g/m<sup>2</sup>) and TC (0.33 g/m<sup>2</sup>) was recorded for *Adiantum venustum* (Table 64).

At E<sub>2</sub>, highest aboveground biomass (17.26 g/m<sup>2</sup>), belowground biomass (5.75 g/m<sup>2</sup>), total biomass (23.01 g/m<sup>2</sup>) and total carbon (11.50 g/m<sup>2</sup>) was recorded for *Sibbaldia cuneata*, followed by *Heracleum candicans* with aboveground biomass (13.28 g/m<sup>2</sup>), belowground biomass (4.43 g/m<sup>2</sup>), total biomass (17.71 g/m<sup>2</sup>) and total carbon (8.85 g/m<sup>2</sup>). However *Podophyllum hexandrum* was recorded for lowest aboveground biomass (1.01 g/m<sup>2</sup>), belowground biomass (0.34 g/m<sup>2</sup>), total biomass (1.35 g/m<sup>2</sup>) and total carbon (0.67 g/m<sup>2</sup>). At E<sub>3</sub> highest aboveground biomass (11.96 g/m<sup>2</sup>), belowground biomass (3.99 g/m<sup>2</sup>), total forb

biomass (15.95 g/m<sup>2</sup>) and total carbon (7.97 g/m<sup>2</sup>) was recorded for *Salvia lanata*, descending to aboveground biomass (10.39 g/m<sup>2</sup>), belowground biomass (3.46 g/m<sup>2</sup>), total forb biomass (13.86 g/m<sup>2</sup>) and total carbon (6.93 g/m<sup>2</sup>) for *Polygonatum multiflorum*. However lowest AGB (0.71 g/m<sup>2</sup>), BGB (0.24 g/m<sup>2</sup>), TB (0.94 g/m<sup>2</sup>) and TC (0.47 g/m<sup>2</sup>) was recorded for *Swertia cordata* (Table 64).

At E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.49 g/m<sup>2</sup> to 21.29 g/m<sup>2</sup>, 0.16 g/m<sup>2</sup> to 7.13 g/m<sup>2</sup>, 0.65 g/m<sup>2</sup> to 28.52 g/m<sup>2</sup> and 0.33 g/m<sup>2</sup> to 14.26 g/m<sup>2</sup> respectively. At E<sub>2</sub> aboveground biomass, belowground biomass, total biomass and total carbon varied from 1.01 g/m<sup>2</sup> to 17.26 g/m<sup>2</sup>, 0.34 g/m<sup>2</sup> to 5.75 g/m<sup>2</sup>, 1.35 g/m<sup>2</sup> to 23.01 g/m<sup>2</sup> and 0.67 g/m<sup>2</sup> to 11.50 g/m<sup>2</sup> respectively, while aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.71 g/m<sup>2</sup> to 11.96 g/m<sup>2</sup>, 0.24 g/m<sup>2</sup> to 3.99 g/m<sup>2</sup>, 0.94 g/m<sup>2</sup> to 15.95 g/m<sup>2</sup> and 0.47 g/m<sup>2</sup> to 7.97 g/m<sup>2</sup> respectively at E<sub>3</sub> (Table 64).

**Table 64: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in moist temperate lower deciduous forests at different elevations**

| Forb Species                                  | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|-----------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                               | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation- E<sub>1</sub> (1000-1800 m)</b> |                             |                   |                    |                            |
| <i>Ainsliaea aptera</i>                       | 21.39                       | 7.13              | 28.52              | 14.26                      |
| <i>Adiantum venustum</i>                      | 0.49                        | 0.16              | 0.65               | 0.33                       |
| <i>Agrimonia pilosa</i>                       | 7.33                        | 2.44              | 9.77               | 4.89                       |
| <i>Ajuga bracteosa</i>                        | 4.76                        | 1.59              | 6.35               | 3.18                       |
| <i>Androsace lanuginosa</i>                   | 2.87                        | 0.96              | 3.82               | 1.91                       |
| <i>Androsace sarmentosa</i>                   | 4.85                        | 1.62              | 6.46               | 3.23                       |
| <i>Anemone obtusiloba</i>                     | 2.95                        | 0.98              | 3.93               | 1.97                       |
| <i>Arctium lappa</i>                          | 5.38                        | 1.79              | 7.18               | 3.59                       |
| <i>Arisaema flavum</i>                        | 3.33                        | 1.11              | 4.44               | 2.22                       |
| <i>Bupleurum hamiltonii</i>                   | 9.19                        | 3.06              | 12.26              | 6.13                       |
| <i>Carex breviculmis</i>                      | 2.46                        | 0.82              | 3.28               | 1.64                       |
| <i>Carex cardiolepis</i>                      | 2.48                        | 0.83              | 3.30               | 1.65                       |
| <i>Carex remota</i>                           | 2.49                        | 0.83              | 3.32               | 1.66                       |
| <i>Chenopodium opulifolium</i>                | 9.04                        | 3.01              | 12.06              | 6.03                       |
| <i>Corydalis govaniana</i>                    | 7.52                        | 2.51              | 10.03              | 5.02                       |
| <i>Dicliptera bupleuroides</i>                | 13.83                       | 4.61              | 18.44              | 9.22                       |



|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Dioscorea deltoidea</i>                    | 2.05          | 0.68         | 2.73          | 1.36          |
| <i>Fagopyrum dibotrys</i>                     | 3.03          | 1.01         | 4.04          | 2.02          |
| <i>Galium aparine</i>                         | 8.13          | 2.71         | 10.84         | 5.42          |
| <i>Galium asperuloides</i>                    | 2.35          | 0.78         | 3.13          | 1.57          |
| <i>Girardinia diversifolia</i>                | 2.26          | 0.75         | 3.02          | 1.51          |
| <i>Habenaria intermedia</i>                   | 3.81          | 1.27         | 5.09          | 2.54          |
| <i>Halenia elliptica</i>                      | 3.13          | 1.04         | 4.18          | 2.09          |
| <i>Heracleum candicans</i>                    | 4.92          | 1.64         | 6.55          | 3.28          |
| <i>Impatiens scabrida</i>                     | 4.69          | 1.56         | 6.26          | 3.13          |
| <i>Iris nepalensis</i>                        | 6.46          | 2.15         | 8.62          | 4.31          |
| <i>Lamium album</i>                           | 2.31          | 0.77         | 3.08          | 1.54          |
| <i>Nepeta laevigata</i>                       | 9.09          | 3.03         | 12.12         | 6.06          |
| <i>Phragmites communis</i>                    | 2.46          | 0.82         | 3.28          | 1.64          |
| <i>Plantago depressa</i>                      | 2.79          | 0.93         | 3.71          | 1.86          |
| <i>Polygala abyssinica</i>                    | 4.49          | 1.50         | 5.99          | 2.99          |
| <i>Polygonatum cirrhifolium</i>               | 6.40          | 2.13         | 8.54          | 4.27          |
| <i>Polygonatum multiflorum</i>                | 6.34          | 2.11         | 8.46          | 4.23          |
| <i>Polygonatum verticillatum</i>              | 3.33          | 1.11         | 4.44          | 2.22          |
| <i>Potentilla fragarioides</i>                | 11.56         | 3.85         | 15.42         | 7.71          |
| <i>Potentilla leschenaultiana</i>             | 2.71          | 0.90         | 3.61          | 1.80          |
| <i>Primula denticulata</i>                    | 7.78          | 2.59         | 10.37         | 5.19          |
| <i>Ranunculus hirtellus</i>                   | 7.77          | 2.59         | 10.36         | 5.18          |
| <i>Ranunculus laetus</i>                      | 18.61         | 6.20         | 24.81         | 12.41         |
| <i>Roscoeia purpurea</i>                      | 17.99         | 6.00         | 23.98         | 11.99         |
| <i>Rumex nepalensis</i>                       | 6.34          | 2.11         | 8.45          | 4.22          |
| <i>Salvia nubicola</i>                        | 5.60          | 1.87         | 7.46          | 3.73          |
| <i>Scrophularia himalensis</i>                | 10.29         | 3.43         | 13.72         | 6.86          |
| <i>Silene griffithii</i>                      | 1.32          | 0.44         | 1.76          | 0.88          |
| <i>Smilax glaucophylla</i>                    | 1.30          | 0.43         | 1.73          | 0.87          |
| <i>Stellaria media</i>                        | 3.17          | 1.06         | 4.22          | 2.11          |
| <i>Thymus linearis</i>                        | 10.01         | 3.34         | 13.35         | 6.68          |
| <i>Verbascum thapsus</i>                      | 3.05          | 1.02         | 4.07          | 2.03          |
| <i>Vicatia coniiifolia</i>                    | 1.17          | 0.39         | 1.56          | 0.78          |
| <b>Total</b>                                  | <b>287.07</b> | <b>95.69</b> | <b>382.76</b> | <b>191.38</b> |
| <b>Elevation- E<sub>2</sub> (1800-2400 m)</b> |               |              |               |               |
| <i>Adiantum venustum</i>                      | 1.18          | 0.39         | 1.57          | 0.79          |
| <i>Ainsliaea aptera</i>                       | 4.45          | 1.48         | 5.94          | 2.97          |
| <i>Ajuga bracteosa</i>                        | 7.94          | 2.65         | 10.58         | 5.29          |
| <i>Anaphalis contorta</i>                     | 9.92          | 3.31         | 13.23         | 6.61          |
| <i>Androsace lanuginosa</i>                   | 9.58          | 3.19         | 12.78         | 6.39          |
| <i>Androsace sarmentosa</i>                   | 2.79          | 0.93         | 3.71          | 1.86          |
| <i>Angelica glauca</i>                        | 4.15          | 1.38         | 5.53          | 2.77          |
| <i>Bergenia stracheyi</i>                     | 1.76          | 0.59         | 2.35          | 1.17          |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Bistorta amplexicaulis</i>                 | 4.06          | 1.35         | 5.41          | 2.71          |
| <i>Carex breviculmis</i>                      | 6.17          | 2.06         | 8.23          | 4.12          |
| <i>Carex remota</i>                           | 11.05         | 3.68         | 14.73         | 7.36          |
| <i>Chenopodium opulifolium</i>                | 5.59          | 1.86         | 7.45          | 3.73          |
| <i>Clinopodium vulgare</i>                    | 2.61          | 0.87         | 3.48          | 1.74          |
| <i>Erigeron bellidioides</i>                  | 2.40          | 0.80         | 3.20          | 1.60          |
| <i>Fagopyrum dibotrys</i>                     | 9.13          | 3.04         | 12.17         | 6.09          |
| <i>Fragaria nubicola</i>                      | 7.77          | 2.59         | 10.36         | 5.18          |
| <i>Galium aparine</i>                         | 11.40         | 3.80         | 15.20         | 7.60          |
| <i>Geranium lucidum</i>                       | 2.41          | 0.80         | 3.22          | 1.61          |
| <i>Gypsophila cerastioides</i>                | 1.75          | 0.58         | 2.33          | 1.17          |
| <i>Halenia elliptica</i>                      | 4.96          | 1.65         | 6.61          | 3.31          |
| <i>Heracleum candicans</i>                    | 13.28         | 4.43         | 17.71         | 8.85          |
| <i>Lotus corniculatus</i>                     | 1.47          | 0.49         | 1.96          | 0.98          |
| <i>Origanum vulgare</i>                       | 5.47          | 1.82         | 7.29          | 3.65          |
| <i>Pedicularis hoffmeisteri</i>               | 5.12          | 1.71         | 6.83          | 3.41          |
| <i>Phragmites communis</i>                    | 6.96          | 2.32         | 9.28          | 4.64          |
| <i>Plantago erosa</i>                         | 3.15          | 1.05         | 4.19          | 2.10          |
| <i>Plectranthus japonicus</i>                 | 6.25          | 2.08         | 8.34          | 4.17          |
| <i>Podophyllum hexandrum</i>                  | 1.01          | 0.34         | 1.35          | 0.67          |
| <i>Polygonatum verticillatum</i>              | 6.09          | 2.03         | 8.12          | 4.06          |
| <i>Potentilla atosanguinea</i>                | 1.80          | 0.60         | 2.40          | 1.20          |
| <i>Primula denticulata</i>                    | 1.61          | 0.54         | 2.15          | 1.08          |
| <i>Pteris cretica-fern</i>                    | 3.70          | 1.23         | 4.93          | 2.46          |
| <i>Ranunculus hirtellus</i>                   | 5.55          | 1.85         | 7.40          | 3.70          |
| <i>Roscoea purpurea</i>                       | 6.06          | 2.02         | 8.08          | 4.04          |
| <i>Salvia nubicola</i>                        | 5.78          | 1.93         | 7.71          | 3.85          |
| <i>Selinum candollii</i>                      | 1.84          | 0.61         | 2.45          | 1.22          |
| <i>Senecio chrysanthemoides</i>               | 1.58          | 0.53         | 2.11          | 1.05          |
| <i>Senecio nudicaulis</i>                     | 6.25          | 2.08         | 8.33          | 4.16          |
| <i>Sibbaldia cuneata</i>                      | 17.26         | 5.75         | 23.01         | 11.50         |
| <i>Silene griffithii</i>                      | 11.46         | 3.82         | 15.28         | 7.64          |
| <i>Smilacina purpurea</i>                     | 4.97          | 1.66         | 6.62          | 3.31          |
| <i>Stellaria media</i>                        | 4.63          | 1.54         | 6.18          | 3.09          |
| <i>Urtica ardens</i>                          | 2.64          | 0.88         | 3.53          | 1.76          |
| <i>Valeriana pyrolaefolia</i>                 | 6.31          | 2.10         | 8.42          | 4.21          |
| <i>Verbascum thapsus</i>                      | 5.99          | 2.00         | 7.99          | 4.00          |
| <i>Vicatia coniiifolia</i>                    | 6.98          | 2.33         | 9.30          | 4.65          |
| <b>Total</b>                                  | <b>254.29</b> | <b>84.76</b> | <b>339.05</b> | <b>169.52</b> |
| <b>Elevation- E<sub>3</sub> (2400-2700 m)</b> |               |              |               |               |
| <i>Achyranthes bidentata</i>                  | 4.91          | 1.64         | 6.54          | 3.27          |
| <i>Ajuga bracteosa</i>                        | 5.77          | 1.92         | 7.70          | 3.85          |
| <i>Amaranthus blitum</i>                      | 6.82          | 2.27         | 9.09          | 4.55          |

|                                |               |              |               |               |
|--------------------------------|---------------|--------------|---------------|---------------|
| <i>Androsace lanuginosa</i>    | 4.16          | 1.39         | 5.54          | 2.77          |
| <i>Apluda mutica</i>           | 1.66          | 0.55         | 2.21          | 1.11          |
| <i>Arisaema flavum</i>         | 5.10          | 1.70         | 6.80          | 3.40          |
| <i>Artemisia roxburghiana</i>  | 3.54          | 1.18         | 4.72          | 2.36          |
| <i>Artemisia vestita</i>       | 8.21          | 2.74         | 10.94         | 5.47          |
| <i>Bistorta amplexicaulis</i>  | 1.78          | 0.59         | 2.37          | 1.19          |
| <i>Clinopodium vulgare</i>     | 3.84          | 1.28         | 5.12          | 2.56          |
| <i>Dioscorea deltoidea</i>     | 6.64          | 2.21         | 8.85          | 4.43          |
| <i>Erigeron multicaulis</i>    | 2.00          | 0.67         | 2.66          | 1.33          |
| <i>Fragaria nubicola</i>       | 2.37          | 0.79         | 3.16          | 1.58          |
| <i>Gerbera gossypina</i>       | 2.14          | 0.71         | 2.85          | 1.42          |
| <i>Habenaria intermedia</i>    | 3.81          | 1.27         | 5.08          | 2.54          |
| <i>Heracleum candicans</i>     | 0.94          | 0.31         | 1.25          | 0.62          |
| <i>Impatiens scabrida</i>      | 6.84          | 2.28         | 9.12          | 4.56          |
| <i>Iris nepalensis</i>         | 8.17          | 2.72         | 10.89         | 5.45          |
| <i>Lamium album</i>            | 4.11          | 1.37         | 5.49          | 2.74          |
| <i>Lotus corniculatus</i>      | 2.49          | 0.83         | 3.31          | 1.66          |
| <i>Nasturtium officinale</i>   | 3.68          | 1.23         | 4.91          | 2.46          |
| <i>Oenothera rosea</i>         | 7.74          | 2.58         | 10.32         | 5.16          |
| <i>Plantago erosa</i>          | 6.56          | 2.19         | 8.74          | 4.37          |
| <i>Polygonatum multiflorum</i> | 10.39         | 3.46         | 13.86         | 6.93          |
| <i>Polygonum hydropiper</i>    | 0.90          | 0.30         | 1.20          | 0.60          |
| <i>Potentilla fragarioides</i> | 2.63          | 0.88         | 3.50          | 1.75          |
| <i>Primula floribunda</i>      | 9.32          | 3.11         | 12.43         | 6.22          |
| <i>Saccharum filifolium</i>    | 0.77          | 0.26         | 1.03          | 0.52          |
| <i>Salvia lanata</i>           | 11.96         | 3.99         | 15.95         | 7.97          |
| <i>Scutellaria scandens</i>    | 2.59          | 0.86         | 3.45          | 1.72          |
| <i>Silene vulgaris</i>         | 6.64          | 2.21         | 8.86          | 4.43          |
| <i>Smilax aspera</i>           | 2.95          | 0.98         | 3.93          | 1.96          |
| <i>Smilax glaucophylla</i>     | 6.21          | 2.07         | 8.28          | 4.14          |
| <i>Stellaria media</i>         | 5.27          | 1.76         | 7.03          | 3.51          |
| <i>Swertia cordata</i>         | 0.71          | 0.24         | 0.94          | 0.47          |
| <i>Themeda anathera</i>        | 4.87          | 1.62         | 6.50          | 3.25          |
| <i>Trifolium pratense</i>      | 5.90          | 1.97         | 7.87          | 3.94          |
| <i>Urtica ardens</i>           | 1.91          | 0.64         | 2.55          | 1.28          |
| <i>Valeriana jatamansi</i>     | 3.41          | 1.14         | 4.55          | 2.27          |
| <i>Viola canescens</i>         | 4.04          | 1.35         | 5.39          | 2.69          |
| <b>Total</b>                   | <b>183.74</b> | <b>61.25</b> | <b>244.99</b> | <b>122.50</b> |

Kail (*Pinus wallichiana*) forests differed for aboveground biomass, belowground biomass, total biomass and total carbon at different elevations, at E<sub>1</sub> highest aboveground biomass (251.79 g/m<sup>2</sup>), belowground biomass (83.93 g/m<sup>2</sup>), total biomass (335.71 g/m<sup>2</sup>) and total carbon (167.86 g/m<sup>2</sup>) was recorded. Which was followed by E<sub>2</sub> with aboveground biomass (224.92 g/m<sup>2</sup>), belowground biomass (56.23 g/m<sup>2</sup>), total biomass (281.14 g/m<sup>2</sup>) and

total carbon ( $140.57 \text{ g/m}^2$ ). The lowest aboveground biomass ( $197.47 \text{ g/m}^2$ ), belowground biomass ( $65.82 \text{ g/m}^2$ ), total biomass ( $263.29 \text{ g/m}^2$ ) and carbon ( $131.65 \text{ g/m}^2$ ) were recorded at  $E_3$  (Table 65).

At  $E_1$  highest values of aboveground biomass ( $21.21 \text{ g/m}^2$ ), belowground biomass ( $7.07 \text{ g/m}^2$ ), total biomass ( $28.28 \text{ g/m}^2$ ) and total carbon ( $14.14 \text{ g/m}^2$ ) was recorded for *Anaphalis contorta*, which was followed by *Primula denticulate* with aboveground biomass ( $14.52 \text{ g/m}^2$ ), belowground biomass ( $4.84 \text{ g/m}^2$ ), total biomass ( $19.36 \text{ g/m}^2$ ) and total carbon ( $9.68 \text{ g/m}^2$ ). While lowest total forb aboveground biomass ( $0.69 \text{ g/m}^2$ ), belowground biomass ( $0.23 \text{ g/m}^2$ ), total biomass ( $0.92 \text{ g/m}^2$ ) and total carbon ( $0.46 \text{ g/m}^2$ ) as recorded for *Pteris creticas* at  $E_1$  (Table 65).

Highest aboveground biomass ( $14.03 \text{ g/m}^2$ ), belowground biomass ( $3.51 \text{ g/m}^2$ ), total biomass ( $17.54 \text{ g/m}^2$ ) and total carbon ( $8.77 \text{ g/m}^2$ ) was recorded for *Themeda anathera*, which was followed by *Oenothera rosea* with aboveground biomass ( $13.11 \text{ g/m}^2$ ), belowground biomass ( $3.28 \text{ g/m}^2$ ), total biomass ( $16.38 \text{ g/m}^2$ ) and total carbon ( $8.19 \text{ g/m}^2$ ) at  $E_2$ . However *Dioscorea deltoidea* exhibited lowest aboveground biomass ( $0.68 \text{ g/m}^2$ ), belowground biomass ( $0.17 \text{ g/m}^2$ ), total biomass ( $0.85 \text{ g/m}^2$ ) and total carbon ( $0.43 \text{ g/m}^2$ ) (Table 65).

At  $E_3$  highest aboveground biomass ( $18.29 \text{ g/m}^2$ ), belowground biomass ( $6.10 \text{ g/m}^2$ ), total biomass ( $24.39 \text{ g/m}^2$ ) and total carbon ( $12.19 \text{ g/m}^2$ ) was recorded for *Trifolium repens*, which was followed by *Bupleurum hamiltonii* with aboveground biomass ( $14.92 \text{ g/m}^2$ ), belowground biomass ( $4.97 \text{ g/m}^2$ ), total biomass ( $19.89 \text{ g/m}^2$ ) and total carbon ( $9.94 \text{ g/m}^2$ ). Whereas, minimum aboveground biomass ( $0.37 \text{ g/m}^2$ ), belowground biomass ( $0.12 \text{ g/m}^2$ ), total biomass ( $0.49 \text{ g/m}^2$ ) and total carbon ( $0.25 \text{ g/m}^2$ ) were exhibited by *Androsace sarmentosa* at  $E_3$  (Table 65).

Range of aboveground biomass, belowground biomass, total biomass and total carbon at  $E_1$  varied from  $0.69 \text{ g/m}^2$  to  $21.21 \text{ g/m}^2$ ,  $0.23 \text{ g/m}^2$  to  $7.07 \text{ g/m}^2$ ,  $0.92 \text{ g/m}^2$  to  $28.28 \text{ g/m}^2$  and  $0.46 \text{ g/m}^2$  to  $14.14 \text{ g/m}^2$  respectively. At  $E_2$  range of aboveground biomass as  $0.68 \text{ g/m}^2$  to  $14.03 \text{ g/m}^2$ , belowground biomass as  $0.17 \text{ g/m}^2$  to  $3.51 \text{ g/m}^2$ , total biomass as  $0.85 \text{ g/m}^2$  to  $17.54 \text{ g/m}^2$  and total carbon as  $0.43 \text{ g/m}^2$  to  $8.77 \text{ g/m}^2$  while at  $E_3$  aboveground biomass, belowground biomass, total biomass and total carbon ranged from  $0.37 \text{ g/m}^2$  to  $18.29 \text{ g/m}^2$ ,  $0.12 \text{ g/m}^2$  to  $6.10 \text{ g/m}^2$ ,  $0.49 \text{ g/m}^2$  to  $24.39 \text{ g/m}^2$  and  $0.25 \text{ g/m}^2$  to  $12.19 \text{ g/m}^2$  respectively (Table 65).

**Table 65: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forb species in Kail (*Pinus wallichiana*) forests at different elevations**

| Forb Species                                  | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|-----------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                               | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation- E<sub>1</sub> (1400-2100 m)</b> |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                      | 1.37                        | 0.46              | 1.83               | 0.91                       |
| <i>Ainsliaea aptera</i>                       | 5.29                        | 1.76              | 7.05               | 3.52                       |
| <i>Ajuga bracteosa</i>                        | 10.06                       | 3.35              | 13.41              | 6.70                       |
| <i>Anaphalis contorta</i>                     | 21.21                       | 7.07              | 28.28              | 14.14                      |
| <i>Androsace lanuginosa</i>                   | 3.17                        | 1.06              | 4.23               | 2.11                       |
| <i>Androsace sarmentosa</i>                   | 3.01                        | 1.00              | 4.01               | 2.01                       |
| <i>Anemone obtusiloba</i>                     | 2.76                        | 0.92              | 3.68               | 1.84                       |
| <i>Angelica glauca</i>                        | 2.85                        | 0.95              | 3.80               | 1.90                       |
| <i>Arabis amplexicaulis</i>                   | 3.79                        | 1.26              | 5.05               | 2.53                       |
| <i>Artemisia roxburghiana</i>                 | 5.17                        | 1.72              | 6.90               | 3.45                       |
| <i>Bergenia stracheyi</i>                     | 6.20                        | 2.07              | 8.26               | 4.13                       |
| <i>Bistorta amplexicaulis</i>                 | 0.80                        | 0.27              | 1.06               | 0.53                       |
| <i>Bupleurum falcatum</i>                     | 5.87                        | 1.96              | 7.83               | 3.92                       |
| <i>Carex breviculmis</i>                      | 1.90                        | 0.63              | 2.54               | 1.27                       |
| <i>Carex cardiolepis</i>                      | 3.79                        | 1.26              | 5.05               | 2.53                       |
| <i>Chenopodium opulifolium</i>                | 4.02                        | 1.34              | 5.36               | 2.68                       |
| <i>Clinopodium vulgare</i>                    | 3.03                        | 1.01              | 4.04               | 2.02                       |
| <i>Corydalis gowaniana</i>                    | 3.22                        | 1.07              | 4.30               | 2.15                       |
| <i>Dioscorea deltoidea</i>                    | 0.79                        | 0.26              | 1.05               | 0.53                       |
| <i>Erigeron bellidioides</i>                  | 1.83                        | 0.61              | 2.44               | 1.22                       |
| <i>Fagopyrum dibotrys</i>                     | 2.07                        | 0.69              | 2.76               | 1.38                       |
| <i>Galium aparine</i>                         | 2.70                        | 0.90              | 3.60               | 1.80                       |
| <i>Geranium lucidum</i>                       | 3.17                        | 1.06              | 4.23               | 2.12                       |
| <i>Gypsophila cerastioides</i>                | 4.59                        | 1.53              | 6.12               | 3.06                       |
| <i>Halenia elliptica</i>                      | 9.35                        | 3.12              | 12.46              | 6.23                       |
| <i>Impatiens scabrida</i>                     | 2.55                        | 0.85              | 3.40               | 1.70                       |
| <i>Iris nepalensis</i>                        | 13.12                       | 4.37              | 17.49              | 8.75                       |
| <i>Lotus corniculatus</i>                     | 4.83                        | 1.61              | 6.44               | 3.22                       |
| <i>Nepeta laevigata</i>                       | 9.63                        | 3.21              | 12.84              | 6.42                       |
| <i>Pedicularis hoffmeisteri</i>               | 2.16                        | 0.72              | 2.88               | 1.44                       |
| <i>Phragmites communis</i>                    | 1.16                        | 0.39              | 1.55               | 0.77                       |
| <i>Plantago depressa</i>                      | 3.43                        | 1.14              | 4.58               | 2.29                       |
| <i>Plectranthus japonicus</i>                 | 4.14                        | 1.38              | 5.52               | 2.76                       |
| <i>Podophyllum hexandrum</i>                  | 1.38                        | 0.46              | 1.84               | 0.92                       |
| <i>Polygonatum cirrhifolium</i>               | 4.14                        | 1.38              | 5.52               | 2.76                       |
| <i>Polygonatum multiflorum</i>                | 6.93                        | 2.31              | 9.23               | 4.62                       |
| <i>Potentilla argyrophylla</i>                | 3.42                        | 1.14              | 4.57               | 2.28                       |
| <i>Potentilla atrosanguinea</i>               | 1.95                        | 0.65              | 2.60               | 1.30                       |
| <i>Primula denticulata</i>                    | 14.52                       | 4.84              | 19.36              | 9.68                       |
| <i>Primula petiolaris</i>                     | 2.07                        | 0.69              | 2.76               | 1.38                       |

|                                              |               |              |               |               |
|----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Pteris cretica</i>                        | 0.69          | 0.23         | 0.92          | 0.46          |
| <i>Ranunculus hirtellus</i>                  | 2.07          | 0.69         | 2.76          | 1.38          |
| <i>Roscoea purpurea</i>                      | 2.99          | 1.00         | 3.99          | 1.99          |
| <i>Salvia nubicola</i>                       | 6.91          | 2.30         | 9.22          | 4.61          |
| <i>Scrophularia himalensis</i>               | 2.29          | 0.76         | 3.05          | 1.53          |
| <i>Selaginella kraussiana</i>                | 3.46          | 1.15         | 4.61          | 2.31          |
| <i>Senecio chrysanthemoides</i>              | 4.28          | 1.43         | 5.71          | 2.85          |
| <i>Sibbaldia cuneata</i>                     | 4.83          | 1.61         | 6.44          | 3.22          |
| <i>Silene griffithii</i>                     | 2.30          | 0.77         | 3.07          | 1.53          |
| <i>Silene vulgaris</i>                       | 1.84          | 0.61         | 2.45          | 1.23          |
| <i>Smilacina purpurea</i>                    | 0.92          | 0.31         | 1.23          | 0.61          |
| <i>Stellaria media</i>                       | 3.08          | 1.03         | 4.10          | 2.05          |
| <i>Thymus linearis</i>                       | 4.16          | 1.39         | 5.55          | 2.77          |
| <i>Urtica ardens</i>                         | 2.29          | 0.76         | 3.05          | 1.52          |
| <i>Valeriana jatamansi</i>                   | 5.79          | 1.93         | 7.72          | 3.86          |
| <i>Valeriana pyrolaefolia</i>                | 2.07          | 0.69         | 2.76          | 1.38          |
| <i>Verbascum thapsus</i>                     | 8.64          | 2.88         | 11.52         | 5.76          |
| <i>Vicatia coniifolia</i>                    | 5.75          | 1.92         | 7.67          | 3.83          |
| <b>Total</b>                                 | <b>251.79</b> | <b>83.93</b> | <b>335.71</b> | <b>167.86</b> |
| <b>Elevation-E<sub>2</sub> (2100-2800 m)</b> |               |              |               |               |
| <i>Achyranthes aspera</i>                    | 2.84          | 0.71         | 3.55          | 1.77          |
| <i>Achyranthes bidentata</i>                 | 6.08          | 1.52         | 7.59          | 3.80          |
| <i>Ajuga bracteosa</i>                       | 4.68          | 1.17         | 5.85          | 2.93          |
| <i>Ajuga parviflora</i>                      | 4.06          | 1.02         | 5.08          | 2.54          |
| <i>Amaranthus blitum</i>                     | 3.69          | 0.92         | 4.61          | 2.30          |
| <i>Androsace lanuginosa</i>                  | 2.72          | 0.68         | 3.40          | 1.70          |
| <i>Arabis amplexicaulis</i>                  | 2.02          | 0.51         | 2.53          | 1.26          |
| <i>Arisaema flavum</i>                       | 2.73          | 0.68         | 3.41          | 1.70          |
| <i>Artemisia roxburghiana</i>                | 1.39          | 0.35         | 1.73          | 0.87          |
| <i>Aster molliusculus</i>                    | 7.78          | 1.95         | 9.73          | 4.87          |
| <i>Atylosia scarabaeoides</i>                | 2.87          | 0.72         | 3.58          | 1.79          |
| <i>Bidens biternata</i>                      | 2.87          | 0.72         | 3.59          | 1.79          |
| <i>Bistorta amplexicaulis</i>                | 4.73          | 1.18         | 5.92          | 2.96          |
| <i>Clinopodium vulgare</i>                   | 1.92          | 0.48         | 2.39          | 1.20          |
| <i>Cyathula tomentosa</i>                    | 4.94          | 1.23         | 6.17          | 3.08          |
| <i>Datura stramonium</i>                     | 4.31          | 1.08         | 5.38          | 2.69          |
| <i>Dicliptera bupleuroides</i>               | 2.03          | 0.51         | 2.53          | 1.27          |
| <i>Dioscorea deltoidea</i>                   | 0.68          | 0.17         | 0.85          | 0.43          |
| <i>Duchesnea indica</i>                      | 3.62          | 0.91         | 4.53          | 2.26          |
| <i>Echinops niveus</i>                       | 2.03          | 0.51         | 2.54          | 1.27          |
| <i>Fagopyrum dibotrys</i>                    | 3.17          | 0.79         | 3.97          | 1.98          |
| <i>Fragaria nubicola</i>                     | 10.49         | 2.62         | 13.12         | 6.56          |
| <i>Galium aparine</i>                        | 5.79          | 1.45         | 7.23          | 3.62          |
| <i>Geranium lucidum</i>                      | 2.04          | 0.51         | 2.55          | 1.28          |
| <i>Gerbera gossypina</i>                     | 2.36          | 0.59         | 2.95          | 1.47          |
| <i>Habenaria intermedia</i>                  | 1.65          | 0.41         | 2.07          | 1.03          |
| <i>Heracleum candicans</i>                   | 2.84          | 0.71         | 3.55          | 1.77          |
| <i>Impatiens scabrida</i>                    | 2.81          | 0.70         | 3.51          | 1.76          |

|                                              |               |              |               |               |
|----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Iris nepalensis</i>                       | 3.94          | 0.98         | 4.92          | 2.46          |
| <i>Leucas lanata</i>                         | 11.79         | 2.95         | 14.74         | 7.37          |
| <i>Micromeria biflora</i>                    | 3.21          | 0.80         | 4.01          | 2.00          |
| <i>Oenothera rosea</i>                       | 13.11         | 3.28         | 16.38         | 8.19          |
| <i>Phragmites communis</i>                   | 5.37          | 1.34         | 6.71          | 3.36          |
| <i>Plantago depressa</i>                     | 7.28          | 1.82         | 9.10          | 4.55          |
| <i>Plantago erosa</i>                        | 4.89          | 1.22         | 6.11          | 3.06          |
| <i>Plectranthus japonicus</i>                | 2.88          | 0.72         | 3.60          | 1.80          |
| <i>Polygonatum multiflorum</i>               | 4.22          | 1.05         | 5.27          | 2.64          |
| <i>Polygonum hydropiper</i>                  | 3.81          | 0.95         | 4.77          | 2.38          |
| <i>Primula floribunda</i>                    | 2.00          | 0.50         | 2.50          | 1.25          |
| <i>Pteris cretica</i>                        | 4.65          | 1.16         | 5.81          | 2.91          |
| <i>Rumex nepalensis</i>                      | 1.13          | 0.28         | 1.41          | 0.70          |
| <i>Salvia lanata</i>                         | 2.77          | 0.69         | 3.46          | 1.73          |
| <i>Scutellaria scandens</i>                  | 3.19          | 0.80         | 3.99          | 2.00          |
| <i>Silene vulgaris</i>                       | 8.04          | 2.01         | 10.05         | 5.03          |
| <i>Stellaria media</i>                       | 1.26          | 0.32         | 1.58          | 0.79          |
| <i>Swertia cordata</i>                       | 2.12          | 0.53         | 2.65          | 1.32          |
| <i>Thalictrum foliolosum</i>                 | 4.73          | 1.18         | 5.91          | 2.95          |
| <i>Themeda anathera</i>                      | 14.03         | 3.51         | 17.54         | 8.77          |
| <i>Trifolium repens</i>                      | 2.29          | 0.57         | 2.86          | 1.43          |
| <i>Urtica ardens</i>                         | 5.24          | 1.31         | 6.55          | 3.28          |
| <i>Urtica dioica</i>                         | 0.98          | 0.25         | 1.23          | 0.61          |
| <i>Valeriana jatamansi</i>                   | 2.86          | 0.71         | 3.57          | 1.79          |
| <i>Verbascum thapsus</i>                     | 6.01          | 1.50         | 7.51          | 3.76          |
| <i>Viola canescens</i>                       | 4.00          | 1.00         | 5.00          | 2.50          |
| <b>Total</b>                                 | <b>224.92</b> | <b>56.23</b> | <b>281.14</b> | <b>140.57</b> |
| <b>Elevation-E<sub>3</sub> (2800-3600 m)</b> |               |              |               |               |
| <i>Anaphalis contorta</i>                    | 1.63          | 0.54         | 2.18          | 1.09          |
| <i>Androsace rotundifolia</i>                | 7.49          | 2.50         | 9.99          | 4.99          |
| <i>Androsace sarmentosa</i>                  | 0.37          | 0.12         | 0.49          | 0.25          |
| <i>Arisaema flavum</i>                       | 1.46          | 0.49         | 1.94          | 0.97          |
| <i>Artemisia indica</i>                      | 6.72          | 2.24         | 8.96          | 4.48          |
| <i>Astilbe rivularis</i>                     | 1.68          | 0.56         | 2.24          | 1.12          |
| <i>Bupleurum hamiltonii</i>                  | 14.92         | 4.97         | 19.89         | 9.94          |
| <i>Carex breviculmis</i>                     | 2.59          | 0.86         | 3.45          | 1.73          |
| <i>Carex remota</i>                          | 3.42          | 1.14         | 4.56          | 2.28          |
| <i>Chenopodium opulifolium</i>               | 1.49          | 0.50         | 1.99          | 1.00          |
| <i>Corydalis govaniana</i>                   | 6.02          | 2.01         | 8.02          | 4.01          |
| <i>Crepis sancta</i>                         | 6.55          | 2.18         | 8.74          | 4.37          |
| <i>Dicliptera bupleuroides</i>               | 1.93          | 0.64         | 2.57          | 1.29          |
| <i>Dioscorea deltoidea</i>                   | 4.27          | 1.42         | 5.70          | 2.85          |
| <i>Erigeron bellidioides</i>                 | 5.31          | 1.77         | 7.08          | 3.54          |
| <i>Erigeron multicaulis</i>                  | 3.07          | 1.02         | 4.10          | 2.05          |
| <i>Fagopyrum dibotrys</i>                    | 3.55          | 1.18         | 4.73          | 2.37          |
| <i>Fragaria nubicola</i>                     | 7.90          | 2.63         | 10.54         | 5.27          |
| <i>Galium asperuloides</i>                   | 1.62          | 0.54         | 2.16          | 1.08          |
| <i>Geranium lucidum</i>                      | 0.72          | 0.24         | 0.96          | 0.48          |

|                                 |               |              |               |               |
|---------------------------------|---------------|--------------|---------------|---------------|
| <i>Gypsophila cerastioides</i>  | 1.73          | 0.58         | 2.30          | 1.15          |
| <i>Halenia elliptica</i>        | 1.68          | 0.56         | 2.24          | 1.12          |
| <i>Iris nepalensis</i>          | 2.25          | 0.75         | 3.00          | 1.50          |
| <i>Lamium album</i>             | 2.55          | 0.85         | 3.40          | 1.70          |
| <i>Lotus corniculatus</i>       | 6.12          | 2.04         | 8.16          | 4.08          |
| <i>Myriactis nepalensis</i>     | 4.24          | 1.41         | 5.65          | 2.83          |
| <i>Nepeta laevigata</i>         | 1.84          | 0.61         | 2.46          | 1.23          |
| <i>Phragmites communis</i>      | 3.68          | 1.23         | 4.90          | 2.45          |
| <i>Polygala abyssinica</i>      | 2.32          | 0.77         | 3.10          | 1.55          |
| <i>Polygonatum cirrhifolium</i> | 1.50          | 0.50         | 2.00          | 1.00          |
| <i>Polygonatum multiflorum</i>  | 5.06          | 1.69         | 6.75          | 3.38          |
| <i>Potentilla argyrophylla</i>  | 4.19          | 1.40         | 5.59          | 2.79          |
| <i>Potentilla nepalensis</i>    | 3.57          | 1.19         | 4.76          | 2.38          |
| <i>Primula petiolaris</i>       | 3.06          | 1.02         | 4.08          | 2.04          |
| <i>Ranunculus hirtellus</i>     | 3.70          | 1.23         | 4.93          | 2.46          |
| <i>Ranunculus laetus</i>        | 2.74          | 0.91         | 3.65          | 1.83          |
| <i>Rosularia rosulata</i>       | 3.67          | 1.22         | 4.90          | 2.45          |
| <i>Rumex nepalensis</i>         | 1.54          | 0.51         | 2.06          | 1.03          |
| <i>Salvia nubicola</i>          | 7.28          | 2.43         | 9.71          | 4.85          |
| <i>Scrophularia himalensis</i>  | 1.66          | 0.55         | 2.22          | 1.11          |
| <i>Smilax glaucophylla</i>      | 0.78          | 0.26         | 1.05          | 0.52          |
| <i>Stellaria media</i>          | 1.87          | 0.62         | 2.50          | 1.25          |
| <i>Swertia cordata</i>          | 8.86          | 2.95         | 11.81         | 5.91          |
| <i>Thymus linearis</i>          | 3.27          | 1.09         | 4.36          | 2.18          |
| <i>Trifolium repens</i>         | 18.29         | 6.10         | 24.39         | 12.19         |
| <i>Urtica ardens</i>            | 0.93          | 0.31         | 1.24          | 0.62          |
| <i>Urtica dioica</i>            | 1.23          | 0.41         | 1.64          | 0.82          |
| <i>Valeriana jatamansi</i>      | 2.50          | 0.83         | 3.33          | 1.67          |
| <i>Valeriana pyrolaefolia</i>   | 5.56          | 1.85         | 7.42          | 3.71          |
| <i>Verbascum thapsus</i>        | 5.21          | 1.74         | 6.95          | 3.47          |
| <i>Vicatia coniiifolia</i>      | 1.86          | 0.62         | 2.47          | 1.24          |
| <b>Total</b>                    | <b>197.47</b> | <b>65.82</b> | <b>263.29</b> | <b>131.65</b> |

A perusal of the data presented in Table 66 reveals that in Kharsu Oak forests among all the elevations, at E<sub>1</sub> highest aboveground forb biomass (220.56 g/m<sup>2</sup>), belowground biomass (73.52 g/m<sup>2</sup>), total biomass (294.08 g/m<sup>2</sup>) and total carbon (147.04 g/m<sup>2</sup>) was recorded which was followed by E<sub>2</sub> with aboveground biomass (130.24 g/m<sup>2</sup>), belowground biomass (43.41 g/m<sup>2</sup>), total biomass (173.65 g/m<sup>2</sup>) and total carbon (86.83 g/m<sup>2</sup>). However, lowest aboveground biomass (108.19 g/m<sup>2</sup>), belowground biomass (36.06 g/m<sup>2</sup>), total biomass (144.26 g/m<sup>2</sup>) and total carbon (72.13 g/m<sup>2</sup>) were recorded at E<sub>3</sub>.

At elevation E<sub>1</sub>, highest values of aboveground biomass (18.73 g/m<sup>2</sup>), belowground biomass (6.24 g/m<sup>2</sup>), total biomass (24.98 g/m<sup>2</sup>) and carbon (12.49 g/m<sup>2</sup>) was recorded for *Viola canescens*, which was followed by *Fragaria nubicola* with aboveground biomass



(11.94 g/m<sup>2</sup>), belowground biomass (3.98 g/m<sup>2</sup>), total biomass (15.91 g/m<sup>2</sup>) and total carbon (7.96 g/m<sup>2</sup>). While lowest aboveground biomass (0.52 g/m<sup>2</sup>), belowground biomass (0.17 g/m<sup>2</sup>), total biomass (0.69 g/m<sup>2</sup>) and total carbon (0.34 g/m<sup>2</sup>) was exhibited by *Galium asperuloides*. At elevation E<sub>2</sub>, highest aboveground biomass (7.60 g/m<sup>2</sup>), belowground biomass (2.53 g/m<sup>2</sup>), total biomass (10.13 g/m<sup>2</sup>) and total carbon (5.07 g/m<sup>2</sup>) was recorded for *Salvia nubicola*, which was followed by *Iris nepalensis* with aboveground biomass (6.36 g/m<sup>2</sup>), belowground biomass (2.12 g/m<sup>2</sup>), total biomass (8.49 g/m<sup>2</sup>) and total carbon (4.24 g/m<sup>2</sup>). However *Silene griffithii* exhibited lowest aboveground biomass (0.39 g/m<sup>2</sup>), belowground biomass (0.13 g/m<sup>2</sup>), total biomass (0.51 g/m<sup>2</sup>) and total carbon (0.26 g/m<sup>2</sup>). At elevation E<sub>3</sub>, maximum aboveground biomass (6.96 g/m<sup>2</sup>), belowground biomass (2.32 g/m<sup>2</sup>), total biomass (9.29 g/m<sup>2</sup>) and total carbon (4.64 g/m<sup>2</sup>) was recorded for *Fragaria nubicola*, which was followed by *Halenia elliptica* with aboveground biomass (5.64 g/m<sup>2</sup>), belowground biomass (1.88 g/m<sup>2</sup>), total biomass (7.52 g/m<sup>2</sup>) and total carbon (3.76 g/m<sup>2</sup>). However *Mentha longifolia* exhibited lowest aboveground biomass (0.12 g/m<sup>2</sup>), belowground biomass (0.04 g/m<sup>2</sup>), total biomass (0.16 g/m<sup>2</sup>) and total carbon (0.08 g/m<sup>2</sup>) at E<sub>2</sub> (Table 66).

At E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.52 g/m<sup>2</sup> to 18.73 g/m<sup>2</sup>, 0.17 g/m<sup>2</sup> to 6.24 g/m<sup>2</sup>, 0.69 g/m<sup>2</sup> to 24.98 g/m<sup>2</sup> and 0.34 g/m<sup>2</sup> to 12.49 g/m<sup>2</sup> respectively. At E<sub>2</sub> aboveground biomass, belowground biomass total biomass varied from 0.39 g/m<sup>2</sup> to 7.60 g/m<sup>2</sup>, 0.13 g/m<sup>2</sup> to 2.53 g/m<sup>2</sup>, 0.51 g/m<sup>2</sup> to 10.13 g/m<sup>2</sup> and 0.26 g/m<sup>2</sup> to 5.07 g/m<sup>2</sup>, while aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.12 g/m<sup>2</sup> to 6.96 g/m<sup>2</sup>, 0.04 g/m<sup>2</sup> to 2.32 g/m<sup>2</sup>, 0.16 g/m<sup>2</sup> to 9.29 g/m<sup>2</sup> and 0.08 g/m<sup>2</sup> to 4.64 g/m<sup>2</sup> respectively at E<sub>3</sub> (Table 66).

**Table 66: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Kharsu Oak (*Q. semecarpifolia*) forests at different elevations**

| Forb Species                                  | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|-----------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                               | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation- E<sub>1</sub> (2300-2800 m)</b> |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                      | 1.82                        | 0.61              | 2.43               | 1.21                       |
| <i>Ainsliaea aptera</i>                       | 3.17                        | 1.06              | 4.23               | 2.12                       |
| <i>Ajuga bracteosa</i>                        | 2.70                        | 0.90              | 3.60               | 1.80                       |
| <i>Anaphalis busua</i>                        | 2.35                        | 0.78              | 3.14               | 1.57                       |
| <i>Anaphalis contorta</i>                     | 2.50                        | 0.83              | 3.33               | 1.67                       |
| <i>Androsace lanuginosa</i>                   | 1.98                        | 0.66              | 2.64               | 1.32                       |

|                                 |       |      |       |      |
|---------------------------------|-------|------|-------|------|
| <i>Anemone obtusiloba</i>       | 2.25  | 0.75 | 3.00  | 1.50 |
| <i>Arabis amplexicaulis</i>     | 4.04  | 1.35 | 5.39  | 2.70 |
| <i>Arisaema flavum</i>          | 3.09  | 1.03 | 4.12  | 2.06 |
| <i>Artemisia indica</i>         | 3.41  | 1.14 | 4.55  | 2.27 |
| <i>Artemisia roxburghiana</i>   | 3.09  | 1.03 | 4.12  | 2.06 |
| <i>Arundinella nepalensis</i>   | 3.05  | 1.02 | 4.06  | 2.03 |
| <i>Asplenium trichomanes</i>    | 6.48  | 2.16 | 8.64  | 4.32 |
| <i>Astilbe rivularis</i>        | 2.37  | 0.79 | 3.16  | 1.58 |
| <i>Bergenia ciliata</i>         | 1.55  | 0.52 | 2.06  | 1.03 |
| <i>Bergenia stracheyi</i>       | 1.15  | 0.38 | 1.53  | 0.77 |
| <i>Carduus nutans</i>           | 3.04  | 1.01 | 4.06  | 2.03 |
| <i>Carex breviculmis</i>        | 2.79  | 0.93 | 3.73  | 1.86 |
| <i>Carex remota</i>             | 2.06  | 0.69 | 2.75  | 1.37 |
| <i>Chenopodium opulifolium</i>  | 2.47  | 0.82 | 3.30  | 1.65 |
| <i>Cirsium wallichii</i>        | 2.32  | 0.77 | 3.09  | 1.55 |
| <i>Clinopodium vulgare</i>      | 2.10  | 0.70 | 2.80  | 1.40 |
| <i>Erigeron bellidioides</i>    | 2.11  | 0.70 | 2.82  | 1.41 |
| <i>Erigeron multicaulis</i>     | 1.69  | 0.56 | 2.26  | 1.13 |
| <i>Fragaria nubicola</i>        | 11.94 | 3.98 | 15.91 | 7.96 |
| <i>Galium asperuloides</i>      | 0.52  | 0.17 | 0.69  | 0.34 |
| <i>Girardinia diversifolia</i>  | 2.69  | 0.90 | 3.59  | 1.79 |
| <i>Gypsophila cerastioides</i>  | 1.43  | 0.48 | 1.91  | 0.96 |
| <i>Habenaria intermedia</i>     | 1.89  | 0.63 | 2.53  | 1.26 |
| <i>Impatiens scabrida</i>       | 1.53  | 0.51 | 2.04  | 1.02 |
| <i>Iris nepalensis</i>          | 1.54  | 0.51 | 2.05  | 1.03 |
| <i>Koeleria cristata</i>        | 1.41  | 0.47 | 1.89  | 0.94 |
| <i>Lamium album</i>             | 3.27  | 1.09 | 4.36  | 2.18 |
| <i>Lotus corniculatus</i>       | 2.58  | 0.86 | 3.44  | 1.72 |
| <i>Myriactis nepalensis</i>     | 2.09  | 0.70 | 2.79  | 1.39 |
| <i>Nasturtium officinale</i>    | 2.77  | 0.92 | 3.69  | 1.85 |
| <i>Nepeta laevigata</i>         | 2.35  | 0.78 | 3.13  | 1.57 |
| <i>Pedicularis hoffmeisteri</i> | 4.33  | 1.44 | 5.77  | 2.88 |
| <i>Phragmites communis</i>      | 2.79  | 0.93 | 3.72  | 1.86 |
| <i>Plectranthus japonicus</i>   | 2.84  | 0.95 | 3.78  | 1.89 |
| <i>Polygonatum cirrhifolium</i> | 6.25  | 2.08 | 8.33  | 4.17 |
| <i>Potentilla argyrophylla</i>  | 2.93  | 0.98 | 3.91  | 1.95 |
| <i>Primula denticulata</i>      | 2.31  | 0.77 | 3.07  | 1.54 |
| <i>Pteris cretica</i>           | 1.02  | 0.34 | 1.36  | 0.68 |
| <i>Ranunculus laetus</i>        | 1.17  | 0.39 | 1.56  | 0.78 |
| <i>Roscoeia purpurea</i>        | 4.13  | 1.38 | 5.51  | 2.76 |
| <i>Rumex nepalensis</i>         | 1.34  | 0.45 | 1.79  | 0.90 |
| <i>Saccharum filifolium</i>     | 8.61  | 2.87 | 11.48 | 5.74 |
| <i>Salvia lanata</i>            | 3.08  | 1.03 | 4.10  | 2.05 |
| <i>Salvia nubicola</i>          | 1.01  | 0.34 | 1.35  | 0.67 |
| <i>Scirpus roylei</i>           | 2.30  | 0.77 | 3.06  | 1.53 |
| <i>Scrophularia himalensis</i>  | 1.89  | 0.63 | 2.53  | 1.26 |
| <i>Selinum vaginatum</i>        | 9.49  | 3.16 | 12.66 | 6.33 |
| <i>Senecio alatus</i>           | 2.07  | 0.69 | 2.76  | 1.38 |

|                                               |               |              |               |               |
|-----------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Senecio chrysanthemoides</i>               | 8.00          | 2.67         | 10.67         | 5.34          |
| <i>Senecio nudicaulis</i>                     | 2.10          | 0.70         | 2.80          | 1.40          |
| <i>Serratula pallida</i>                      | 3.08          | 1.03         | 4.11          | 2.05          |
| <i>Silene griffithii</i>                      | 2.41          | 0.80         | 3.21          | 1.60          |
| <i>Smilacina purpurea</i>                     | 6.17          | 2.06         | 8.22          | 4.11          |
| <i>Solena amplexicaulis</i>                   | 2.90          | 0.97         | 3.87          | 1.93          |
| <i>Sonchus asper</i>                          | 2.75          | 0.92         | 3.66          | 1.83          |
| <i>Swertia cordata</i>                        | 1.56          | 0.52         | 2.08          | 1.04          |
| <i>Taraxacum officinale</i>                   | 3.81          | 1.27         | 5.09          | 2.54          |
| <i>Thymus linearis</i>                        | 2.89          | 0.96         | 3.85          | 1.93          |
| <i>Trifolium repens</i>                       | 1.98          | 0.66         | 2.64          | 1.32          |
| <i>Urtica dioica</i>                          | 2.31          | 0.77         | 3.08          | 1.54          |
| <i>Verbascum thapsus</i>                      | 2.57          | 0.86         | 3.43          | 1.72          |
| <i>Vicatia conifolia</i>                      | 2.11          | 0.70         | 2.82          | 1.41          |
| <i>Viola canescens</i>                        | 18.73         | 6.24         | 24.98         | 12.49         |
| <b>Total</b>                                  | <b>220.56</b> | <b>73.52</b> | <b>294.08</b> | <b>147.04</b> |
| <b>Elevation- E<sub>2</sub> (2800-3200 m)</b> |               |              |               |               |
| <i>Achyranthes bidentata</i>                  | 2.88          | 0.96         | 3.84          | 1.92          |
| <i>Adiantum venustum</i>                      | 0.94          | 0.31         | 1.25          | 0.62          |
| <i>Ainsliaea aptera</i>                       | 3.85          | 1.28         | 5.14          | 2.57          |
| <i>Ajuga bracteosa</i>                        | 2.62          | 0.87         | 3.49          | 1.75          |
| <i>Androsace rotundifolia</i>                 | 3.63          | 1.21         | 4.84          | 2.42          |
| <i>Anemone obtusiloba</i>                     | 1.16          | 0.39         | 1.55          | 0.77          |
| <i>Angelica glauca</i>                        | 1.49          | 0.50         | 1.99          | 1.00          |
| <i>Arabis amplexicaulis</i>                   | 1.45          | 0.48         | 1.94          | 0.97          |
| <i>Arisaema flavum</i>                        | 1.21          | 0.40         | 1.62          | 0.81          |
| <i>Artemisia indica</i>                       | 3.30          | 1.10         | 4.40          | 2.20          |
| <i>Artemisia roxburghiana</i>                 | 1.52          | 0.51         | 2.03          | 1.02          |
| <i>Arundinella nepalensis</i>                 | 1.07          | 0.36         | 1.42          | 0.71          |
| <i>Astilbe rivularis</i>                      | 0.84          | 0.28         | 1.12          | 0.56          |
| <i>Bergenia stracheyi</i>                     | 1.62          | 0.54         | 2.16          | 1.08          |
| <i>Bistorta amplexicaulis</i>                 | 1.83          | 0.61         | 2.45          | 1.22          |
| <i>Carduus nutans</i>                         | 2.13          | 0.71         | 2.84          | 1.42          |
| <i>Carex cardiolepis</i>                      | 1.62          | 0.54         | 2.16          | 1.08          |
| <i>Carex remota</i>                           | 1.65          | 0.55         | 2.20          | 1.10          |
| <i>Cirsium wallichii</i>                      | 4.00          | 1.33         | 5.33          | 2.66          |
| <i>Clinopodium vulgare</i>                    | 1.11          | 0.37         | 1.47          | 0.74          |
| <i>Erigeron bellidioides</i>                  | 0.47          | 0.16         | 0.63          | 0.31          |
| <i>Fagopyrum dibotrys</i>                     | 1.62          | 0.54         | 2.16          | 1.08          |
| <i>Fragaria nubicola</i>                      | 1.82          | 0.61         | 2.43          | 1.21          |
| <i>Galium aparine</i>                         | 1.28          | 0.43         | 1.71          | 0.86          |
| <i>Geranium lucidum</i>                       | 2.66          | 0.89         | 3.55          | 1.77          |
| <i>Geranium wallichianum</i>                  | 0.58          | 0.19         | 0.78          | 0.39          |
| <i>Gypsophila cerastioides</i>                | 2.63          | 0.88         | 3.50          | 1.75          |
| <i>Habenaria intermedia</i>                   | 0.89          | 0.30         | 1.18          | 0.59          |
| <i>Impatiens scabrida</i>                     | 3.40          | 1.13         | 4.53          | 2.26          |
| <i>Iris nepalensis</i>                        | 6.36          | 2.12         | 8.49          | 4.24          |
| <i>Lamium album</i>                           | 4.46          | 1.49         | 5.94          | 2.97          |

|                                               |               |              |               |              |
|-----------------------------------------------|---------------|--------------|---------------|--------------|
| <i>Lotus corniculatus</i>                     | 1.09          | 0.36         | 1.46          | 0.73         |
| <i>Myriactis nepalensis</i>                   | 1.20          | 0.40         | 1.60          | 0.80         |
| <i>Nepeta laevigata</i>                       | 1.02          | 0.34         | 1.36          | 0.68         |
| <i>Nepeta leucophylla</i>                     | 1.68          | 0.56         | 2.24          | 1.12         |
| <i>Pedicularis hoffmeisteri</i>               | 1.74          | 0.58         | 2.32          | 1.16         |
| <i>Phragmites communis</i>                    | 1.74          | 0.58         | 2.32          | 1.16         |
| <i>Polygonatum cirrhifolium</i>               | 2.56          | 0.85         | 3.41          | 1.70         |
| <i>Polygonatum multiflorum</i>                | 2.22          | 0.74         | 2.96          | 1.48         |
| <i>Polygonum nepalense</i>                    | 2.15          | 0.72         | 2.87          | 1.44         |
| <i>Potentilla argyrophylla</i>                | 3.73          | 1.24         | 4.97          | 2.49         |
| <i>Primula denticulata</i>                    | 1.73          | 0.58         | 2.31          | 1.16         |
| <i>Primula petiolaris</i>                     | 1.15          | 0.38         | 1.53          | 0.76         |
| <i>Pteris cretica</i>                         | 1.72          | 0.57         | 2.30          | 1.15         |
| <i>Rosularia rosulata</i>                     | 4.28          | 1.43         | 5.71          | 2.85         |
| <i>Salvia nubicola</i>                        | 7.60          | 2.53         | 10.13         | 5.07         |
| <i>Scirpus roylei</i>                         | 2.82          | 0.94         | 3.76          | 1.88         |
| <i>Selinum vaginatum</i>                      | 1.43          | 0.48         | 1.91          | 0.96         |
| <i>Senecio alatus</i>                         | 1.55          | 0.52         | 2.07          | 1.03         |
| <i>Senecio chrysanthemoides</i>               | 1.72          | 0.57         | 2.29          | 1.14         |
| <i>Senecio nudicaulis</i>                     | 1.12          | 0.37         | 1.49          | 0.75         |
| <i>Silene griffithii</i>                      | 0.39          | 0.13         | 0.51          | 0.26         |
| <i>Silene vulgaris</i>                        | 2.50          | 0.83         | 3.33          | 1.66         |
| <i>Smilacina purpurea</i>                     | 1.02          | 0.34         | 1.37          | 0.68         |
| <i>Stellaria media</i>                        | 1.36          | 0.45         | 1.82          | 0.91         |
| <i>Swertia cordata</i>                        | 1.34          | 0.45         | 1.79          | 0.89         |
| <i>Taraxacum officinale</i>                   | 0.92          | 0.31         | 1.23          | 0.62         |
| <i>Thalictrum foliolosum</i>                  | 2.76          | 0.92         | 3.69          | 1.84         |
| <i>Thymus linearis</i>                        | 3.61          | 1.20         | 4.82          | 2.41         |
| <i>Tragopogon gracilis</i>                    | 1.69          | 0.56         | 2.25          | 1.12         |
| <i>Urtica ardens</i>                          | 1.17          | 0.39         | 1.55          | 0.78         |
| <i>Valeriana jatamansi</i>                    | 1.06          | 0.35         | 1.41          | 0.71         |
| <i>Vicatia conifolia</i>                      | 1.18          | 0.39         | 1.57          | 0.79         |
| <i>Youngia japonica</i>                       | 0.89          | 0.30         | 1.18          | 0.59         |
| <b>Total</b>                                  | <b>130.24</b> | <b>43.41</b> | <b>173.65</b> | <b>86.83</b> |
| <b>Elevation- E<sub>3</sub> (3200-3600 m)</b> |               |              |               |              |
| <i>Ajuga bracteosa</i>                        | 2.87          | 0.96         | 3.83          | 1.92         |
| <i>Anaphalis contorta</i>                     | 1.52          | 0.51         | 2.02          | 1.01         |
| <i>Androsace sarmentosa</i>                   | 1.22          | 0.41         | 1.63          | 0.81         |
| <i>Anemone obtusiloba</i>                     | 1.39          | 0.46         | 1.85          | 0.93         |
| <i>Angelica glauca</i>                        | 2.63          | 0.88         | 3.51          | 1.76         |
| <i>Aquilegia fragrans</i>                     | 1.85          | 0.62         | 2.47          | 1.23         |
| <i>Artemisia indica</i>                       | 1.11          | 0.37         | 1.48          | 0.74         |
| <i>Artemisia roxburghiana</i>                 | 0.78          | 0.26         | 1.04          | 0.52         |
| <i>Aster molliusculus</i>                     | 4.16          | 1.39         | 5.55          | 2.78         |
| <i>Bergenia stracheyi</i>                     | 1.51          | 0.50         | 2.01          | 1.01         |
| <i>Bistorta amplexicaulis</i>                 | 0.78          | 0.26         | 1.04          | 0.52         |
| <i>Carduus nutans</i>                         | 2.13          | 0.71         | 2.83          | 1.42         |
| <i>Carex breviculmis</i>                      | 4.90          | 1.63         | 6.53          | 3.27         |

|                                  |               |              |               |              |
|----------------------------------|---------------|--------------|---------------|--------------|
| <i>Carex cardiolepis</i>         | 1.90          | 0.63         | 2.54          | 1.27         |
| <i>Carex remota</i>              | 1.51          | 0.50         | 2.02          | 1.01         |
| <i>Cirsium wallichii</i>         | 1.36          | 0.45         | 1.81          | 0.91         |
| <i>Clinopodium vulgare</i>       | 0.96          | 0.32         | 1.28          | 0.64         |
| <i>Corydalis govaniana</i>       | 1.05          | 0.35         | 1.39          | 0.70         |
| <i>Erigeron bellidioides</i>     | 1.70          | 0.57         | 2.27          | 1.13         |
| <i>Eriophorum comosum</i>        | 1.32          | 0.44         | 1.76          | 0.88         |
| <i>Fagopyrum dibotrys</i>        | 2.58          | 0.86         | 3.44          | 1.72         |
| <i>Fragaria nubicola</i>         | 6.96          | 2.32         | 9.29          | 4.64         |
| <i>Galium aparine</i>            | 1.25          | 0.42         | 1.66          | 0.83         |
| <i>Gypsophila cerastioides</i>   | 0.72          | 0.24         | 0.96          | 0.48         |
| <i>Halenia elliptica</i>         | 5.64          | 1.88         | 7.52          | 3.76         |
| <i>Impatiens scabrida</i>        | 1.61          | 0.54         | 2.14          | 1.07         |
| <i>Koeleria cristata</i>         | 3.07          | 1.02         | 4.09          | 2.05         |
| <i>Lotus corniculatus</i>        | 3.42          | 1.14         | 4.57          | 2.28         |
| <i>Mentha longifolia</i>         | 0.92          | 0.31         | 1.23          | 0.62         |
| <i>Pedicularis hoffmeisteri</i>  | 3.66          | 1.22         | 4.88          | 2.44         |
| <i>Podophyllum hexandrum</i>     | 0.12          | 0.04         | 0.16          | 0.08         |
| <i>Polygonatum cirrhifolium</i>  | 1.54          | 0.51         | 2.05          | 1.02         |
| <i>Polygonatum verticillatum</i> | 1.39          | 0.46         | 1.85          | 0.92         |
| <i>Primula denticulata</i>       | 1.31          | 0.44         | 1.75          | 0.88         |
| <i>Primula petiolaris</i>        | 1.70          | 0.57         | 2.26          | 1.13         |
| <i>Ranunculus hirtellus</i>      | 2.50          | 0.83         | 3.34          | 1.67         |
| <i>Rumex nepalensis</i>          | 0.59          | 0.20         | 0.79          | 0.39         |
| <i>Salvia nubicola</i>           | 1.96          | 0.65         | 2.62          | 1.31         |
| <i>Selinum candolli</i>          | 1.83          | 0.61         | 2.44          | 1.22         |
| <i>Selinum vaginatum</i>         | 1.81          | 0.60         | 2.41          | 1.21         |
| <i>Senecio chrysanthemoides</i>  | 1.66          | 0.55         | 2.21          | 1.10         |
| <i>Sibbaldia cuneata</i>         | 5.33          | 1.78         | 7.11          | 3.55         |
| <i>Silene griffithii</i>         | 1.16          | 0.39         | 1.55          | 0.77         |
| <i>Silene vulgaris</i>           | 1.31          | 0.44         | 1.75          | 0.88         |
| <i>Smilacina purpurea</i>        | 3.55          | 1.18         | 4.73          | 2.37         |
| <i>Sonchus asper</i>             | 1.86          | 0.62         | 2.49          | 1.24         |
| <i>Stellaria media</i>           | 1.31          | 0.44         | 1.75          | 0.87         |
| <i>Taraxacum officinale</i>      | 1.17          | 0.39         | 1.57          | 0.78         |
| <i>Thlaspi cochleariforme</i>    | 1.26          | 0.42         | 1.68          | 0.84         |
| <i>Thymus linearis</i>           | 1.27          | 0.42         | 1.70          | 0.85         |
| <i>Urtica ardens</i>             | 0.59          | 0.20         | 0.78          | 0.39         |
| <i>Valeriana pyrolaefolia</i>    | 1.54          | 0.51         | 2.05          | 1.03         |
| <i>Verbascum thapsus</i>         | 1.46          | 0.49         | 1.95          | 0.97         |
| <i>Vicatia coniifolia</i>        | 1.32          | 0.44         | 1.76          | 0.88         |
| <i>Youngia japonica</i>          | 2.16          | 0.72         | 2.88          | 1.44         |
| <b>Total</b>                     | <b>108.19</b> | <b>36.06</b> | <b>144.26</b> | <b>72.13</b> |

A perusal of the data exhibited in Table 67 reveals that among the elevations, highest aboveground biomass (231.95 g/m<sup>2</sup>), belowground biomass (77.32 g/m<sup>2</sup>), total biomass (309.26 g/m<sup>2</sup>) and total carbon (154.63 g/m<sup>2</sup>) exhibited at E<sub>1</sub> followed by E<sub>2</sub> with ABG

(188.35 g/m<sup>2</sup>), BGB (62.78 g/m<sup>2</sup>), TB (251.13 g/m<sup>2</sup>) and TC (125.57 g/m<sup>2</sup>). Least aboveground biomass (158.51 g/m<sup>2</sup>), belowground biomass (52.84 g/m<sup>2</sup>), total biomass (211.35 g/m<sup>2</sup>) and total carbon (105.67 g/m<sup>2</sup>) were observed at E<sub>3</sub> (Table 67).

Among individual forb species, at E<sub>1</sub>, maximum aboveground biomass (14.73 g/m<sup>2</sup>), belowground biomass (4.91 g/m<sup>2</sup>), total biomass (19.64 g/m<sup>2</sup>) and total carbon (9.82 g/m<sup>2</sup>) was recorded in *Anaphalis contorta*. Minimum aboveground biomass (0.77 g/m<sup>2</sup>), belowground biomass (0.26 g/m<sup>2</sup>), total biomass (1.03 g/m<sup>2</sup>) and total carbon (0.51 g/m<sup>2</sup>) at E<sub>1</sub> exhibited by *Thymus linearis* (Table 67).

At E<sub>2</sub>, *Eriophorum comosum* showed highest aboveground biomass (13.62 g/m<sup>2</sup>), belowground biomass (4.54 g/m<sup>2</sup>), total biomass (18.16 g/m<sup>2</sup>) and total carbon (9.08 g/m<sup>2</sup>). Whereas *Rumex nepalensis* exhibited lowest aboveground biomass, belowground, total biomass and total carbon of 0.68 g/m<sup>2</sup>, 0.23 g/m<sup>2</sup>, 0.90 g/m<sup>2</sup> and 0.45 g/m<sup>2</sup> respectively (Table 67).

At E<sub>3</sub>, *Anaphalis contorta* recorded with maximum aboveground biomass (14.96 g/m<sup>2</sup>), belowground biomass (4.98 g/m<sup>2</sup>), total biomass (19.94 g/m<sup>2</sup>) and highest total carbon (9.97 g/m<sup>2</sup>). However, lowest aboveground biomass (0.49 g/m<sup>2</sup>), belowground biomass (0.16 g/m<sup>2</sup>), total biomass (0.66 g/m<sup>2</sup>) and total carbon (0.33 g/m<sup>2</sup>) exhibited by *Podophyllum hexandrum* (Table 67).

Range of aboveground biomass, belowground biomass, total biomass and total carbon at E<sub>1</sub> varied from 0.77 g/m<sup>2</sup> to 14.73 g/m<sup>2</sup>, 0.26 g/m<sup>2</sup> to 4.91 g/m<sup>2</sup>, 1.03 g/m<sup>2</sup> to 19.64 g/m<sup>2</sup> and 0.51 g/m<sup>2</sup> to 9.82 g/m<sup>2</sup> respectively. At E<sub>2</sub> range of aboveground biomass as 0.67 g/m<sup>2</sup> to 13.62 g/m<sup>2</sup>, belowground biomass as 0.22 g/m<sup>2</sup> to 4.54 g/m<sup>2</sup>, total biomass as 0.90 g/m<sup>2</sup> to 18.16 g/m<sup>2</sup> and total carbon as 0.45 g/m<sup>2</sup> to 9.08 g/m<sup>2</sup> while at E<sub>3</sub> aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.49 g/m<sup>2</sup> to 14.96 g/m<sup>2</sup>, 0.16 g/m<sup>2</sup> to 4.98 g/m<sup>2</sup>, 0.66 g/m<sup>2</sup> to 19.94 g/m<sup>2</sup> and 0.33 g/m<sup>2</sup> to 9.97 g/m<sup>2</sup> respectively (Table 67).

**Table 67: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in Upper Oak-Fir forests at different elevations**

| Forb Species                             | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                          | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| Elevation - E <sub>1</sub> (2100-2600 m) |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                 | 5.40                        | 1.80              | 7.20               | 3.60                       |

|                                |       |      |       |      |
|--------------------------------|-------|------|-------|------|
| <i>Agrimonia pilosa</i>        | 4.57  | 1.52 | 6.09  | 3.05 |
| <i>Ainsliaea aptera</i>        | 1.02  | 0.34 | 1.35  | 0.68 |
| <i>Ajuga bracteosa</i>         | 2.91  | 0.97 | 3.88  | 1.94 |
| <i>Anaphalis contorta</i>      | 14.73 | 4.91 | 19.64 | 9.82 |
| <i>Androsace lanuginosa</i>    | 9.85  | 3.28 | 13.13 | 6.56 |
| <i>Anemone obtusiloba</i>      | 3.18  | 1.06 | 4.24  | 2.12 |
| <i>Arabis amplexicaulis</i>    | 2.08  | 0.69 | 2.77  | 1.39 |
| <i>Arctium lappa</i>           | 2.37  | 0.79 | 3.16  | 1.58 |
| <i>Arisaema flavum</i>         | 10.28 | 3.43 | 13.71 | 6.85 |
| <i>Artemisia roxburghiana</i>  | 11.13 | 3.71 | 14.83 | 7.42 |
| <i>Arundinella nepalensis</i>  | 3.27  | 1.09 | 4.36  | 2.18 |
| <i>Bergenia ciliata</i>        | 4.72  | 1.57 | 6.30  | 3.15 |
| <i>Carex remota</i>            | 6.01  | 2.00 | 8.02  | 4.01 |
| <i>Chenopodium opulifolium</i> | 1.75  | 0.58 | 2.34  | 1.17 |
| <i>Erigeron multicaulis</i>    | 6.46  | 2.15 | 8.62  | 4.31 |
| <i>Eriophorum comosum</i>      | 5.14  | 1.71 | 6.85  | 3.43 |
| <i>Fagopyrum dibotrys</i>      | 0.80  | 0.27 | 1.07  | 0.53 |
| <i>Fragaria nubicola</i>       | 7.43  | 2.48 | 9.90  | 4.95 |
| <i>Galium aparine</i>          | 4.05  | 1.35 | 5.40  | 2.70 |
| <i>Habenaria intermedia</i>    | 8.57  | 2.86 | 11.42 | 5.71 |
| <i>Impatiens scabrida</i>      | 10.08 | 3.36 | 13.44 | 6.72 |
| <i>Iris nepalensis</i>         | 5.69  | 1.90 | 7.58  | 3.79 |
| <i>Koeleria cristata</i>       | 3.82  | 1.27 | 5.09  | 2.55 |
| <i>Phragmites communis</i>     | 4.02  | 1.34 | 5.36  | 2.68 |
| <i>Plectranthus japonicus</i>  | 4.50  | 1.50 | 6.00  | 3.00 |
| <i>Polygonatum multiflorum</i> | 2.94  | 0.98 | 3.93  | 1.96 |
| <i>Polygonum nepalense</i>     | 1.04  | 0.35 | 1.38  | 0.69 |
| <i>Primula denticulata</i>     | 10.41 | 3.47 | 13.88 | 6.94 |
| <i>Pteris cretica</i>          | 1.09  | 0.36 | 1.45  | 0.72 |
| <i>Ranunculus hirtellus</i>    | 3.58  | 1.19 | 4.78  | 2.39 |
| <i>Roscoea purpurea</i>        | 1.81  | 0.60 | 2.41  | 1.21 |
| <i>Rumex nepalensis</i>        | 9.72  | 3.24 | 12.95 | 6.48 |
| <i>Salvia nubicola</i>         | 3.37  | 1.12 | 4.49  | 2.24 |
| <i>Scirpus roylei</i>          | 1.47  | 0.49 | 1.96  | 0.98 |
| <i>Smilacina purpurea</i>      | 1.69  | 0.56 | 2.25  | 1.12 |
| <i>Solena amplexicaulis</i>    | 3.64  | 1.21 | 4.85  | 2.42 |
| <i>Sonchus asper</i>           | 11.50 | 3.83 | 15.33 | 7.67 |
| <i>Swertia cordata</i>         | 5.12  | 1.71 | 6.83  | 3.41 |
| <i>Thymus linearis</i>         | 0.77  | 0.26 | 1.03  | 0.51 |
| <i>Trifolium repens</i>        | 6.11  | 2.04 | 8.14  | 4.07 |
| <i>Urtica ardens</i>           | 10.14 | 3.38 | 13.52 | 6.76 |
| <i>Valeriana jatamansi</i>     | 0.91  | 0.30 | 1.21  | 0.61 |
| <i>Verbascum thapsus</i>       | 3.77  | 1.26 | 5.03  | 2.52 |
| <i>Vicatia coniifolia</i>      | 5.77  | 1.92 | 7.69  | 3.85 |

|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Viola canescens</i>                         | 3.28          | 1.09         | 4.37          | 2.19          |
| <b>Total</b>                                   | <b>231.95</b> | <b>77.32</b> | <b>309.26</b> | <b>154.63</b> |
| <b>Elevation – E<sub>2</sub> (2600-3100 m)</b> |               |              |               |               |
| <i>Achyranthes bidentata</i>                   | 7.77          | 2.59         | 10.362        | 5.18          |
| <i>Adiantum venustum</i>                       | 1.200         | 0.40         | 1.59          | 0.80          |
| <i>Agrimonia pilosa</i>                        | 3.56          | 1.18         | 4.74          | 2.37          |
| <i>Ainsliaea aptera</i>                        | 2.88          | 0.96         | 3.84          | 1.92          |
| <i>Ajuga bracteosa</i>                         | 3.66          | 1.22         | 4.88          | 2.44          |
| <i>Anaphalis contorta</i>                      | 3.93          | 1.31         | 5.24          | 2.62          |
| <i>Androsace rotundifolia</i>                  | 0.81          | 0.27         | 1.08          | 0.54          |
| <i>Anemone obtusiloba</i>                      | 2.76          | 0.92         | 3.68          | 1.84          |
| <i>Angelica glauca</i>                         | 3.22          | 1.07         | 4.29          | 2.14          |
| <i>Arisaema flavum</i>                         | 2.58          | 0.86         | 3.44          | 1.72          |
| <i>Artemisia indica</i>                        | 3.91          | 1.30         | 5.22          | 2.61          |
| <i>Arundinella nepalensis</i>                  | 1.97          | 0.65         | 2.63          | 1.31          |
| <i>Asplenium trichomanes</i>                   | 6.95          | 2.31         | 9.27          | 4.63          |
| <i>Aster molliusculus</i>                      | 2.81          | 0.94         | 3.75          | 1.87          |
| <i>Bergenia ciliata</i>                        | 3.88          | 1.29         | 5.17          | 2.58          |
| <i>Bistorta amplexicaulis</i>                  | 9.07          | 3.02         | 12.10         | 6.05          |
| <i>Clinopodium vulgare</i>                     | 3.42          | 1.14         | 4.56          | 2.28          |
| <i>Erigeron multicaulis</i>                    | 4.26          | 1.42         | 5.69          | 2.84          |
| <i>Eriophorum comosum</i>                      | 13.62         | 4.54         | 18.16         | 9.08          |
| <i>Fagopyrum dibotrys</i>                      | 6.34          | 2.11         | 8.45          | 4.22          |
| <i>Fragaria nubicola</i>                       | 2.76          | 0.92         | 3.68          | 1.84          |
| <i>Galium aparine</i>                          | 3.13          | 1.04         | 4.18          | 2.09          |
| <i>Galium asperuloides</i>                     | 2.54          | 0.84         | 3.38          | 1.69          |
| <i>Habenaria intermedia</i>                    | 7.27          | 2.42         | 9.70          | 4.85          |
| <i>Heracleum candicans</i>                     | 0.76          | 0.25         | 1.01          | 0.51          |
| <i>Impatiens scabrida</i>                      | 7.72          | 2.57         | 10.30         | 5.15          |
| <i>Iris nepalensis</i>                         | 9.59          | 3.19         | 12.78         | 6.39          |
| <i>Koeleria cristata</i>                       | 3.22          | 1.07         | 4.29          | 2.15          |
| <i>Myriactis nepalensis</i>                    | 2.93          | 0.97         | 3.90          | 1.95          |
| <i>Phragmites communis</i>                     | 1.18          | 0.39         | 1.57          | 0.79          |
| <i>Plectranthus japonicus</i>                  | 3.63          | 1.21         | 4.84          | 2.42          |
| <i>Polygonatum multiflorum</i>                 | 6.26          | 2.08         | 8.34          | 4.17          |
| <i>Potentilla argyrophylla</i>                 | 3.08          | 1.02         | 4.11          | 2.05          |
| <i>Primula denticulata</i>                     | 3.75          | 1.25         | 5.00          | 2.50          |
| <i>Pteris cretica</i>                          | 2.23          | 0.74         | 2.98          | 1.49          |
| <i>Ranunculus hirtellus</i>                    | 3.67          | 1.22         | 4.90          | 2.45          |
| <i>Rumex nepalensis</i>                        | 0.67          | 0.22         | 0.90          | 0.45          |
| <i>Salvia nubicola</i>                         | 6.83          | 2.28         | 9.11          | 4.56          |
| <i>Selinum vaginatum</i>                       | 2.03          | 0.67         | 2.71          | 1.35          |
| <i>Senecio alatus</i>                          | 2.44          | 0.81         | 3.26          | 1.63          |
| <i>Smilacina purpurea</i>                      | 4.59          | 1.53         | 6.12          | 3.06          |



|                                                |               |              |               |               |
|------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Thalictrum foliolosum</i>                   | 5.87          | 1.95         | 7.83          | 3.91          |
| <i>Thymus linearis</i>                         | 3.46          | 1.15         | 4.62          | 2.31          |
| <i>Urtica ardens</i>                           | 6.19          | 2.06         | 8.26          | 4.13          |
| <i>Verbascum thapsus</i>                       | 3.75          | 1.25         | 5.01          | 2.50          |
| <b>Total</b>                                   | <b>188.35</b> | <b>62.78</b> | <b>251.13</b> | <b>125.57</b> |
| <b>Elevation – E<sub>3</sub> (3100-3500 m)</b> |               |              |               |               |
| <i>Anaphalis contorta</i>                      | 14.955        | 4.98         | 19.94         | 9.970         |
| <i>Androsace sarmentosa</i>                    | 6.49          | 2.16         | 8.65          | 4.32          |
| <i>Anemone obtusiloba</i>                      | 2.27          | 0.75         | 3.03          | 1.51          |
| <i>Angelica glauca</i>                         | 5.65          | 1.88         | 7.54          | 3.77          |
| <i>Aquilegia fragrans</i>                      | 12.88         | 4.29         | 17.19         | 8.59          |
| <i>Artemisia indica</i>                        | 3.31          | 1.10         | 4.42          | 2.21          |
| <i>Artemisia roxburghiana</i>                  | 5.971         | 1.99         | 7.96          | 3.98          |
| <i>Aster molliusculus</i>                      | 3.09          | 1.03         | 4.12          | 2.06          |
| <i>Bergenia stracheyi</i>                      | 7.73          | 2.57         | 10.36         | 5.15          |
| <i>Bistorta amplexicaulis</i>                  | 1.88          | 0.63         | 2.51          | 1.25          |
| <i>Carex remota</i>                            | 9.16          | 3.05         | 12.22         | 6.11          |
| <i>Corydalis govaniana</i>                     | 1.89          | 0.63         | 2.52          | 1.26          |
| <i>Eriophorum comosum</i>                      | 6.06          | 2.02         | 8.09          | 4.04          |
| <i>Fagopyrum dibotrys</i>                      | 2.38          | 0.79         | 3.18          | 1.59          |
| <i>Fragaria nubicola</i>                       | 5.27          | 1.75         | 7.03          | 3.51          |
| <i>Galium aparine</i>                          | 3.35          | 1.11         | 4.46          | 2.23          |
| <i>Gypsophila cerastioides</i>                 | 4.85          | 1.61         | 6.47          | 3.23          |
| <i>Heracleum candicans</i>                     | 2.80          | 0.93         | 3.73          | 1.86          |
| <i>Impatiens scabrida</i>                      | 3.34          | 1.11         | 4.45          | 2.22          |
| <i>Koeleria cristata</i>                       | 5.57          | 1.86         | 7.43          | 3.71          |
| <i>Lotus corniculatus</i>                      | 4.93          | 1.64         | 6.57          | 3.28          |
| <i>Podophyllum hexandrum</i>                   | 0.49          | 0.16         | 0.66          | 0.33          |
| <i>Polygonatum verticillatum</i>               | 3.18          | 1.06         | 4.24          | 2.12          |
| <i>Ranunculus hirtellus</i>                    | 5.31          | 1.77         | 7.08          | 3.54          |
| <i>Rumex nepalensis</i>                        | 11.15         | 3.71         | 14.87         | 7.43          |
| <i>Salvia nubicola</i>                         | 2.88          | 0.96         | 3.84          | 1.92          |
| <i>Selinum candolli</i>                        | 0.57          | 0.19         | 0.76          | 0.38          |
| <i>Silene griffithii</i>                       | 2.68          | 0.89         | 3.58          | 1.79          |
| <i>Smilacina purpurea</i>                      | 7.16          | 2.38         | 9.55          | 4.77          |
| <i>Stellaria media</i>                         | 5.55          | 1.85         | 7.41          | 3.70          |
| <i>Urtica ardens</i>                           | 2.19          | 0.73         | 2.92          | 1.46          |
| <i>Valeriana pyrolaefolia</i>                  | 3.36          | 1.12         | 4.49          | 2.24          |
| <b>Total</b>                                   | <b>158.51</b> | <b>52.84</b> | <b>211.35</b> | <b>105.67</b> |

In upper moist temperate deciduous forests among the elevations, at E<sub>1</sub> highest aboveground biomass (275.91 g/m<sup>2</sup>), belowground biomass (91.97 g/m<sup>2</sup>), total biomass

(367.88 g/m<sup>2</sup>) and total carbon (183.94 g/m<sup>2</sup>) was recorded followed by E<sub>2</sub> with aboveground biomass as 257.64 g/m<sup>2</sup>, belowground biomass as 85.88 g/m<sup>2</sup>, total biomass as 343.52 g/m<sup>2</sup> and total carbon as 171.76 g/m<sup>2</sup>. Least aboveground biomass (239.64 g/m<sup>2</sup>), belowground biomass (79.88 g/m<sup>2</sup>), total biomass (319.52 g/m<sup>2</sup>) and total carbon (159.76 g/m<sup>2</sup>) was recorded at E<sub>3</sub> (Table 68).

With respect to individual forb species, at E<sub>1</sub> highest values of aboveground biomass (23.00 g/m<sup>2</sup>), belowground biomass (7.67 g/m<sup>2</sup>), total biomass (30.66 g/m<sup>2</sup>) and total carbon (15.33 g/m<sup>2</sup>) was recorded for *Fragaria nubicola*, followed by *Anaphalis contorta* with aboveground biomass (21.79 g/m<sup>2</sup>), belowground biomass (7.26 g/m<sup>2</sup>), total biomass (29.05 g/m<sup>2</sup>) and total carbon (14.53 g/m<sup>2</sup>). While lowest aboveground biomass (0.79 g/m<sup>2</sup>), belowground biomass (0.26 g/m<sup>2</sup>), total biomass (1.05 g/m<sup>2</sup>) and total carbon (0.53 g/m<sup>2</sup>) was recorded for *Adiantum venustum* at E<sub>1</sub>. At E<sub>2</sub>, *Carex remota* exhibited highest aboveground biomass (29.43 g/m<sup>2</sup>), belowground biomass (9.81 g/m<sup>2</sup>), total biomass (39.24 g/m<sup>2</sup>) and total carbon (19.62 g/m<sup>2</sup>), followed by *Bergenia stracheyi* with AGB, BGB, TB and TC as 24.72 g/m<sup>2</sup>, 8.24 g/m<sup>2</sup>, 32.96 g/m<sup>2</sup> and 16.48 g/m<sup>2</sup> respectively. Whereas *Polygonatum cirrhifolium* was recorded for lowest aboveground biomass (0.96 g/m<sup>2</sup>), belowground biomass (0.32 g/m<sup>2</sup>), total biomass (1.27 g/m<sup>2</sup>) and total carbon (0.64 g/m<sup>2</sup>). At E<sub>3</sub> highest aboveground biomass (23.60 g/m<sup>2</sup>), belowground biomass (7.87 g/m<sup>2</sup>), total biomass (31.47 g/m<sup>2</sup>) and total carbon (15.73 g/m<sup>2</sup>) was recorded for *Anaphalis contorta*, that descended in *Taraxacum officinale* with aboveground biomass, belowground biomass, total biomass and total carbon as 15.88 g/m<sup>2</sup>, 5.29 g/m<sup>2</sup>, 21.18 g/m<sup>2</sup> and 10.59 g/m<sup>2</sup> respectively while *Cirsium wallichii* exhibited lowest aboveground biomass (0.94 g/m<sup>2</sup>), belowground biomass (0.31 g/m<sup>2</sup>), total biomass (1.26 g/m<sup>2</sup>) and total carbon (0.63 g/m<sup>2</sup>) at E<sub>3</sub> (Table 68).

At E<sub>1</sub>, aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.79 g/m<sup>2</sup> to 23.00 g/m<sup>2</sup>, 0.26 g/m<sup>2</sup> to 7.67 g/m<sup>2</sup>, 1.05 g/m<sup>2</sup> to 30.66 g/m<sup>2</sup> and 0.53 g/m<sup>2</sup> to 15.33 g/m<sup>2</sup> respectively. At E<sub>2</sub> aboveground biomass, belowground biomass total biomass varied from 0.96 g/m<sup>2</sup> to 29.43 g/m<sup>2</sup>, 0.32 g/m<sup>2</sup> to 9.81 g/m<sup>2</sup>, 1.27 g/m<sup>2</sup> to 39.24 g/m<sup>2</sup> and 0.64 g/m<sup>2</sup> to 19.62 g/m<sup>2</sup>, while aboveground biomass, belowground biomass, total biomass and total carbon ranged from 0.94 g/m<sup>2</sup> to 23.60 g/m<sup>2</sup>, 0.31 g/m<sup>2</sup> to 7.87 g/m<sup>2</sup>, 1.26 g/m<sup>2</sup> to 31.47 g/m<sup>2</sup> and 0.63 g/m<sup>2</sup> to 15.73 g/m<sup>2</sup> respectively at E<sub>3</sub> (Table 68).

**Table 68: Aboveground (AGB), belowground (BGB), total biomass (TB) and total carbon (TC) of forbs in upper moist temperate deciduous forests at different elevations**

| Forb Species                                   | Biomass (g/m <sup>2</sup> ) |                   |                    | Carbon (g/m <sup>2</sup> ) |
|------------------------------------------------|-----------------------------|-------------------|--------------------|----------------------------|
|                                                | Aboveground (AGB)           | Belowground (BGB) | Total biomass (TB) | Total (TC)                 |
| <b>Elevation - E<sub>1</sub> (1700-2300 m)</b> |                             |                   |                    |                            |
| <i>Adiantum venustum</i>                       | 0.79                        | 0.26              | 1.05               | 0.53                       |
| <i>Ajuga bracteosa</i>                         | 8.08                        | 2.69              | 10.77              | 5.38                       |
| <i>Anaphalis contorta</i>                      | 21.79                       | 7.26              | 29.05              | 14.53                      |
| <i>Androsace lanuginosa</i>                    | 3.44                        | 1.15              | 4.59               | 2.29                       |
| <i>Androsace rotundifolia</i>                  | 3.46                        | 1.15              | 4.61               | 2.31                       |
| <i>Arctium lappa</i>                           | 12.33                       | 4.11              | 16.45              | 8.22                       |
| <i>Asplenium trichomanes</i>                   | 6.30                        | 2.10              | 8.40               | 4.20                       |
| <i>Astilbe rivularis</i>                       | 3.71                        | 1.24              | 4.94               | 2.47                       |
| <i>Bergenia stracheyi</i>                      | 4.46                        | 1.49              | 5.94               | 2.97                       |
| <i>Carduus nutans</i>                          | 6.41                        | 2.14              | 8.54               | 4.27                       |
| <i>Carex remota</i>                            | 6.86                        | 2.29              | 9.15               | 4.57                       |
| <i>Chenopodium opulifolium</i>                 | 9.57                        | 3.19              | 12.76              | 6.38                       |
| <i>Duchesnea indica</i>                        | 3.51                        | 1.17              | 4.68               | 2.34                       |
| <i>Erigeron bellidioides</i>                   | 7.26                        | 2.42              | 9.68               | 4.84                       |
| <i>Fragaria nubicola</i>                       | 23.00                       | 7.67              | 30.66              | 15.33                      |
| <i>Galium aparine</i>                          | 5.03                        | 1.68              | 6.70               | 3.35                       |
| <i>Geranium spp</i>                            | 4.63                        | 1.54              | 6.17               | 3.09                       |
| <i>Koeleria cristata</i>                       | 4.84                        | 1.61              | 6.45               | 3.23                       |
| <i>Lamium album</i>                            | 3.92                        | 1.31              | 5.22               | 2.61                       |
| <i>Mentha longifolium</i>                      | 4.98                        | 1.66              | 6.64               | 3.32                       |
| <i>Nasturtium officinale</i>                   | 1.26                        | 0.42              | 1.69               | 0.84                       |
| <i>Nepeta leucophylla</i>                      | 5.18                        | 1.73              | 6.90               | 3.45                       |
| <i>Phragmites communis</i>                     | 7.30                        | 2.43              | 9.74               | 4.87                       |
| <i>Polygonatum verticillatum</i>               | 5.18                        | 1.73              | 6.90               | 3.45                       |
| <i>Potentilla leschenaultiana</i>              | 4.93                        | 1.64              | 6.58               | 3.29                       |
| <i>Roscoea purpurea</i>                        | 4.38                        | 1.46              | 5.83               | 2.92                       |
| <i>Salvia nubicola</i>                         | 9.04                        | 3.01              | 12.05              | 6.03                       |
| <i>Scirpus roylei</i>                          | 5.31                        | 1.77              | 7.08               | 3.54                       |
| <i>Senecio alatus</i>                          | 15.25                       | 5.08              | 20.33              | 10.17                      |
| <i>Senecio chrysanthemoides</i>                | 3.78                        | 1.26              | 5.04               | 2.52                       |
| <i>Silene griffithii</i>                       | 5.22                        | 1.74              | 6.96               | 3.48                       |
| <i>Silene vulgaris</i>                         | 6.48                        | 2.16              | 8.63               | 4.32                       |
| <i>Smilacina purpurea</i>                      | 5.10                        | 1.70              | 6.80               | 3.40                       |
| <i>Sonchus asper</i>                           | 6.31                        | 2.10              | 8.41               | 4.21                       |
| <i>Taraxacum officinale</i>                    | 6.31                        | 2.10              | 8.41               | 4.20                       |
| <i>Thalictrum foliolosum</i>                   | 3.58                        | 1.19              | 4.77               | 2.39                       |

|                                                 |               |              |               |               |
|-------------------------------------------------|---------------|--------------|---------------|---------------|
| <i>Thymus linearis</i>                          | 3.58          | 1.19         | 4.77          | 2.39          |
| <i>Valeriana jatamansi</i>                      | 3.59          | 1.20         | 4.79          | 2.39          |
| <i>Verbascum thapsus</i>                        | 7.00          | 2.33         | 9.33          | 4.67          |
| <i>Vicatia coniifolia</i>                       | 5.88          | 1.96         | 7.85          | 3.92          |
| <i>Viola canescens</i>                          | 12.61         | 4.20         | 16.82         | 8.41          |
| <i>Youngia japonica</i>                         | 4.30          | 1.43         | 5.73          | 2.87          |
| <b>Total</b>                                    | <b>275.91</b> | <b>91.97</b> | <b>367.88</b> | <b>183.94</b> |
| <b>Elevation – E<sub>2</sub> (2300-2900 m)</b>  |               |              |               |               |
| <i>Achyranthes bidentata</i>                    | 14.61         | 4.87         | 19.47         | 9.74          |
| <i>Adiantum venustum</i>                        | 4.38          | 1.46         | 5.84          | 2.92          |
| <i>Agrimonia pilosa</i>                         | 14.61         | 4.87         | 19.49         | 9.74          |
| <i>Ainsliaea aptera</i>                         | 21.69         | 7.23         | 28.93         | 14.46         |
| <i>Anaphalis contorta</i>                       | 5.67          | 1.89         | 7.56          | 3.78          |
| <i>Anemone obtusiloba</i>                       | 3.66          | 1.22         | 4.89          | 2.44          |
| <i>Arisaema flavum</i>                          | 8.63          | 2.88         | 11.51         | 5.76          |
| <i>Bergenia stracheyi</i>                       | 24.72         | 8.24         | 32.96         | 16.48         |
| <i>Carex cardiolepis</i>                        | 1.22          | 0.41         | 1.62          | 0.81          |
| <i>Carex remota</i>                             | 29.43         | 9.81         | 39.24         | 19.62         |
| <i>Clinopodium vulgare</i>                      | 5.01          | 1.67         | 6.68          | 3.34          |
| <i>Erigeron bellidioides</i>                    | 7.22          | 2.41         | 9.63          | 4.82          |
| <i>Erigeron multicaulis</i>                     | 4.70          | 1.57         | 6.27          | 3.13          |
| <i>Fagopyrum dibotrys</i>                       | 4.05          | 1.35         | 5.40          | 2.70          |
| <i>Heracleum candicans</i>                      | 3.78          | 1.26         | 5.04          | 2.52          |
| <i>Iris nepalensis</i>                          | 3.12          | 1.04         | 4.16          | 2.08          |
| <i>Polygonatum cirrhifolium</i>                 | 0.96          | 0.32         | 1.27          | 0.64          |
| <i>Polygonatum verticillatum</i>                | 15.87         | 5.29         | 21.16         | 10.58         |
| <i>Primula petiolaris</i>                       | 13.97         | 4.66         | 18.63         | 9.31          |
| <i>Rumex nepalensis</i>                         | 5.95          | 1.98         | 7.93          | 3.96          |
| <i>Salvia nubicola</i>                          | 2.90          | 0.97         | 3.87          | 1.94          |
| <i>Scirpus roylei</i>                           | 3.16          | 1.05         | 4.22          | 2.11          |
| <i>Senecio chrysanthemoides</i>                 | 8.80          | 2.93         | 11.73         | 5.86          |
| <i>Senecio nudicaulis</i>                       | 3.80          | 1.27         | 5.06          | 2.53          |
| <i>Silene griffithii</i>                        | 4.00          | 1.33         | 5.33          | 2.67          |
| <i>Smilacina purpurea</i>                       | 4.20          | 1.40         | 5.59          | 2.80          |
| <i>Swertia cordata</i>                          | 7.88          | 2.63         | 10.51         | 5.26          |
| <i>Thalictrum foliolosum</i>                    | 23.73         | 7.91         | 31.64         | 15.82         |
| <i>Tragopogon gracilis</i>                      | 5.92          | 1.97         | 7.90          | 3.95          |
| <b>Total</b>                                    | <b>257.64</b> | <b>85.88</b> | <b>343.52</b> | <b>171.76</b> |
| <b>Elevation – E<sub>3</sub> (2900 -3500 m)</b> |               |              |               |               |
| <i>Agrimonia pilosa</i>                         | 3.29          | 1.10         | 4.38          | 2.19          |
| <i>Ainsliaea aptera</i>                         | 4.69          | 1.56         | 6.25          | 3.13          |
| <i>Ajuga bracteosa</i>                          | 4.65          | 1.55         | 6.20          | 3.10          |
| <i>Anaphalis contorta</i>                       | 23.60         | 7.87         | 31.47         | 15.73         |
| <i>Androsace sarmentosa</i>                     | 3.12          | 1.04         | 4.15          | 2.08          |

|                                  |               |              |               |               |
|----------------------------------|---------------|--------------|---------------|---------------|
| <i>Anemone obtusiloba</i>        | 5.28          | 1.76         | 7.03          | 3.52          |
| <i>Angelica glauca</i>           | 7.93          | 2.64         | 10.58         | 5.29          |
| <i>Artemisia roxburghiana</i>    | 9.40          | 3.13         | 12.53         | 6.27          |
| <i>Bergenia stracheyi</i>        | 4.50          | 1.50         | 6.00          | 3.00          |
| <i>Carduus nutans</i>            | 4.94          | 1.65         | 6.59          | 3.30          |
| <i>Carex remota</i>              | 4.25          | 1.42         | 5.67          | 2.83          |
| <i>Cirsium wallichii</i>         | 0.94          | 0.31         | 1.26          | 0.63          |
| <i>Clinopodium vulgare</i>       | 2.63          | 0.88         | 3.51          | 1.75          |
| <i>Eriophorum comosum</i>        | 13.84         | 4.61         | 18.46         | 9.23          |
| <i>Fragaria nubicola</i>         | 4.56          | 1.52         | 6.08          | 3.04          |
| <i>Gypsophila cerastioides</i>   | 5.39          | 1.80         | 7.18          | 3.59          |
| <i>Halenia elliptica</i>         | 13.02         | 4.34         | 17.36         | 8.68          |
| <i>Heracleum candicans</i>       | 4.15          | 1.38         | 5.53          | 2.76          |
| <i>Impatiens scabrada</i>        | 3.67          | 1.22         | 4.90          | 2.45          |
| <i>Koeleria cristata</i>         | 13.69         | 4.56         | 18.26         | 9.13          |
| <i>Lotus corniculatus</i>        | 3.38          | 1.13         | 4.50          | 2.25          |
| <i>Pedicularis hoffmeisteri</i>  | 5.62          | 1.87         | 7.49          | 3.75          |
| <i>Polygonatum verticillatum</i> | 15.03         | 5.01         | 20.04         | 10.02         |
| <i>Ranunculus hirtellus</i>      | 5.07          | 1.69         | 6.76          | 3.38          |
| <i>Salvia nubicola</i>           | 4.55          | 1.52         | 6.07          | 3.04          |
| <i>Selinum candolli</i>          | 7.99          | 2.66         | 10.66         | 5.33          |
| <i>Senecio chrysanthemoides</i>  | 8.09          | 2.70         | 10.79         | 5.40          |
| <i>Sibbaldia cuneata</i>         | 7.84          | 2.61         | 10.46         | 5.23          |
| <i>Silene vulgaris</i>           | 6.85          | 2.28         | 9.14          | 4.57          |
| <i>Smilacina purpurea</i>        | 3.84          | 1.28         | 5.13          | 2.56          |
| <i>Taraxacum officinale</i>      | 15.88         | 5.29         | 21.18         | 10.59         |
| <i>Thlaspi cochleariforme</i>    | 4.18          | 1.39         | 5.58          | 2.79          |
| <i>Thymus linearis</i>           | 3.04          | 1.01         | 4.05          | 2.03          |
| <i>Valeriana pyrolaefolia</i>    | 5.74          | 1.91         | 7.66          | 3.83          |
| <i>Vicatia coniifolia</i>        | 2.29          | 0.76         | 3.05          | 1.52          |
| <i>Youngia japonica</i>          | 2.69          | 0.90         | 3.58          | 1.79          |
| <b>Total</b>                     | <b>239.64</b> | <b>79.88</b> | <b>319.52</b> | <b>159.76</b> |

Nine different forest types at their three elevations were found to have significantly different total biomass (aboveground + belowground) and total carbon in their forb component. The total (mean) herb biomass varied in the range from 204.00 to 409.16 g/m<sup>2</sup>. It is evident from the Table 69 that maximum total forb biomass was recorded in Deodar forests (409.16 g/m<sup>2</sup>), which was followed by western mixed coniferous forests and moist temperate upper deciduous forests with total biomass of 350.25 g/m<sup>2</sup> and 343.64 g/m<sup>2</sup> respectively. However lowest total biomass was recorded from Kharsu Oak forests (204.00 g/m<sup>2</sup>). Total forb biomass decreased in different forests in the order: Deodar Forests > western mixed coniferous forests > Moist temperate upper deciduous forests > Moist temperate lower

deciduous forests > Moru Oak forests > Kail forests> Ban Oak forests > Upper Oak- Fir forests > Kharsu Oak forests. Among three elevations, highest values of total biomass of forbs was recorded at elevation E<sub>1</sub> (356.18 g/m<sup>2</sup>) followed by E<sub>2</sub> (303.62 g/m<sup>2</sup>) and least total biomass was observed at elevation E<sub>3</sub> (258.45 g/m<sup>2</sup>), thereby showing that forb biomass decreased with an increase in elevation. Forb carbon followed similar trend that of forb biomass.

Likewise, mean total forb biomass carbon among forest types varied significantly. Maximum total carbon in forbs was observed in Deodar forests (204.58 g/m<sup>2</sup>) which decreased to 175.13 g/m<sup>2</sup> in western mixed coniferous forests. While lowest total carbon was recorded in Kharsu Oak forests as 102.00 g/m<sup>2</sup>. With respect to elevation maximum total carbon (178.09 g/m<sup>2</sup>) was recorded at elevation E<sub>1</sub> followed by elevation E<sub>2</sub> (151.81 g/m<sup>2</sup>), while least was recorded at elevation E<sub>3</sub> (129.22 g/m<sup>2</sup>) showing similar trend as the total biomass of forbs (Table 69).

**Table 69: Change in total biomass (TB) and total carbon (TC) of forbs among forests (F) and elevations (E)**

| Forest Types (F) | Total Biomass (g/m <sup>2</sup> ) at different elevations (E) |                |                | Mean          | Total Carbon (g/m <sup>2</sup> ) at different elevations (E) |                |                | Mean          |
|------------------|---------------------------------------------------------------|----------------|----------------|---------------|--------------------------------------------------------------|----------------|----------------|---------------|
|                  | E <sub>1</sub>                                                | E <sub>2</sub> | E <sub>3</sub> |               | E <sub>1</sub>                                               | E <sub>2</sub> | E <sub>3</sub> |               |
| <b>FT-1</b>      | 315.57                                                        | 264.28         | 247.50         | <b>275.78</b> | 157.79                                                       | 132.14         | 123.75         | <b>137.89</b> |
| <b>FT-2</b>      | 333.96                                                        | 300.30         | 262.84         | <b>299.03</b> | 166.98                                                       | 150.15         | 131.42         | <b>149.52</b> |
| <b>FT-3</b>      | 463.04                                                        | 443.70         | 320.73         | <b>409.16</b> | 231.52                                                       | 221.85         | 160.36         | <b>204.58</b> |
| <b>FT-4</b>      | 403.38                                                        | 335.83         | 311.55         | <b>350.25</b> | 201.69                                                       | 167.92         | 155.78         | <b>175.13</b> |
| <b>FT-5</b>      | 382.76                                                        | 339.05         | 244.99         | <b>322.27</b> | 191.38                                                       | 169.52         | 122.50         | <b>161.13</b> |
| <b>FT-6</b>      | 335.71                                                        | 281.14         | 263.29         | <b>293.38</b> | 167.86                                                       | 140.57         | 131.65         | <b>146.69</b> |
| <b>FT-7</b>      | 294.08                                                        | 173.65         | 144.26         | <b>204.00</b> | 147.04                                                       | 86.83          | 72.13          | <b>102.00</b> |
| <b>FT-8</b>      | 309.26                                                        | 251.13         | 211.35         | <b>257.25</b> | 154.63                                                       | 125.57         | 105.67         | <b>128.62</b> |
| <b>FT-9</b>      | 367.88                                                        | 343.52         | 319.52         | <b>343.64</b> | 183.94                                                       | 171.76         | 159.76         | <b>171.82</b> |
| <b>Mean</b>      | <b>356.18</b>                                                 | <b>303.62</b>  | <b>258.45</b>  |               | <b>178.09</b>                                                | <b>151.81</b>  | <b>129.22</b>  |               |
|                  | C.D. 0.05                                                     |                |                |               | C.D. 0.05                                                    |                |                |               |
|                  |                                                               | <b>C.D.</b>    | <b>SE (d)</b>  |               |                                                              | <b>C.D.</b>    | <b>SE (d)</b>  |               |
|                  | <b>F</b>                                                      | 14.36          | 7.13           |               | <b>F</b>                                                     | 7.18           | 3.57           |               |
|                  | <b>E</b>                                                      | 8.29           | 4.12           |               | <b>E</b>                                                     | 4.15           | 2.06           |               |
|                  | <b>F X E</b>                                                  | 24.86          | 12.36          |               | <b>F X E</b>                                                 | 12.43          | 7.18           |               |

Where: FT-1 = Ban Oak forests, FT-2 = Moru Oak forests, FT-3 = Deodar forests, FT-4 = Western mixed coniferous forests, FT-5 = Moist temperate lower deciduous forests, FT-6 = Kail forests, FT-7 = Kharsu Oak forests, FT-8 = Upper Oak-Fir forests and FT-9 = Moist temperate upper deciduous forests and, for each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different.

Herbaceous flora is a dynamic layer in forest stratum (Gilliam and Christensen 1986) although it contributes only a small proportion to total forest biomass but plays an important role in ecological characteristics (Whittaker 1966). The quantification of understory vegetation is essential for understanding the forest dynamics and ecological processes like, providing habitat to many organisms, influence on nutrient cycling and energy flow, resources availability and contribution to plant diversity (Moore and Allen 1999; Muir *et al.* 2002; Scheller and Mladenoff 2002; Kerns and Ohmann 2004). Understory communities of plants determines the carrying capacity, reproduction, survival rate and fitness of the tree layer (Leslie *et al.* 1984; Gonzalez-Fernandez *et al.* 1998; Ponder 2008) and are also vital for mycorrhizal fungi, invertebrates and their predators (Muir *et al.* 2002). Thus, their complimentary role in forests makes the vegetation a potential store house of carbon which can have direct influence on local, regional and even global climate, particularly on air temperature and humidity. In any vegetation the herbaceous layer accounts for more species than any other vegetal layer and thus is important in terms of biodiversity. Conservation of species diversity is one of the principles of sustainable forestry for maintaining ecological values of forests (Crow 1989; Hunter 1990; Burton *et al.* 1992).

In the present study herbaceous biomass was estimated in different forest types at different elevations in Himalayan moist temperate forest zone and it emerged from the result that there was significant difference in forb biomass among forests. Such difference in forbs biomass among forest communities at different elevations can be related to corresponding difference in species composition and their growth characters (density and basal area) as discussed in section two of this chapter. Many workers have reported such results with different reasons like, soil moisture availability for optimum nutrient flow in soil-plant system, air temperature, soil structure, aspect, slope, altitude, characters of overgrowing tree species, reduced light availability under closed canopies etc. Singh and Yadava 1974; Dass 1995; Dalai 1997; Rao *et al.* 1998; Guleria *et al.* 1999; Kumar 2001; Mutanga *et al.* 2004; Dutt and Gupta 2005; Kunhikannan 2008; Mahmoud 2009; Kukshal *et al.* 2009; Masoodi 2010; Kharkwal and Rawat 2010; Gupta and Bandhna 2011; Joshi and Pant 2012; Thokchom and Yadava 2017). Many studies have pointed out that overstory age is the major factor affecting the understory species composition and diversity (Peterken 1993; Nyland 1996; Kiyono 1990; Ito *et al.* 2003). Thinning, which modifies the light environment in the short-term, is another major factor controlling understory vegetation (Kiyono 1990; Thomas *et al.* 1999; Son *et al.* 2004). The spatial arrangement of tree stands in relation to potential

colonising sources is reported to be crucial for biodiversity conservation (Moore and Allen 1999; Sarlov-Herlin and Fly 2000), while topography will often also affect the understory composition (Ito *et al.* 2003). The production of any ecological system is governed by climatic conditions, edaphic characteristics, phenology and floristic diversity (Bahar 2003). Productivity and nutrient relationship of herbaceous plants often indicate the soil fertility (Gilliam 1988) that depends upon elevation gradient including slope, orientation and climatic regime (Perez-Corona *et al.* 1998).

The type of forb species and their individuals varied in nine forests. Floral species diversity and genetic diversity of the species in these forests is one of the reasons for difference in their biomass production. Booth and Grime (2003), Vellend and Geber (2005), Vellend (2006) and Crawford and Rudgers (2012) opined that it is possible that genetic diversity and species diversity may interact to influence community structure and ecosystem functioning. Biomass production is also controlled by the turnover in species (Cottingham *et al.* 2001).

In the present study, there was decrease in biomass production of forbs with increase in elevation. This decrease in biomass of forbs with increasing elevation may be because of changing in environmental conditions along the altitude (Restetter *et al.* 2004; Jamwal and Uniyal 2008; Carolina and Frangi 2000; Sevgi and Teciman 2008; Jun *et al.* 2012) and the reduced growing period. Similar variations in biomass along the elevation in different vegetation types across the Indian Himalayan region have been reported by Sharma (2012) Farooq 2012; Mahato (2013) and Singh (2014) and, elsewhere in the other parts of the world by Perez and Frangi (2000) and Aarcher (1990). Other studies on mountain ecosystems has also found a monotonous decrease of biomass with elevation, in tropical Asia (Kitayama and Aiba 2002) and the Andes (Girardin *et al.* 2010; Moser *et al.* 2011). The decrease in biomass (aboveground and belowground) productivity with increase in altitude can be related to difference in climate, slope and moisture (Sundriyal *et al.* 1987).

In the present study total biomass of shrubs in different forests at different elevations varied from 144.26 (FT-5 at E<sub>3</sub>) - 463.04 (FT-1 at E<sub>1</sub>) g/m<sup>2</sup> and total carbon in forbs from 72.13 (FT-5 at E<sub>3</sub>) to 231.52 (FT-1 at E<sub>1</sub>) g/m<sup>2</sup>. The biomass production of vegetation is an expression of the production potential of its constituent species in a set of environment, density and types of species, climatic and edaphic factors, their management and age (Swamy and Puri 2005; Oelbermann 2002; Nair *et al.* 2009; Graham *et al.* 1992; Niu and Duiker



2006; Jana *et al.* 2009; Dash and Behera 2013; Liu *et al.* 2015; Yadav *et al.* 2016). In other words, production is diversity dependent, more diverse communities have been shown to have higher and more temporally stable ecosystem functioning than less diverse ones, suggesting they should have a consistently higher level of functioning over time (Allan *et al.* 2011). Soil condition and phenology (Gupta and Singh 1981), better root net-working, efficient and economical use of limited resources, higher photosynthetic activities, leaf area index, better light interception (Gupta and Sharma 2015) and water use efficiency (Sehgal 1999 and Huxley 1983), are some other reasons for difference in biomass production.

In the present study range of total biomass of forbs in different forests (1.44-4.63 t/ha) is almost similar to the findings of Bhutia (2017) who gave a range of biomass of herbaceous vegetation from 2.95-4.83 t/ha in different tree based natural systems and 5.49 t/ha in grasslands. Yadav *et al.* (2016) studied chir pine and mixed forests in central Himalaya and reported that herbs biomass varied from 3.80 to 4.27 t/ha and herbs biomass carbon from 1.71 to 1.92 t/ha. Total biomass of herbage recorded in the present study is similar to the findings of Gupta *et al.* (2015) who reported total biomass of herbaceous vegetation ranging from 3.02-4.72 t/ha under different tree based systems. Kharkwal *et al.* (2010) reported 30.2-305.2 gm<sup>-2</sup> herbage production in Oak forests (*Quercus leucotrichophora*, *Quercus floribunda* and *Quercus semecarpifolia*) located at different aspects and slope in Kumaon Himalaya. Higher herbage biomass production i.e 6.7 and 7.4 Mg ha<sup>-1</sup> have been reported in the South American Andes, Paramo and Puna vegetation by Gibbon *et al.* (2010) and Oliveras *et al.* (2014).

#### 4.7 SOIL STUDIES

Results in the Table 70 reveals that, in general, there was significant decrease in bulk density of soil along the elevation in both the depths of soil. Further, bulk density of soil in different forests was significantly low at depth 0-15 cm as compared to 15-30 cm depth of soil. Comparing bulk density of soil in different forests at different elevations it was evident that in Ban Oak and Moru Oak forests the bulk density of the soil was higher as compared to other forests. Soil bulk density in Deodar, western mixed coniferous and upper Oak-Fir forests was at par and in moist temperate lower deciduous, Kail, and Kharsu Oak forests it showed at par values.

At the depth of 0-15 cm, at E<sub>1</sub>, highest bulk density of 1.12 g/cm<sup>3</sup> was recorded in Ban Oak forests, which was statistically at par with western mixed coniferous forests and Moru

Oak forest with bulk density of 1.11 g/cm<sup>3</sup> and 1.10 g/cm<sup>3</sup> respectively, while lowest bulk density at E<sub>1</sub> was observed in Kharsu Oak forests (0.89 g/cm<sup>3</sup>). At elevation E<sub>2</sub>, maximum bulk density was recorded in Ban Oak forests (1.07 g/cm<sup>3</sup>), followed by Moru Oak forests (0.98 g/cm<sup>3</sup>) whereas least bulk density was recorded in upper Oak-Fir forests (0.89 g/cm<sup>3</sup>). Highest and lowest bulk density at E<sub>3</sub> was observed in Ban Oak forests (0.98 g/cm<sup>3</sup>) and western mixed coniferous forests (0.82 g/cm<sup>3</sup>), respectively (Table 70).

**Table 70: Change in Soil bulk density (g/cm<sup>3</sup>) among forests (F) and elevations (E)**

| Forest types<br>(T)                                                                                                    | Soil bulk density (g/cm <sup>3</sup> ) at two depths (D) |                |                |             |                |                |                |             |
|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|----------------|----------------|-------------|----------------|----------------|----------------|-------------|
|                                                                                                                        | 0-15 cm                                                  |                |                |             | 15-30 cm       |                |                |             |
|                                                                                                                        | E <sub>1</sub>                                           | E <sub>2</sub> | E <sub>3</sub> | Mean        | E <sub>1</sub> | E <sub>2</sub> | E <sub>3</sub> | Mean        |
| Ban Oak forests                                                                                                        | 1.12                                                     | 1.07           | 0.98           | <b>1.06</b> | 1.32           | 1.09           | 1.04           | <b>1.15</b> |
| Moru Oak forests                                                                                                       | 1.10                                                     | 0.98           | 0.92           | <b>1.00</b> | 1.20           | 1.08           | 1.01           | <b>1.10</b> |
| Deodar forests                                                                                                         | 0.98                                                     | 0.93           | 0.93           | <b>0.95</b> | 1.04           | 1.01           | 0.97           | <b>1.01</b> |
| Western mixed coniferous forests                                                                                       | 1.11                                                     | 0.96           | 0.82           | <b>0.96</b> | 1.14           | 1.00           | 0.94           | <b>1.03</b> |
| Moist temperate lower deciduous forests                                                                                | 0.92                                                     | 0.90           | 0.85           | <b>0.89</b> | 1.11           | 0.97           | 0.92           | <b>1.00</b> |
| Kail forests                                                                                                           | 0.90                                                     | 0.92           | 0.86           | <b>0.89</b> | 0.97           | 0.94           | 0.90           | <b>0.94</b> |
| Kharsu Oak forests                                                                                                     | 0.89                                                     | 0.92           | 0.83           | <b>0.88</b> | 1.01           | 0.94           | 0.89           | <b>0.95</b> |
| Upper Oak-Fir forests                                                                                                  | 1.02                                                     | 0.89           | 0.90           | <b>0.94</b> | 1.07           | 0.93           | 0.91           | <b>0.97</b> |
| Moist temperate upper deciduous forests                                                                                | 0.92                                                     | 0.90           | 0.83           | <b>0.87</b> | 1.13           | 1.04           | 0.88           | <b>1.02</b> |
| <b>Mean</b>                                                                                                            | <b>0.92</b>                                              | <b>0.90</b>    | <b>0.83</b>    |             | <b>1.13</b>    | <b>1.04</b>    | <b>0.88</b>    |             |
| <b>CD<sub>0.05</sub></b><br><b>T = 0.038, E = 0.022, D = 0.018; T x E = 0.053; E x D = 0.031 and T x E x D = 0.092</b> |                                                          |                |                |             |                |                |                |             |

Note: For each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different.

At 15-30 cm depth, at E<sub>1</sub> maximum bulk density of 1.32 g/cm<sup>3</sup> existed in Ban Oak forests that decreased to 1.20 g/cm<sup>3</sup> in Moru Oak forests while least value of bulk density was recorded in Kail forests (0.97 g/cm<sup>3</sup>). Highest bulk density at E<sub>2</sub> was recorded in Ban Oak forests (1.09 g/cm<sup>3</sup>) which was statistically at par with Moru Oak forests (1.08 g/cm<sup>3</sup>). Upper Oak-Fir forests exhibited lowest bulk density of 0.93 g/cm<sup>3</sup>. At E<sub>3</sub>, maximum bulk density was recorded in Ban Oak forests (1.04 g/cm<sup>3</sup>), followed by Moru Oak forests (1.01 g/cm<sup>3</sup>) while lowest bulk density (0.88 g/cm<sup>3</sup>) was observed in moist temperate upper deciduous forests (Table 70).

Perusal of data in Table 70 revealed a significant difference between different forest types, soil depths and elevations. Irrespective of elevations, at both the soil depths, highest mean bulk density was observed in Ban Oak forests (1.06 g/cm<sup>3</sup> at 0-15cm and 1.15 g/cm<sup>3</sup> at 15-30cm), followed by Moru Oak forests (1.00 g/cm<sup>3</sup> at 0-15 cm and 1.10 g/cm<sup>3</sup> at 15-30

cm). Least mean bulk density was recorded in moist temperate upper deciduous forests as  $0.87 \text{ g/cm}^3$  at 0-15 cm depth and in Kail forests as  $0.94 \text{ g/cm}^3$  at 15-30 cm depth. With respect to elevations, the trend observed in change in bulk density along the elevation was:  $E_1$  ( $0.92 \text{ g/cm}^3$  at 0-15 cm and  $1.13 \text{ g/cm}^3$  at 15-30 cm)  $> E_2$  ( $0.90 \text{ g/cm}^3$  at 0-15 cm and  $1.04 \text{ g/cm}^3$  at 15-30 cm)  $> E_3$  ( $0.83 \text{ g/cm}^3$  at 0-15 cm and  $0.88 \text{ g/cm}^3$  at 15-30 cm).

The bulk density of the soil reflects the level of compaction and amount of pore space in the soil. The variation in the bulk density under different forests can be owed to their varying rate of leaf-litter deposition. Bulk density in natural ecosystems could be altered due to fine root mat formation with microbial and arthropod activities that subsequently lead to aeration of the soil (Jobbagy and Jackson 2000). Bulk density was dependent on available macronutrients and micronutrients in the soil. It decreases as the total macronutrient or total micronutrient contents in the soil increases. In the present study, bulk density of soil (mean of 0-15 and 15-30 cm) ranged from  $0.92 \text{ g/cm}^3$  (Kail forests and Kharsu Oak forests) to  $1.11 \text{ g/cm}^3$  (Ban Oak forests). In other forests its value was  $1.05 \text{ g/cm}^3$  (Moru Oak forests),  $1.00 \text{ g/cm}^3$  (western mixed coniferous forests),  $0.95 \text{ g/cm}^3$  in moist temperate lower deciduous forests,  $0.98 \text{ g/cm}^3$  in Deodar forests,  $0.96 \text{ g/cm}^3$  in upper Fir-Oak forests and  $0.95 \text{ g/cm}^3$  in moist temperate upper deciduous forests. Results of bulk density showed that soil bulk density differed significantly among forest types. Yimer *et al.* (2006) opined that soil bulk density can be quite variable in different forest types and changes in bulk density in the forest floor can alter SOC stocks.

Soil bulk density in the range of  $0.89\text{--}1.44 \text{ g/cm}^3$  in different vegetation systems of Himalaya has been reported by many workers (Sanneh 2007; Bhardwaj *et al.* 2013; Mahato 2013; Gupta *et al.* 2015; Bhutia 2017; Kumar *et al.* 2013; Singh and Rawat 2013; Yadav 2017).

There was decrease in soil bulk density with increase in elevation. Many workers have reported a negative correlation of bulk density with increasing elevation (Karan *et al.* 1991; Cihacek and Ulmer 1998; Sharma *et al.* 2010; Hanawalt and Whittaker 1976 and Kanagaraj *et al.* 2017). Decreasing bulk density along elevation was related to increasing soil organic matter. Leifeld *et al.* (2005) and Morisada *et al.* (2004) contended that the bulk density depends on several factors such as compaction, consolidation and amount of SOC present in the soil but it is highly correlated to the organic carbon content. Sanjay *et al.* (2010) also reported lower bulk density at top altitudes and opined that it is a good indicator

of soil which has coarser structure of organic matter that enriches the spaces by soil organic carbon.

**Table 71: Change in soil organic carbon (SOC %) among forests (F) and elevations (E)**

| Forest type                                                                                                        | Soil Organic Carbon (%) at two depths (D) |                |                |             |                |                |                |             |
|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------|----------------|-------------|----------------|----------------|----------------|-------------|
|                                                                                                                    | 0-15 cm                                   |                |                |             | 15-30 cm       |                |                |             |
|                                                                                                                    | E <sub>1</sub>                            | E <sub>2</sub> | E <sub>3</sub> | Mean        | E <sub>1</sub> | E <sub>2</sub> | E <sub>3</sub> | Mean        |
| Ban Oak forests                                                                                                    | 1.66                                      | 1.32           | 1.29           | <b>1.42</b> | 1.41           | 1.22           | 1.04           | <b>1.22</b> |
| Moru Oak forests                                                                                                   | 1.64                                      | 1.04           | 1.01           | <b>1.23</b> | 1.09           | 1.06           | 0.99           | <b>1.05</b> |
| Deodar forests                                                                                                     | 1.19                                      | 1.25           | 1.13           | <b>1.19</b> | 1.23           | 1.16           | 1.08           | <b>1.16</b> |
| Western mixed coniferous forests                                                                                   | 1.54                                      | 1.31           | 1.24           | <b>1.36</b> | 0.98           | 0.96           | 0.96           | <b>0.97</b> |
| Moist temperate lower deciduous forests                                                                            | 1.23                                      | 1.11           | 1.07           | <b>1.14</b> | 0.96           | 0.96           | 0.92           | <b>0.95</b> |
| Kail forests                                                                                                       | 1.58                                      | 1.23           | 1.19           | <b>1.33</b> | 1.08           | 0.94           | 0.93           | <b>0.98</b> |
| Kharsu Oak forests                                                                                                 | 1.31                                      | 1.14           | 1.09           | <b>1.18</b> | 1.17           | 1.08           | 1.02           | <b>1.09</b> |
| Upper Oak-Fir forests                                                                                              | 1.44                                      | 1.06           | 0.95           | <b>1.15</b> | 1.06           | 0.93           | 0.89           | <b>0.96</b> |
| Moist temperate upper deciduous forests                                                                            | 1.46                                      | 1.21           | 1.16           | <b>1.28</b> | 1.10           | 1.15           | 1.07           | <b>1.11</b> |
| <b>Mean</b>                                                                                                        | <b>1.45</b>                               | <b>1.19</b>    | <b>1.13</b>    |             | <b>1.12</b>    | <b>1.05</b>    | <b>0.99</b>    |             |
| CD <sub>0.05</sub> T = 0.160, E = 0.075, D = 0.092, T x E = 0.226, T x D = 0.277, E x D = 0.131, T x E x D = 0.392 |                                           |                |                |             |                |                |                |             |

**Note:** For each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different.

A perusal of the data presented in the Table 71 reveals that soil organic carbon was significantly influenced by elevation and soil depth. The result reveals that soil organic carbon (%) declined significantly with ascending elevation and increase in depth. At the depth of 0-15 cm, maximum soil organic carbon was recorded in Ban Oak forests at all the three elevations (E<sub>1</sub> = 1.66 %, E<sub>2</sub> = 1.32 % and E<sub>3</sub> = 1.29 %) while lowest soil organic carbon was recorded in Deodar forests at E<sub>1</sub> (1.19 %), in Moru Oak forests at E<sub>2</sub> (1.04 %) and in upper Oak-Fir forests at E<sub>3</sub> (0.95 %). At the depth of 15-30 cm, Ban Oak forests exhibited highest soil organic carbon at three elevations (E<sub>1</sub> as 1.41 %, E<sub>2</sub> as 1.22 % and E<sub>3</sub> as 1.04 %), followed by Deodar forests (E<sub>1</sub> as 1.23 %, E<sub>2</sub> as 1.16 % and E<sub>3</sub> as 1.08 %) while lowest soil organic carbon was recorded in Moist temperate lower deciduous forests (E<sub>1</sub> = 0.96 % and E<sub>3</sub> = 0.92 %) and in Kail forests (0.94 %) at E<sub>2</sub>.

Analysis of data in Table 71 revealed a significant difference between different forest types, soil depths and elevations. At both the soil depths, highest mean soil organic carbon was observed in Ban Oak forests (1.42 % at 0-15cm and 1.22 % at 15-30cm), irrespective of elevations. Least mean soil organic carbon was recorded in moist temperate lower deciduous forests (1.14 % at 0-15 cm and 0.95 % at 15-30 cm). Considering elevation effect, soil organic carbon was highest at elevation E<sub>1</sub> (1.45 % at 0-15 cm and 1.12 % at 15-30 cm) followed by E<sub>2</sub> (1.19 % at 0-15 cm and 1.05 % at 15-30 cm) and E<sub>3</sub> (1.13 % at 0-15 cm and 0.99 % at 15-30 cm).

Earth's carbon, soils contain approximately 75% of the carbon pool on land-three times more than the amount stored in living plants and animals. Therefore, soils play a major role in maintaining a balanced global carbon cycle. Thus, it becomes important to study carbon storage in soils. In the present study the soils of nine types of forests in Himalayan moist temperate forest it was evident that soil organic carbon was highest (1.66 %) in Ban Oak forests, followed by Moru Oak Forests at 0-15 cm at E<sub>1</sub> (Table 71). The higher soil organic carbon (SOC) in Oak forest and Oak mixed forest could be due to higher inputs of litter resulting in which enriches SOC (Anuradha 2014). Compared to our results Devi (2011) recorded higher bulk density (2.96 %) under Oak and pine forest. There was gradual decline in the organic carbon in lower soil depth. Higher organic carbon accumulation in surface soil than sub-surface layers could be attributed to higher amount of litter accumulation on surface. These results are in accordance with the findings of Banerjee and Badola (1980), Gupta *et al.* (1991), Kaushal (1992), Saralch (1994), Bhola (1995), Nayak (1996) and Gosain *et al.* (2015). Increase in the SOC can be due to the change in the climatic condition at higher elevation as well as the decrease in organic matter accumulation along the elevation gradients (Kanagaraj *et al.* 2017).

In the present study average (0-15 and 15-30 cm depth) soil organic carbon in different forests ranged from 1.14% (Moru Oak and Kail forests) to 1.32% (Ban Oak forests). Similar to our finding Gosain *et al.* 2015 in their study on eighteen forest stands dominated by *Pinus roxburghii* and *Quercus leucotrichophora* forests in Almora. Central Himalaya also reported that soil organic matter highest was highest in Oak forests. Bhutia (2017) also reported highest soil organic carbon in her studies on different forests of northwest Himalaya. Differences in carbon stocks in top soil in different ecosystems reflect the differences in the quantity and quality of the litter input, litter carbon decomposition, and litter biomass carbon (Mo *et al.* 2002). Bhutia (2017) reported SOC in soils of different vegetation systems of north west Himalaya in the range of 1.68 to 2.10 %. Many workers have reported comparable soil organic carbon in similar vegetation in north-west Himalaya (Dutt 1999; Masoodi 2010; Farooq 2012; Devi *et al.* 2013; Sharma *et al.* 2010; Gairola *et al.* 2012; Kumar *et al.* 2013; Singh and Rawat 2013; Kanime *et al.* 2013; Arora *et al.* 2014; Negi *et al.* 2015). The SOC % recorded in different forests in our study is very high as compared to the findings of Saha *et al.* (2018), they analysed the soil properties in different seasons at varying altitudes of forests in temperate region of Garhwal Himalaya and reported soil organic carbon values between 0.14 and 0.19%.

**Table 72: Change in soil organic carbon stocks (t/ha) among forests (F) and elevations (E).**

| Forest types<br>(T)                                                                                                           | Soil organic carbon stock (t/ha) at two depths (D) |                |                |              |                |                |                |              |
|-------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|----------------|----------------|--------------|----------------|----------------|----------------|--------------|
|                                                                                                                               | 0-15 cm                                            |                |                |              | 15-30 cm       |                |                |              |
|                                                                                                                               | E <sub>1</sub>                                     | E <sub>2</sub> | E <sub>3</sub> | Mean         | E <sub>1</sub> | E <sub>2</sub> | E <sub>3</sub> | Mean         |
| Ban Oak forests                                                                                                               | 27.89                                              | 21.19          | 18.96          | <b>22.68</b> | 27.52          | 19.95          | 16.22          | <b>21.36</b> |
| Moru Oak forests                                                                                                              | 27.06                                              | 15.29          | 13.94          | <b>18.76</b> | 19.62          | 17.17          | 15.00          | <b>17.26</b> |
| Deodar forests                                                                                                                | 17.49                                              | 17.44          | 15.76          | <b>16.90</b> | 19.19          | 17.57          | 15.71          | <b>17.49</b> |
| Western mixed coniferous forests                                                                                              | 25.64                                              | 18.86          | 15.25          | <b>19.92</b> | 16.76          | 14.40          | 13.54          | <b>14.90</b> |
| Moist temperate lower deciduous forests                                                                                       | 16.97                                              | 14.99          | 13.64          | <b>15.20</b> | 15.98          | 13.97          | 12.70          | <b>14.22</b> |
| Kail forests                                                                                                                  | 21.33                                              | 16.97          | 15.35          | <b>17.89</b> | 15.71          | 13.25          | 12.56          | <b>13.84</b> |
| Kharsu Oak forests                                                                                                            | 17.49                                              | 15.73          | 13.57          | <b>15.60</b> | 17.73          | 15.23          | 13.62          | <b>15.52</b> |
| Upper Oak-Fir forests                                                                                                         | 22.03                                              | 14.15          | 12.83          | <b>16.34</b> | 17.01          | 12.97          | 12.15          | <b>14.05</b> |
| Moist temperate upper deciduous forests                                                                                       | 20.15                                              | 16.34          | 14.44          | <b>16.98</b> | 18.65          | 17.94          | 14.26          | <b>16.95</b> |
| <b>Mean</b>                                                                                                                   | <b>21.78</b>                                       | <b>16.77</b>   | <b>14.86</b>   |              | <b>18.73</b>   | <b>15.83</b>   | <b>13.97</b>   |              |
| <b>CD<sub>0.05</sub>      T = 0.110, E = 1.180, D = 0.084, T x E = 0.121, T x D = 0.158, E x D = 0.111, T x E x D = 0.325</b> |                                                    |                |                |              |                |                |                |              |

**Note:** For each forest type elevation range in E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> is different

A perusal of the data presented in the Table 72 reveals that soil carbon density (t/ ha) is significantly influenced by the elevation and soil depth. Further it is evident that significant difference occurs in carbon density of soil between forest types, soil depths and elevations. There was decrease in carbon density in soil with increase in soil depth. At 0-15 cm soil depth, maximum soil carbon density was recorded in Ban Oak forests (at E<sub>1</sub> as 27.89 t/ha, at E<sub>2</sub> as 21.19 t/ha and at E<sub>3</sub> as 18.96 t/ha), while least soil carbon density at E<sub>1</sub> was observed in moist temperate lower deciduous forests (16.97 t/ha), in upper Oak-Fir forests at E<sub>2</sub> (14.15 t/ha) and E<sub>3</sub> (12.83 t/ha). At 15-30 cm, at E<sub>1</sub>, Ban Oak forests recorded with highest soil carbon density at the three elevations (E<sub>1</sub> as 27.52 t/ha, at E<sub>2</sub> as 19.95 t/ha and at E<sub>3</sub> as 16.22 t/ha). Lowest soil carbon density (15.71 t/ha) was observed in Kail forests at E<sub>1</sub> while at E<sub>2</sub> (12.97 t/ha) and E<sub>3</sub> (12.15 t/ha) it was recorded in upper Oak-Fir forests.

Likewise, there was decrease in carbon density in soil at both the depths with increase in elevation (Table 72). It decreased in the order: E<sub>1</sub> (21.78 t/ha at 0-15 cm and 18.73 t/ha at 15-30 cm) > E<sub>2</sub> (16.77 t/ha at 0-15 cm and 15.83 t/ha at 15-30 cm) > E<sub>3</sub> (14.86 t/ha at 0-15 cm and 13.97 t/ha at 15-30 cm).

At both the soil depths, mean soil carbon density was observed in Ban Oak forests (22.68 t/ha at 0-15 cm and 21.36 t/ha at 15-30 cm, irrespective of elevations. Least soil carbon density was recorded in moist temperate lower deciduous forests (15.20 t/ha at 0-15 cm) and Kail forests (13.84 t/ha at 15-30 cm). This can be attributed to changes that have

occurred in these forests over their lifetime due to overgrowing trees resulting in different quality and quantity of litter, aboveground biomass belowground biomass, and basal area of the trees as contended by Dar and Sundarapandian (2015a). In addition to that climate, temperature and precipitation along an altitudinal gradient also play an important role. Edge effect (edge-affected forest fragments - placement of sample plots from core to edge) has been found to cause differences in soil carbon stock. The soil carbon storage depends on the tree species, as well as their litter quality and quantity (Lugo and Brown, 1993; Ullah and Al-Amin 2012).

SOC showed decreasing trend with increasing elevation and soil depth. This might be because soil organic carbon (SOC) depends upon various biotic and abiotic factors such as microclimate, faunal diversity, land use and management. Soil organic carbon at lower altitude is generally high and due to change in climatic condition at higher elevation there may be decrease in organic matter accumulation along the elevation gradients (Kanagaraj *et al.* 2017). Changes in climatic variables, particularly precipitation and temperature along altitudinal gradients in mountain forest ecosystems, influence the type of vegetation and, consequently, the amount, chemical composition, and turnover of SOC (Jobbágy and Jackson 2000; Lemenih and Itanna 2004). Therefore, SOC stocks are altered with elevation (Garten and Hanson 2006) as precipitation increases and temperature decreases (Hontoria *et al.* 1999; Lemenih and Itanna 2004; Wang *et al.* 2004). Literature on studies on soil C stocks along elevation gradients provide different results i.e. decrease, unimodal response, or no change (Britton *et al.* 2011).

The SOC stocks decreased with increasing soil depth in all the forest types. The relatively large mean SOC density in the 0-15 cm depth could be attributed to higher organic matter inputs by litter fall causing higher accumulation of SOC in the upper layer of the mineral soil. The upper layer remains in dynamic equilibrium with biological and anthropological activities and is generally richer in carbon than the lower layers (Kanagaraj *et al.* 2017; Shrestha *et al.* (2007). The trend of decreasing SOC with increasing depth may be due to the increased proportion of slower cycling of SOC pools at depth and compaction of soil (Paul *et al.* 1997; Trumbore 2000; Jobbágy and Jackson 2000).

In the present investigation, comparing different forests carbon stock in the soil (30 cm depth) ranged from 29.42 to 44.04 t/ha, lowest being in moist temperate upper deciduous forests and highest in Ban Oak forests. In Moru Oak forest carbon stock in soil was 36.02

t/ha, in Deodar forests 34.39 t/ha, in western mixed coniferous forests 34.82 t/ha, in Kharsu Oak forests 31.12 t/ha, in Kail forests 31.73 t/ha, in upper Fir-Oak forests 30.39 t/ha and in moist temperate upper deciduous forests 33.93 t/ha. This proves from the results that soil carbon storage is influenced by vegetation type. This variation thus attributed to difference in structural components i.e., type of species, their morphology, numbers etc. that cause variation in quantity and quality of leaf litter deposition and root turnover in upper soil layers. Similar observations have been recorded by many researchers (Singh *et al.* 1989; Scheu and Schauerermann 1994; Trujillo *et al.* 1997; Samra and Singh 2000; Rasse *et al.* 2005; Bell and Worrall 2009; Nair *et al.* 2010; Zhang *et al.* 2011; Kell 2012; Gupta *et al.* 2015) who concluded that structural components and the management practices in any ecosystem effect soil carbon storage. Beside this, type of soil (Coomes *et al.* 2002; Liebens and VanMolle 2003; Davis *et al.* 2004; Gupta *et al.* 2009; Chiti *et al.* 2012) and age of the trees (Maikhuri *et al.* 2000; Chauhan *et al.* 2015) are the factors which regulate soil carbon storage in any systems.

Dar and Sundarapandian (2015a) studied *Populus deltoides*, *Juglans regia*, *Cedrus deodara*, *Pinus wallichiana*, mixed coniferous, *Abies pindrow* and *Betula utilis* forests in temperate forests of Kashmir Himalaya and reported carbon stock of soil in them ranging from 39.1–91.4 Mg ha<sup>-1</sup>. Pempa (2017) recorded 68.64 to 72.05 t/ha in different types of ecosystems in northwest Himalaya. 26.37-219.86 Mg C ha<sup>-1</sup> in soils has been reported by many workers in agroforestry systems/silvipastures/ forests/grasslands of north-west Himalaya (Kumar 2003; Minj 2008; Goswami 2008; Sharma 2009; Rajput 2010; Masoodi 2010; Negi and Gupta 2010; Farooq 2012; Tripathi 2012; Sharma 2012; Devi *et al.* 2013; Mahato 2013; Singh 2014; Singh 2014; Rajput 2015; Gupta *et al.* 2015; Rajput *et al.* 2016). In central Himalaya soil carbon stock in the range of 38.57 - 218.57 in similar ecosystems have been reported by Sheikh *et al.* (2009), Sharma *et al.* (2011), Kumar *et al.* (2011), Kumar *et al.* (2012), Chaturvedi and Melkania (2013), Bohra *et al.* (2014) and Choudhary and Saxena (2015).

It was estimated that in Himalayan moist temperate forest of Shimla district in Himachal Pradesh, that covers an area of 169432.04 ha area, has 9944.65 x 10<sup>4</sup> m<sup>3</sup> timber volume, 16256.46 x 10<sup>4</sup> t aboveground biomass of vegetation, 19659.59 x 10<sup>4</sup> t total biomass of vegetation, 9829.79 x 10<sup>4</sup> t total carbon stock in vegetation and 11607.00 x 10<sup>4</sup> t total carbon stock (Table 73).



**Table 73. Timber volume, aboveground biomass of vegetation, total biomass of vegetation, total carbon stock in vegetation and total carbon stock in Himalayan moist temperate forest of Shimla district (HP).**

| Forest type                             | Timber volume<br>(m <sup>3</sup> /ha) x 10 <sup>4</sup> | Aboveground Biomass<br>(t/ha) x 10 <sup>4</sup> | Total biomass<br>(t/ha) x 10 <sup>4</sup> | Total carbon in vegetation<br>(t/ha) x 10 <sup>4</sup> | Total carbon stock<br>(t/ha) x 10 <sup>4</sup> |
|-----------------------------------------|---------------------------------------------------------|-------------------------------------------------|-------------------------------------------|--------------------------------------------------------|------------------------------------------------|
| <b>Elevation-E1</b>                     |                                                         |                                                 |                                           |                                                        |                                                |
| Ban Oak forests                         | 207.65                                                  | 656.27                                          | 784.01                                    | 392.01                                                 | 466.42                                         |
| Moru Oak forests                        | 5.20                                                    | 10.87                                           | 13.14                                     | 6.57                                                   | 7.63                                           |
| Deodar forests                          | 1527.77                                                 | 2619.37                                         | 3207.92                                   | 1603.96                                                | 1802.85                                        |
| Western mixed coniferous forests        | 1807.13                                                 | 2818.33                                         | 3388.37                                   | 1694.18                                                | 1988.61                                        |
| Moist temperate lower deciduous forests | 11.47                                                   | 19.38                                           | 23.44                                     | 11.72                                                  | 14.09                                          |
| Kail forests                            | 217.59                                                  | 424.86                                          | 511.60                                    | 255.80                                                 | 320.81                                         |
| Kharsu Oak forests                      | 6.43                                                    | 12.87                                           | 15.47                                     | 7.73                                                   | 8.74                                           |
| Upper Oak-Fir forests                   | 23.26                                                   | 44.44                                           | 53.00                                     | 26.50                                                  | 29.61                                          |
| Moist temperate upper deciduous forests | 270.85                                                  | 494.90                                          | 593.84                                    | 296.92                                                 | 346.42                                         |
| <b>Elevation-E2</b>                     |                                                         |                                                 |                                           |                                                        |                                                |
| Ban Oak forests                         | 174.39                                                  | 528.75                                          | 629.85                                    | 314.92                                                 | 370.18                                         |
| Moru Oak forests                        | 3.82                                                    | 6.08                                            | 7.41                                      | 3.70                                                   | 4.44                                           |
| Deodar forests                          | 1155.26                                                 | 1700.93                                         | 2069.75                                   | 1034.87                                                | 1224.71                                        |
| Western mixed coniferous forests        | 1405.07                                                 | 1999.41                                         | 2406.38                                   | 1203.19                                                | 1434.15                                        |
| Moist temperate lower deciduous forests | 9.11                                                    | 15.48                                           | 18.79                                     | 9.40                                                   | 11.48                                          |
| Kail forests                            | 197.44                                                  | 329.81                                          | 396.36                                    | 198.18                                                 | 251.22                                         |
| Kharsu Oak forests                      | 5.49                                                    | 9.05                                            | 10.95                                     | 5.47                                                   | 6.36                                           |
| Upper Oak-Fir forests                   | 20.60                                                   | 32.12                                           | 38.53                                     | 19.27                                                  | 21.43                                          |
| Moist temperate upper deciduous forests | 215.58                                                  | 375.23                                          | 451.78                                    | 225.89                                                 | 269.62                                         |
| <b>Elevation-E3</b>                     |                                                         |                                                 |                                           |                                                        |                                                |
| Ban Oak forests                         | 140.04                                                  | 350.60                                          | 422.06                                    | 211.03                                                 | 258.28                                         |
| Moru Oak forests                        | 2.73                                                    | 4.59                                            | 5.59                                      | 2.80                                                   | 3.45                                           |
| Deodar forests                          | 1105.65                                                 | 1282.50                                         | 1560.66                                   | 780.33                                                 | 950.97                                         |
| Western mixed coniferous forests        | 1082.31                                                 | 2019.23                                         | 2440.54                                   | 1220.27                                                | 1420.19                                        |
| Moist temperate lower deciduous forests | 7.51                                                    | 13.58                                           | 16.59                                     | 8.29                                                   | 10.19                                          |
| Kail forests                            | 175.77                                                  | 245.63                                          | 300.71                                    | 150.36                                                 | 199.34                                         |
| Kharsu Oak forests                      | 4.77                                                    | 7.24                                            | 8.76                                      | 4.38                                                   | 5.15                                           |
| Upper Oak-Fir forests                   | 14.76                                                   | 21.05                                           | 25.40                                     | 12.70                                                  | 14.69                                          |
| Moist temperate upper deciduous forests | 146.99                                                  | 213.87                                          | 258.70                                    | 129.35                                                 | 165.97                                         |
| <b>Total</b>                            | <b>9944.65</b>                                          | <b>16256.46</b>                                 | <b>19659.59</b>                           | <b>9829.79</b>                                         | <b>11607.00</b>                                |

**Note:** For each forest type elevation range in E1, E2 and E3 is different; Aboveground biomass = aboveground biomass of trees + shrubs + forbs; Total biomass = aboveground + belowground biomass of trees + shrubs + forbs; Total carbon stock in vegetation = aboveground + belowground carbon stock in trees + shrubs + forbs; Total carbon stock = total carbon stock in vegetation + soil (up to 30 cm depth).

It was evident from the result that western mixed coniferous forests covers 40.98 % of the total area under Himalayan moist temperate forest in Shimla district which is reflected as 43.18 % ( $4294.51 \times 10^4 \text{ m}^3$ ) of timber volume, 42.06 % ( $6836.97 \times 10^4 \text{ t}$ ) of aboveground biomass of vegetation, 41.89 % ( $8235.29 \times 10^4 \text{ t}$ ) of total biomass of vegetation, 41.86 % ( $4117.64 \times 10^4 \text{ t}$ ) of carbon stock in vegetation and 41.72 % ( $4842.95 \times 10^4 \text{ t}$ ) of total carbon stock available in Himalayan moist temperate forest. The result suggests that this forest type is most important from ecological and ecosystem services point of view (Table 73).

But, if the data is further viewed carefully, the upper Ban Oak, Oak-Fir, and Deodar forests types have better carbon storage potential per unit area (825.61 t/ha, 815.23 t/ha and 733.74 t/ha, respectively; Table 49, 59, 69 and 72) as compared to western mixed coniferous forest type (697.42 t/ha; 49, 59, 69 and 72) that reflects that they have better potential to sequester or lock carbon and thus are more important than western mixed coniferous forest type. Deodar forests are widely distributed (54222.31 ha) and have 38.10 % ( $3788.68 \times 10^4 \text{ m}^3$ ) of timber volume, 34.47 % ( $5602.80 \times 10^4 \text{ t}$ ) of aboveground biomass of vegetation, 34.78 % ( $6838.33 \times 10^4 \text{ t}$ ) of total biomass of vegetation, 34.76 % ( $3419.16 \times 10^4 \text{ t}$ ) of carbon stock in vegetation and 34.28 % ( $3978.53 \times 10^4 \text{ Mt}$ ) of total carbon stock available in Himalayan moist temperate forest in Shimla district. It is therefore recommended that if the forest management strategies are formulated in favour of expansion of areas under Ban Oak forests, upper Oak-Fir and Deodar forest types then Himalayan moist temperate forest in Shimla district will be better natural capital that provide enhanced ecosystem services besides combating the global warming than at present.

## Chapter-5

### SUMMARY AND CONCLUSION

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The present investigations entitled “**Assessment of floral diversity and carbon stocks of Himalayan moist temperate forest in Himachal Pradesh**” was carried out in Shimla district of HP with the aim to identify distribution, structure and functional characteristics of forest types in ‘Himalayan moist temperate forest’. The results are summarized as below:

#### 5.1 REMOTE SENSING AND GIS

Digital data in GIS platform provided nine forest types viz., viz., *Q. leucotrichophora* (FT-1), *Q. semecarpifolia* (FT-2), *C. deodara* (FT-3), western mixed coniferous (FT-4), moist temperate lower deciduous (FT-5), *P. wallichiana* (FT-6), *Q. floribunda* (FT-7), upper *Abies-Picea* (FT-8) and moist temperate upper deciduous (FT-9) forests. These forest types were distributed between elevation 700-3600 m amsl in the district (Figure 5-14). The area covered and elevation range in each forest type was different: FT-4 (69441.06 ha; 1200-3900 m), FT-3 (54222.31 ha; 900-3600 m), FT-6 (17550.64 ha; 1400-3600 m), FT-1 (13430.28 ha; 700-2500 m), FT-9 (12758.72 ha; 1700-3500 m), FT-8 (796.05 ha; 2100-3500 m), FT-5 (720.55 ha; 1000-2700 m), FT-7 (284.78 ha; 2300-3600 m) and FT-2 (227.65 ha; 1800-3300 m). Use of DEM was made to stratify elevation classes ( $E_1$ ,  $E_2$ , and  $E_3$ ) in each forest type based on their elevation range. NDVI images of Shimla district were compared for the years 2008 and 2013 which revealed that there was decrease in area under compact forests (Figure 15). Around 82892.06 ha in the district have increased in NDVI range 0-3 (Table 3).

#### 5.2 FLORISTIC COMPOSITION

In all, 303 plant species were recorded in nine forest types of which 34 were trees, 96 shrubs and 173 forbs. The total number of plant species in different forests was: in FT-1 = 180, in FT-2 = 158, in FT-3 = 154, in FT-4 = 173, in FT-5 = 159, in FT-6 = 181, in FT-7 = 158, in FT-8 = 128 and in FT-9 = 123 (Tables 4-6). Tree species number in different forests ranged from 9 (FT-9) to 20 (FT-6); shrubs number from varied from 41 (FT-7 & FT-9) to 60 (FT-1) and forbs number fluctuated from 73 (FT-9) to 105 (FT-6). Ban Oak, Kharsu Oak and western mixed coniferous forests showed high number (104-105). The important plant

species in the flora of these forest types were: *A. pindrow*, *A. spectabilis*, *A. caesium*, *C. deodara*, *J. regia*, *P. smithiana*, *P. roxburghii*, *P. wallichiana*, *P. cornuta*, *Q. floribunda* and *Q. semecarpifolia*, *B. aristata*, *B. lycium*, *C. nepalensis*, *E. parvifolia*, *L. gerardiana*, *L. juncea*, *R. biflorus*, *V. cotinifolium*, *V. foetens*, *A. indica*, *A. molliusculus*, *D. deltoidea*, *H. intermedia*, *P. japonicus*, *P. hexandrum*, *U. dioica*, *A. venustum*, *C. cardiolepis*, *F. nubicola*, *G. aparine*, *P. communis*, *R. nepalensis*, *T. foliolosum* and *V. jatamansi* (Tables 4-6 ).

### 5.3 VEGETATION INDICES

Shannon-Wiener index of diversity (H) and Simpson index of dominance (D) and Margalef's index of richness ( $D_{mg}$ ) of trees in Himalayan moist temperate forest were 1.36, 0.38 and 0.67, respectively; in shrubs they were: 2.91, 0.07 and 0.44, respectively and in forbs they were: 3.66, 0.03 and 0.33, respectively. In different forests 'H' ranged from 0.97 (FT-1) to 1.72 (FT-5) for trees, 2.68 (FT-7) to 3.12 (FT-1) for shrubs and 3.32 (FT-9) to 3.93 (FT-7) in forbs. 'D' varied from 0.21 (FT-1) to 0.59 (FT-5) for trees, 0.05 (FT-1) to 0.09 (FT-7 & FT-8) for shrubs and 0.02 (FT-4 & FT-7) to 0.05 (FT-9) in forbs a. ' $D_{mg}$ ' ranged from 0.64 (FT-7) to - 0.70 (FT-8) in trees, 0.40 (FT-1) to 0.45 (FT-9) in shrubs and 0.32 (FT-2, FT-3, FT-4, FT-5, FT-7 & FT-9) to 0.37 (FT-1) in forbs (Table 7).

### 5.4 PHYTOSOCIOLOGY

In phytosociology growth parameters viz., density and basal area of trees, shrubs and forbs at three elevations ( $E_1$ ,  $E_2$  and  $E_3$ ) was computed in each forest type. Based on these growth characters, importance value index (IVI) of constituent species of trees, shrubs and herbs in different forest types at three elevations suggested various plants associations. The summary of the findings is as follow:

#### 5.4.1 Phytosociology of trees

Density and basal area of trees at three elevations ranged from 359.69 ( $E_3$ ) to 494.53 trees/ha ( $E_1$ ) and 45.52 ( $E_3$ ) to 66.72  $m^2$ /ha ( $E_1$ ). The density (trees/ha) and basal area ( $m^2$ /ha) of trees in different forests ranged from 387.57 (FT-8) to 610.11 (FT-7) and 54.58 (FT-2) and 88.13 (FT-3) at elevation  $E_1$ , from 280.66 (FT-8) to 525.09 (FT-7) and 48.10 (FT-2) and 65.45(FT-7) at elevation  $E_2$  and from 277.55 (FT-8) to 407.57(FT-7) and 40.57 (FT-8) and 56.04 (FT-6) at elevation  $E_3$  (Table 8-16 ). Tree dominance in forest types revealed that in FT-1, FT-2 and FT-3 forests pure forests of *Q. leucotichophora*, *Q. floribunda*, *C. deodara*, respectively were existing at all the three elevations. In FT-4 (western mixed coniferous

forests) *Abies-Picea* communities were identified at all the three elevations. In FT-5 forests, at elevation  $E_1$ , *Acer- Pinus*, at  $E_2$ , *Acer-Cedrus* and at elevation  $E_3$ , *Acer-Picea-Abies* communities were identified. In FT-6 forests, at all the three elevations *P. wallichiana* formed pure forests. In FT-7 (Kharsu Oak forests), at elevations  $E_1$  and  $E_2$  *Quercus- Abies* communities were present, while at elevation  $E_3$  *Quercus-Abies-Picea community* was identified. In FT-8 forests, *Abies-Quercus* communities were identified at different elevations. In FT-9 forests, *Acer-Quercus* communities were identified at all the three elevations (Tables 8-17).

#### 5.4.2 Phytosociology of shrubs

The range of density and basal area of shrubs at three elevations was 7825.92 ( $E_3$ ) to 10137.04 ( $E_1$ ) plants/ha and 13.915 ( $E_3$ ) to 18.383 ( $E_1$ )  $m^2/ha$ . The density and basal area of shrubs in individual forests varied from 8200.00 (FT-9) to 11900.00 (FT-5) plants/ha and 16.241 (FT-8) to 21.562 (FT-2)  $m^2/ha$  at  $E_1$ , 7433.33 (FT-9) to 10533.33 (FT-5) plants/ha and 14.305 (FT-9) to 19.387 (FT-2)  $m^2/ha$  at  $E_2$  and 6766.65 (FT-6) to 8600.00 (FT-4) plants/ha and 9.120 (FT-3) to 16.437 (FT-2)  $m^2/ha$  at  $E_3$  (Tables 18-26).

In FT-1 forests, the shrub communities identified were: *Carissa- Prinsepia*, *Berberis-Carissa* and *Zanthoxylum-Rosa* at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-2 forests, *Rosa-Agave*, *Jasminum-Berberis* and *Rubus-Cotoneaster* communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-3 forests, *Prinsepia-Hypericum*, *Viburnum-Rubus* and *Viburnum-Rosa-Rubus* communities were present at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-4 forests, *Berberis-Prinsepia*, *Hypericum-Cotoneaster* and *Viburnum-Berberis* communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-5 forests, *Viburnum-Cotoneaster* shrub community existed at elevation  $E_1$ , *Berberis- Hypericum* community was identified at elevation  $E_2$  and *Berberis-Myrsine* was present at  $E_3$ . In FT-6 forests, *Hypericum-Myrsine*, *Viburnum-Myrsine* and *Cotoneaster-Myrsine* shrub communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-7 forests, *Myrsine-Berberis-Prinsepia*, *Myrsine-Rosa*, *Berberis-Rosa* shrub communities were present at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-8 forests, *Berberis-Rubus* community existed at  $E_1$  and  $E_2$  whereas; *Rosa-Rubus* community was present at  $E_2$ . In FT-9 forests, *Prinsepia-Myrsine*, *Berberis-Rosa* and *Rosa-Viburnum* shrub communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively (Tables 18-27).

### 5.4.3 Phytosociology of forbs

In three elevations, density and basal area of forbs in forest types varied from 193125.51 ( $E_3$ ) to 250989.48 ( $E_1$ ) plants/ha and 66.092 ( $E_3$ ) to 88.74 ( $E_1$ )  $\text{cm}^2/\text{m}^2$ . The density and basal area of forbs in individual forests ranged from 218167.33 (FT-6) to 278333.33 (FT-4) plants/ha and 49.684 (FT-2) to 123.975 (FT-3)  $\text{cm}^2/\text{m}^2$  at  $E_1$ , 195001.33 (FT-6) to 258333.33 (FT-4) plants/ha and 40.845 (FT-2) to 110.601 (FT-3)  $\text{cm}^2/\text{m}^2$  at  $E_2$  and 173902.00 (FT-6) to 236666.67 (FT-4) plants/ha and 35.897 (FT-2) to 105.296 (FT-3)  $\text{cm}^2/\text{m}^2$  at  $E_3$  (Tables 28-37).

In FT-1 forests, *Verbascum-Primula*, *Fragaria-Urtica* and *Verbascum-Trifolium* communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-2 forests, *Erigeron-Stellaria*, *Vicatia-Potentilla* and *Viola-Valeriana* communities were present at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-3 forests, *Dicliptera-Artemisia*, *Androsace-Impatiens* and *Ajuga-Dichanthium* communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-4 forests, *Fragaria-Artemisia*, *Viola-Plectranthus* and *Thalictrum-Plantago* forb communities existed at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-5 forests, *Ainsliaea-Ranunculus*, *Carex-Verbascum* and *Salvia-Oenothera* forb communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-6 forests, *Verbascum-Primula*, *Fragaria-Urtica* and *Verbascum-Trifolium* communities were present at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-7 forests, *Viola-Saccharum*, *Salvia-Iris* and *Fragaria-Halenia* forb communities existed at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-8 forests, *Anaphalis-Urtica*, *Iris-Achyranthes* and *Rumex-Anaphali* forb communities were present at  $E_1$ ,  $E_2$  and  $E_3$ , respectively. In FT-9 forests, *Anaphalis-Fragaria*, *Bergenia-Carex* and *Anaphalis Polygonatum* forb communities were identified at  $E_1$ ,  $E_2$  and  $E_3$ , respectively (Tables 28-36).

## 5.5 REGENERATION STUDIES

At  $E_1$  maximum number of recruits (plants/ha) among all the forests types was recorded in Deodar forests (10698.54 plants/ha), while minimum values (470.08 plants/ha) were recorded in FT-4. Maximum number of un-established regeneration was recorded in FT-6 (1378.95 plants/ha) and (FT-8) exhibited low un-established regeneration (253.67 plants/ha). Whereas FT-3 showed highest number of established regeneration (1428.76 plants/ha) and minimum (196.35 plants/ha) was observed in FT-8 (Table 38-39).

At  $E_2$ , maximum recruits (7327.77 plants/ha), un-established (1354.28 plants/ha), established (1363.48 plants/ha) regeneration was also observed in FT-3, Lowest un-established and established regeneration (223.58 plants/ha and 149.78 plants/ha, respectively) was observed in FT-8. At  $E_3$ , FT-3 exhibited highest number of recruits (5197.24 plants/ha). Whereas, maximum un-established (1236.35 plants/ha) regeneration was recorded in FT-6, while minimum un-established regeneration (204.57 plants/ha) was observed in FT-8. Highest established regeneration (1249.84 plants/ha) was recorded for FT-3, while in FT-8 lowest un-established and established regeneration was recorded as: 204.57 and 132.15 plants/ha, respectively (Table 38-39). Among different forests, at  $E_1$  regeneration per cent varied from 10.39% to 70.13% while at  $E_2$  and  $E_3$  regeneration per cent ranged from 8.23 to 68.05 % and 7.35 to 60.89 % respectively with highest and lowest regeneration per cent in FT-3 and FT-8 forests, respectively at all the three elevations.

## **5.6 BIOMASS AND CARBON**

### **5.6.1 Tree biomass and carbon**

Mean total biomass and carbon in trees in Himalayan moist temperate forest decreased along the elevation as:  $E_1$  (476.02 t/ha and 238.01 t/ha C) >  $E_2$  (335.26 t/ha and 167.63 t/ha C) >  $E_3$  (249.40 t/ha and 124.70 t/ha C). Total biomass in different forests ranged from 205.21 to 468.81 t/ha and total carbon varied from 102.60 to 234.4 t/ha (Table 40-49).

In individual forests total biomass and carbon varied at three elevations, in FT-1 forests they fluctuated between 291.06 to 552.76 t/ha and 145.53 to 276.38 t/ha C. In FT-2 forests, total tree biomass ranged in between 223.71 to 548.62 t/ha and total tree carbon varied from 111.86 to 274.31 t/ha C. In FT-3 forests, total tree biomass ranged from 270.06 to 564.30 t/ha and total tree carbon ranged between 135.03 to 282.16 t/ha C. In FT-4 forests, tree biomass varied from 330.21 to 459.48 t/ha, while tree carbon from 165.11 to 229.74 t/ha C. In FT-5 forests, tree biomass and tree carbon fluctuated from 207.61 to 293.80 t/ha and 103.81 to 146.90 t/ha C. In FT-6 forests, total tree biomass ranged from 149.81 to 263.71 t/ha and tree carbon from 74.91 to 131.85 t/ha C. In FT-7 forests, tree biomass ranged from 284.41 to 514.14 t/ha and tree carbon from 142.21 to 257.07 t/ha. In FT-8 forests, trees total biomass and carbon ranged from 301.09 to 641.82 t/ha and 150.55 to 320.91 t/ha C. In FT-9 forests, total tree biomass ranged from 186.60 to 445.52 t/ha and total tree carbon fluctuated between 93.30 to 222.76 t/ha C (Tables 40-49).

In general, among 34 tree species across the Himalayan moist temperate forest in Shimla district of Himachal Pradesh tree species viz., *Q. leuchotrichophora*, *Q. floribunda*, *C. deodara*, *A. pindrow*, *A. spectabilis*, *P. smithiana*, *P. wallichiana*, *Acer caesium* and *Q. semecarpifolia* were the major contributors to tree biomass and carbon accumulation at different elevations. At lower elevations *Q. leuchotrichophora*, at middle elevations *C. deodara* forests and at upper elevations *Abies-Picea* forests exhibited better biomass and carbon storage (Tables 40-49).

### 5.6.2 Shrub biomass and carbon

Mean total biomass and carbon in shrubs in Himalayan moist temperate forest decreased along the elevation as:  $E_1$  (23.930 t/ha and 11.966 t/ha C) >  $E_2$  (20.913 t/ha and 10.460 t/ha C) >  $E_3$  (18.032 t/ha and 9.017 t/ha C). Mean total biomass of shrubs in forests ranged from 14.378 to 23.932 t/ha and carbon ranged from 7.199 to 11.966 t/ha C (Table 50-59).

In individual forests total shrub biomass and carbon varied at different elevations. In FT-1 forests, they fluctuated between 20.721 to 27.844 t/ha and 10.361 to 13.922 t/ha C. In FT-2 forests, total shrub biomass ranged between 19.219 to 25.250 t/ha and total shrub carbon varied from 9.610 to 12.625 t/ha. In FT-3 forests, total shrub biomass ranged between 14.556 to 22.693 t/ha and shrub carbon ranged from 7.278 to 11.347 t/ha C. In FT-4 forests, total shrub biomass ranged from 18.125 to 24.439 t/ha and total shrub carbon ranged from 9.063 to 12.219 t/ha C. In FT-5 forests, total carbon varied from 20.129 to 27.629 t/ha and shrub carbon fluctuated between 10.065 to 13.815 t/ha C. In FT-6 forests, shrub biomass ranged from 18.900 to 24.438 t/ha and carbon varied from 9.450 to 12.219 t/ha C. In FT-7 forests, shrub biomass fluctuated from 21.743 to 26.024 t/ha and carbon varied from 10.871 to 13.017 t/ha C. In FT-8 forests, shrub biomass ranged from 15.935 to 20.817 t/ha and shrub carbon ranged from 7.969 to 10.409 t/ha C. In FT-9 forests, shrub biomass ranged from 12.964 to 16.239 t/ha and total carbon fluctuated between 6.482 to 8.119 t/ha C (Table 50-59).

Among 96 shrubs across the Himalayan moist temperate forest in Shimla district *C. carandas*, *B. lycium*, *R. brunonii*, *B. aristata*, *J. humile*, *H. oblongifolium*, *R. sericea*, *C. microphylla*, *P. utilis*, *V. cotinifolium*, *C. bacillaris*, *V. nervosum*, *V. mullaha*, *H. dyeri*, *M.*



*africana*, and *R. macrophylla* shrub species were major contributors to total biomass and carbon in different forest types located at three elevations (Table 50-59).

### 5.6.3 Forbs biomass and carbon

Total biomass and carbon in forbs in Himalayan moist temperate forest decreased along the elevation as: E<sub>1</sub> (356.18 g/m<sup>2</sup> and 178.09 g/m<sup>2</sup> C) > E<sub>2</sub> (303.62 g/m<sup>2</sup> and 151.81 g/m<sup>2</sup> C) > E<sub>3</sub> (258.45 g/m<sup>2</sup> and 129.22 g/m<sup>2</sup> C). Total biomass in different forests ranged from 204.00 to 409.16 g/m<sup>2</sup> and total carbon ranged from 102.00 to 189.30 t/ha (Table 60-69).

In individual forests total forbs biomass and carbon was different at three elevations. In FT-1 forests, they fluctuated between 247.50 to 315.57 g/m<sup>2</sup> and 123.75 to 157.79 g/m<sup>2</sup> C. In FT-2 forests forbs biomass ranged from 262.84 to 333.96 g/m<sup>2</sup> and total forbs carbon varied 131.42 to 166.98 g/m<sup>2</sup> C. In FT-3 forests, forbs biomass ranged from 320.73 to 463.04 g/m<sup>2</sup> and carbon varied from 160.36 to 231.52 g/m<sup>2</sup> C. In FT-4 forests, total biomass of forbs ranged from 311.55 to 403.38 g/m<sup>2</sup> and total forbs carbon varied from 155.78 to 201.69 g/m<sup>2</sup> C. In FT-5 forests, total forbs biomass fluctuated between 244.99 to 382.76 g/m<sup>2</sup> and forbs carbon ranged from 122.50 to 191.38 g/m<sup>2</sup> C. In FT-6 forests, total biomass of forbs ranged from 263.29 to 335.71 g/m<sup>2</sup> and carbon from 131.65 to 167.86 g/m<sup>2</sup> C. In FT-7 forests, total forbs biomass ranged from 144.26 to 294.08 g/m<sup>2</sup> and carbon fluctuated from 72.13 to 147.04 g/m<sup>2</sup> C. In FT-8 forests, total biomass of forbs ranged from 211.35 to 309.26 g/m<sup>2</sup> and carbon from 105.67 to 154.63 g/m<sup>2</sup> C. In FT-9 forests, total forb biomass ranged from 319.52 to 367.88 g/m<sup>2</sup> and total forbs carbon fluctuated between 159.76 to 183.94 g/m<sup>2</sup> C (Table 60-69).

In general, among 173 forbs species across the Himalayan moist temperate forest in Shimla district of Himachal Pradesh the following forb species, *A. aptera*, *A. contorta*, *A. rotundifolia*, *A. vitifolia*, *B. stracheyi*, *B. hamiltonii*, *C. remota*, *D. annulatum*, *E. comosum*, *F. nubicola*, *H. elliptica*, *H. candicans*, *I. nepalensis*, *O. rosea*, *P. japonicas*, *P. multiflorum*, *P. leschenaultianav*, *P. denticulate*, *P. floribunda*, *R. laetus*, *S. lanata*, *S. nubicola*, *S. cuneata*, *S. media*, *T. officinale*, *T. foliolosum*, *T. anathera*, *T. repens*, *V. coniifolia* and *V. canescens* were the major contributors to biomass production and carbon accumulation in forbs (Table 60-69).

## **5.7 SOIL PROPERTIES**

### **5.7.1 Bulk density**

At the depth of 0-15 cm, bulk density at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub> ranged from 0.89 g/cm<sup>3</sup> to 1.12 g/cm<sup>3</sup>, 0.89 g/cm<sup>3</sup> to 1.07 g/cm<sup>3</sup> and 0.82 g/cm<sup>3</sup> to 0.98 g/cm<sup>3</sup>, respectively. In 15-30 cm depth of soil at E<sub>1</sub> bulk density ranged from 0.97 g/cm<sup>3</sup> to 1.32 g/cm<sup>3</sup>. At E<sub>2</sub> and E<sub>3</sub> bulk density varied from 0.93 g/cm<sup>3</sup> to 1.09 g/cm<sup>3</sup> and 0.88 g/cm<sup>3</sup> to 1.04 g/cm<sup>3</sup> (Table 70). Highest average bulk density at 0-15 cm irrespective of elevation was recorded in Ban Oak forests (1.06 g/cm<sup>3</sup>) and lowest in moist temperate upper deciduous forests (0.87 g/cm<sup>3</sup>). At 15-30 cm depth, bulk density in different forests varied from 0.94 (Kail forests) to 1.15 (Ban Oak forests).

### **5.7.2 Soil organic carbon**

Mean soil organic carbon in depth 0-15 cm at different elevations varied from 1.19 % to 1.66 %, 1.04 % to 1.32 % and 0.95 % to 1.29 % at E<sub>1</sub>, E<sub>2</sub> and E<sub>3</sub>, respectively. At 15-30 cm mean soil organic carbon ranged from 0.96 % to 1.41 % at E<sub>1</sub>, 0.93 % to 1.22 % at E<sub>2</sub> and 0.89 % to 1.04 %. Among forest types, in Ban Oak forests highest soil organic carbon was recorded at the depth of 0-15 cm (1.42 %) and 15-30 cm (1.22 %) while lowest soil organic carbon was recorded in moist temperate lower deciduous forests as 1.14 % at 0-15 cm and 0.95 % at 15-30 cm % (Table 71).

### **5.7.3 Soil organic carbon stock**

Mean soil organic carbon stock (t/ha) in 0-15 cm depth of soils in forest types ranged from 16.97 to 27.89 t/ha at E<sub>2</sub>, from 14.15 to 21.19 t/ha and from 12.83 to 18.96 at E<sub>3</sub>. Mean soil organic carbon in 15-30 cm depth of soils in forest types ranged from 15.71 to 27.52 t/ha at E<sub>1</sub>, 12.97 to 19.95 t/ha at E<sub>2</sub> and 12.15 to 16.22 t/ha at E<sub>3</sub>. Among different forest types, highest mean soil organic carbon stock (t/ha) at 0-15 cm, irrespective of elevations, was recorded in Ban Oak forests (22.68 t/ha C) and lowest in moist temperate lower deciduous forests (15.20 t/ha C). In 15-30 cm depth, highest mean soil organic carbon stock was observed in Kail forests (21.36 t/ha C) while lowest in Upper Oak-Fir forests as 14.05 t/ha C (Table 72).

#### 5.7.4 Productivity potential of Himalayan moist temperate forests in Shimla district (HP).

Himalayan moist temperate forests of Shimla district in Himachal Pradesh covers an area of 169432.04 ha area, has  $9944.65 \times 10^4 \text{ m}^3$  timber volume,  $16256.46 \times 10^4 \text{ t}$  aboveground biomass of vegetation,  $19659.59 \times 10^4 \text{ t}$  total biomass of vegetation,  $9829.79 \times 10^4 \text{ t}$  total carbon stock in vegetation and  $11607.00 \times 10^4 \text{ t}$  total carbon stock (Table 73).

#### CONCLUSION

1. Nine forest types were identified in moist temperate forest in Shimla district, H.P. viz., Ban Oak forests, Moru Oak forests, Deodar forests, western mixed coniferous forests, moist temperate lower deciduous forests, Kail forests, Kharsu Oak forests, upper Oak-Fir forests and moist temperate upper deciduous forests.
2. NDVI changes in vegetation suggest that forest degradation and /or land use change has occurred in the area during time interval of 2008 to 2013.
3. In all 303 plant species were recorded in Himalayan moist temperate forest in Shimla district of HP which includes 34 species of trees, 96 species of shrubs and 173 species of forbs.
4. Phytosociological attributes of trees, shrubs and forbs i.e. density and basal area decreased with increase in elevation. Biomass and carbon stock in trees, shrubs and forbs also decreased with increase in elevation.
5. At lower elevations *Q. leuchotrichophora*, at middle elevations *C. deodara* forests and at upper elevations *Abies-Picea* forests and showed better biomass production and carbon storage
6. Regeneration success was highest in Deodar forests at all the three elevations. Moru Oak forests and Kail forests revealed intermediate regeneration success at different elevations. Upper Oak-Fir forests had poor regeneration success at all the elevations.
7. Soil bulk density increased with soil depth. While per cent organic carbon (%) and soil organic carbon stock was found decreased with soil depth. In both the depths (0-15cm and 15-30 cm) per cent organic carbon (%) and soil organic carbon stock (t/ha) decreased with increase in elevation.
8. Ban Oak forests showed highest soil carbon stocks (t/ha) at both the soil depths.
9. Appropriate forest management strategies favoring expansion of Ban Oak forest, upper Oak-Fir forests and Deodar forests in the district can provide enhanced ecosystem services.

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## APPENDIX-I

### Different volume equations used to calculate volume of the major tree species

| Tree species                    | Volume equation                                 |
|---------------------------------|-------------------------------------------------|
| <i>Abies pindrow</i>            | $V=0.293884 -3.441808 * D+15.922114*D^2$        |
| <i>Acer caesium</i>             | $\sqrt{V}=-0.10851+3.0450 * D$                  |
| <i>Albizia chinensis</i>        | $\sqrt{V}=-0.07109+2.99732*D-0.26953 \sqrt{D}$  |
| <i>Alnus nitida</i>             | $V = 0.193297-2.267002*D+10.679492*D^2$         |
| <i>Bauhinia variegata</i>       | $V =-0.04262+6.09491*D^2$                       |
| <i>Cedrus deodara</i>           | $V=0.167174-1.735312 * D+12.039017 * D^2$       |
| <i>Juglans regia</i>            | $\sqrt{V} = 0.207299+3.254007* D$               |
| <i>Lyonia ovalifolia</i>        | $V=0.03468-0.56878*D+4.72282 D^2$               |
| <i>Mallotus philippensis</i>    | $V=0.14749-2.87503*D+19.61977*D^2-19.11630*D^3$ |
| <i>Picea smithiana</i>          | $V=0.28318+0.0337/D^2 H$                        |
| <i>Pinus roxburghii</i>         | $V=0.034529+0.284662 * D^2 H$                   |
| <i>Pinus wallichiana</i>        | $V=0.251311-2.683081*D+13.484565 * D^2$         |
| <i>Populus ciliata</i>          | $V = 0.193297-2.267002* D + 10.679492*D^2$      |
| <i>Prunus armeniaca</i>         | $V = 0.193297-2.267002 * D + 10.679492*D^2$     |
| <i>Prunus cerasoides</i>        | $V = 0.193297-2.267002* D + 10.679492*D^2$      |
| <i>Prunus cornuta</i>           | $V = 0.193297-2.267002* D + 10.679492*D^2$      |
| <i>Quercus floribunda</i>       | $V/D^2 = 0.0988/D^2-1.5547/D+10.1631$           |
| <i>Quercus leucotrichophora</i> | $V= 0.682380+5.049937*D-2.770924*D$             |
| <i>Quercus semecarpifolia</i>   | $V=0.1358/D^2 1.84908/D+10.8234-0.6276*D$       |
| <i>Rhododendron arboreum</i>    | $V=0.6007-0.21874*D+3.63428*D^2$                |
| <i>Taxus baccata</i>            | $V= 0.04430-0.84266*D+6.32239*D^2+2.27556 D^3$  |
| <i>Ulmus wallichiana</i>        | $V = 0.193297-2.267002 * D + 10.679492*D^2$     |
| Others                          | $V=0.01284+0.2138*D*D^2 H$                      |

## APPENDIX-II

### Wood specific gravity of tree species

| Tree Species                    | Specific gravity |
|---------------------------------|------------------|
| <i>Abies pindrow</i>            | 0.48             |
| <i>Acer caesium</i>             | 0.70             |
| <i>Albizia chinensis</i>        | 0.55             |
| <i>Alnus nitida</i>             | 0.43             |
| <i>Bauhinia variegata</i>       | 0.67             |
| <i>Cedrus deodara</i>           | 0.46             |
| <i>Juglans regia</i>            | 0.46             |
| <i>Lyonia ovalifolia</i>        | 0.67             |
| <i>Mallotus philippensis</i>    | 0.64             |
| <i>Picea smithiana</i>          | 0.38             |
| <i>Pinus roxburghii</i>         | 0.47             |
| <i>Pinus wallichiana</i>        | 0.35             |
| <i>Populus ciliata</i>          | 0.40             |
| <i>Prunus armeniaca</i>         | 0.47             |
| <i>Prunus cerasoides</i>        | 0.48             |
| <i>Prunus cornuta</i>           | 0.47             |
| <i>Quercus floribunda</i>       | 0.74             |
| <i>Quercus leucotrichophora</i> | 0.75             |
| <i>Quercus semecarpifolia</i>   | 0.88             |
| <i>Rhododendron arboreum</i>    | 0.57             |
| <i>Taxus baccata</i>            | 0.55             |
| <i>Ulmus wallichiana</i>        | 0.43             |

## APPENDIX-III

**Default biomass conversion and expansion factors (BCEF), tonnes biomass (m<sup>3</sup> of wood volume) given by IPCC (2006)**

| BCEF for expansion of merchantable growing stock volume to aboveground biomass (BCEFS), for conversion of net annual increment (BCEFI) and for conversion of wood and fuelwood removal volume to aboveground biomass removal (BCEFR) |                |       |                |                 |                |                |                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------|----------------|-----------------|----------------|----------------|----------------|
|                                                                                                                                                                                                                                      |                |       | <20            | 21-40           | 41-100         | 100 -200       | >200           |
| Temperate                                                                                                                                                                                                                            | Hardwoods      | BCEFS | 3.0 (0.8-4.5)  | 1.7 (0.8-2.6)   | 1.4 (0.7-1.9)  | 1.05 (0.6-1.4) | 0.8 (0.55-1.1) |
|                                                                                                                                                                                                                                      |                | BCEFI | 1.5            | 1.3             | 0.9            | 0.6            | 0.48           |
|                                                                                                                                                                                                                                      |                | BCEFR | 3.33           | 1.89            | 1.55           | 1.17           | 0.89           |
|                                                                                                                                                                                                                                      | Pines          | BCEFS | 1.8 (0.6 -2.4) | 1.0 (0.65 -1.5) | 0.75 (0.6-1.0) | 0.7 (0.4-1.0)  | 0.7 (0.4-1.0)  |
|                                                                                                                                                                                                                                      |                | BCEFI | 1.5            | 0.75            | 0.6            | 0.67           | 0.69           |
|                                                                                                                                                                                                                                      |                | BCEFR | 2.0            | 1.11            | 0.83           | 0.77           | 0.77           |
|                                                                                                                                                                                                                                      | Other conifers | BCEFS | 3.0 (0.7-4.0)  | 1.4 (0.5-2.5)   | 1.0 (0.5-1.4)  | 0.75 (0.4-1.2) | 0.7 (0.35-0.9) |
|                                                                                                                                                                                                                                      |                | BCEFI | 1.0            | 0.83            | 0.57           | 0.53           | 0.60           |
|                                                                                                                                                                                                                                      |                | BCEFR | 3.33           | 1.55            | 1.11           | 0.83           | 0.77           |

## APPENDIX-IV

**Ratio of below-ground biomass to above-ground biomass (r) given by IPCC (2006)**

| Domain    | Ecological zone                                                                          | Above-ground biomass                                   | R [tonne root d.m. (tonne shoot d.m.)-1] | References                  |
|-----------|------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------------------------------|-----------------------------|
| Temperate | Temperate oceanic forest,<br>Temperate continental forest,<br>Temperate mountain systems | conifers above-ground biomass<br>< 50 tonnes ha-1      | 0.40 (0.21 - 1.06)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | conifers above-ground biomass 50-150 tonnes ha-1       | 0.29 (0.24 - 0.50)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | conifers above-ground biomass > 150 tonnes ha-1        | 0.20 (0.12 - 0.49)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | Quercus spp. aboveground biomass >70 tonnes ha-1       | 0.30 (0.20 - 1.16)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | Eucalyptus spp. aboveground biomass < 50 tonnes ha-1   | 0.44 (0.29 - 0.81)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | Eucalyptus spp. aboveground biomass 50-150 tonnes ha-1 | 0.28 (0.15 - 0.81)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | Eucalyptus spp. aboveground biomass > 150 tonnes ha-1  | 0.20 (0.10 - 0.33)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | other broadleaf aboveground biomass < 75 tonnes ha-1   | 0.46 (0.12 - 0.93)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | other broadleaf aboveground biomass 75-150 tonnes ha-1 | 0.23 (0.13 - 0.37)                       | Mokany <i>et al.</i> (2006) |
|           |                                                                                          | other broadleaf aboveground biomass >150 tonnes ha-1   | 0.24 (0.17 - 0.44)                       | Mokany <i>et al.</i> (2006) |

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**Title of Thesis** : “Assessment of floral diversity and carbon stocks of Himalayan moist temperate forest in Himachal Pradesh”  
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**Admission Number** : F-2012-28-D  
**Major Field** : Forestry  
**Minor Field(s)** : Silviculture  
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**ABSTRACT**

The present study was done to identify distribution of nine forest types viz., *Quercus leucotrichophora* (FT-1), *Quercus semecarpifolia* (FT-2), *Cedrus deodara* (FT-3), western mixed coniferous (FT-4), moist temperate lower deciduous (FT-5), *Pinus wallichiana* (FT-6), *Quercus floribunda* (FT-7), upper *Abies-Picea* (FT-8) and moist temperate upper deciduous (FT-9) forests, their structural and functional characteristics in Himalayan moist temperate forest of Shimla district of HP. 303 plant species were recorded in these forests of which 34 were trees, 96 shrubs and 173 forbs. The total number of plant species in different forests varied from 181 (FT-6) to 123 (FT-9). Shannon Weiner index for trees, shrubs and forbs in different forests varied from 0.97-1.57, 0.21-0.59 and 0.64-0.70, respectively. Simpson index for trees, shrubs and forbs in different forests ranged from 2.68-3.12, 0.05-0.09 and 0.40-0.45, respectively and Margelef's species richness for trees, shrubs and forbs in different forests varied from 3.32-3.93, 0.02-0.05 and 0.32-0.37, respectively. Phytosociological attributes i.e. density and basal area of trees in different forests varied from 315.20 (FT-8) to 514.26 (FT-7) trees/ha and 48.59 (FT-2) to 66.44 (FT-3) m<sup>2</sup>/ha, respectively, in shrubs from 10.34 x10<sup>3</sup> (FT-5) to 7.46 x10<sup>3</sup> (FT-9) plants/ha and 14.74 to 19.12 m<sup>2</sup>/ha, respectively and in forbs from 1.95 x10<sup>5</sup> (FT-6) to 2.57 x 10<sup>5</sup> (FT-4) plants/ha and 42.12 (FT-2) to 113.29 (FT-3) m<sup>2</sup>/ha, respectively. Total biomass production of trees in different forests varied from 205.21 to 468.81 t/ha, total biomass production of shrubs ranged from 14.38 (FT-8) to 23.89 (FT-1) t/ha and total biomass production of forbs ranged from 204.00 to 409.16 g/m<sup>2</sup>. Carbon stock in trees of in different forests varied from 102.60 (FT-6) to 234.41 (FT-8) t/ha, in shrubs from 7.34 (FT-8) to 11.94 (FT-1) t/ha and in forbs from 102.00 to 189.30 g/m<sup>2</sup>. All the characteristics of vegetation in forests showed declining trend with increase in elevation. Soil bulk density, Soil organic carbon and carbon stock in soil at 0-15cm depth in different forests varied from 0.88 (FT-7) to 1.06 (FT-1) g/cm<sup>3</sup>, 1.14 (FT-5) to 1.42 (FT-1) %, 15.20 (FT-5) to 22.68 (FT-1) t/ha, respectively whereas, in 15-30 cm depth of soil their values were: 0.94 (FT-6) to 1.15 (FT-1) g/cm<sup>3</sup>, 0.95 (FT-5) to 1.22 (FT-1)% and 13.84 (FT-6) to 21.36 (FT-1) t/ha, respectively. It is concluded that Oak forests in Himalayan moist temperate zone has slightly better potential in carbon sequestration than conifers. Both the types of forests should be given preference for any management plan.

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